Abstract Summaries

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Contents

The International Society for Optical Engineering

Monday 2 October 2006

The NSF/SBIR innovation model

M. S. Nair, National Science Foundation

General information about the Small Business Innovation Research/ Small Business Technology Transfer Programs at the National Science Foundation will be provided. The presentation will then describe the NSF/SBIR Innovation Model and provide key program statistics. The review criteria and the review process will then be explained.

Insight into upcoming topics areas and the development of various future solicitations, with special focus on the “Electronics” solicitation will be provided. The funding of small businesses pursuing electro-optics, photonics, MEMS, RF, Instrumentation and sensor technologies is described. Finally, commercialization strategies used by the NSF/ SBIR program to help portfolio companies will be presented.

Prospects of silicon photonics for future VLSI interconnects

M. J. Paniccia, Intel Corp.

The silicon chip has been the mainstay of the electronics industry for the last 40 years and has revolutionized the way the world operates. Today a silicon chip the size of a fingernail contains nearly one billion transistors and has the computing power that only a decade ago would take up an entire room of servers. Silicon photonics that mainly based upon silicon on insulator (SOI) has recently attracted a great deal of attention since it offers an opportunity for low cost opto-electronic solutions for applications ranging from telecommunications down to chip-to-chip interconnects.

Recent advances and research breakthroughs in silicon photonic device performance over last few years have shown that silicon can be considered as a material onto which one can build future optical devices. While significant efforts are needed to improve device performance and to “commercialize” these technologies, progress is moving at a rapid rate. If successful, silicon photonics may similarly come to dominate the optical communications as it has the electronics industry.

In this session, Dr. Paniccia will provide an overview of silicon photonics research at Intel and discuss the key building blocks needed for “siliconizing” photonics . The talk will also discuss if and how the combination of advanced CMOS electronics with photonics could be used for future optical interconnects and discuss what key challenges are needed to be addressed in order to make this transition happen. In addition the presentation will discuss some of the practical issues and challenges with processing silicon photonic devices in a high volume CMOS manufacturing environment.

Flexible optical transport networks: demands and trends on new Layer 2 techniques

G. J. Eilenberger, Alcatel SEL AG (Germany)

This talk deals with potential evolution scenarios from today’s networks towards long term network architectures for multi-layer transport with a novel Layer 2 transport service based on optical and opto-electronic burst/packet techniques providing the flexibility, scalability, reliability and Quality of Service to support all future higher layer services optimizing both CAPEX and OPEX. An integrated control plane on the basis of GMPLS protocols will support the mostly automatic network operation by a vertical integration of Layer 1-2-3 technologies and a horizontal integration of domains providing end-to-end control and QoS. This long term evolutionary process needs to cover as well the necessary steps in the evolution of current standards.

Sunday-Monday 1-2 October 2006

Part of Proceedings of SPIE Vol. 6368 Optoelectronic Devices: Physics, Fabrication, and Application III

6368-01, Session 1

Photoluminescence of Si nanocrystals embedded in microcavities

R. D. Kekatpure, Stanford Univ.; A. Tewary, Stanford Univ. and Intel Corporation, Santa Clara; M. L. Brongersma, Stanford Univ.

An efficient on-chip silicon based light emitter is a prime requirement for realization of short distance optical interconnects. Low dimensional Si nanostructures are being intensely investigated toward that end. There have been numerous reports on observation of continuous-wave and transient gain in planar optical waveguides with Si nanocrystal active layer. However, there are relatively very few investigations focusing on photoluminescence emission from Si nanocrystals (quantum dots) embedded in on-chip optical microcavities. Microcavities spectrally filter the luminescence from the quantum dots and, depending on the (Q/V) ratio, can significantly alter the spontaneous photoemission from the quantum confined excitons. We intend to present the results of our continuous-wave and sub-nanosecond time-resolved photoluminescence measurements from Si quantum dots embedded in high Q cavities in microring and microdisc configurations. The Si quantum dot active layer in these microcavities is optimized for photoluminescence by carbon dioxide laser irradiation of Si-rich SiO2 and an optimal annealing temperature of ~1273 oC is determined. Planar optical microcavities are patterned on the emitter layer by high resolution electron beam lithography and a combination of dry and wet chemical etching. Fabrication procedure is optimized to maximize the ratio of the quality factor and the mode volume. Continuous-wave photoluminescence measurements are performed by top-pumping the resonators with a 488 nm line of an argon ion laser. We also study temporal photoemission dynamics of Si quantum dots with a sub-nanosecond time resolution to probe fast non-radiative decay channels such as Auger recombination. We believe that our studies will help gain further insight into photoemission physics of the group-IV nanostructures.

6368-02, Session 1

Photonic crystal cavities for low-power light sources on Si: a simplified model development

Z. Qiang, W. Zhou, The Univ. of Texas at Arlington

Infrared technology is very important for thermal imaging and gas sensing, due to its non-destructive and non-reactive nature. However, wide spread applications of photonic technology in sensing requires the revolutionary design of photonic devices with extremely low cost, ultra-compact sizes and flexible integration capability.

We propose here a new class of nano-cavity surface-emitting light source on potentially any substrates, at any wavelengths, based on the integration of colloidal quantum dots (CQDs) and air-hole two-dimensional photonic crystal (2D PC) slab waveguide cavities. The wavelength tunability can be controlled with the size and choice of CQD materials and lithographically defined PC cavity resonance. Ultra-compact high efficient light source is feasible based on these relative low gain CQDs, as compared to conventional epitaxial III-V material systems, owing to the relaxed gain threshold in PC cavities.

A simplified model is being proposed and developed to investigate this nanolasers. The gain threshold conditions in relation to the cavity design and PC defect configurations have been investigated based on this simplified model and rate equation analysis. Over one order of magnetitude in gain threshold reduction was obtained in PC cavities, due to the spontaneous emission control. It is feasible to design a single defect cavity laser with cavity size <2 um, optical power \>20uW, and total size of the laser to be below 10um based on our simulation results. The tradeoffs in spectral selectivity and power will be discussed.

6368-03, Session 1

Optically pumped Si emitting device for mid-infrared band

V. K. Malyutenko, S. Chyrchyk, Institute of Semiconductor Physics (Ukraine)

To suppress non-radiative recombination in Si and make this indirect bandgap material efficiently radiate in the near IR (<2 um), Si nanocrystals, Si/SiO2 superlattices, Si-based matrix, and high-purity Si with textured and passivated surface were developed and tested. However for longer wavelengths these approaches do not work. In this report, fundamentals, design, fabrication technology, and parameters are presented for contactless photonic emitter operated in the 3-5 um atmosphere transparency window at well above room temperature. To bypass Si band structure limitation, we utilized shorter wavelength light-induced free carrier thermal emission and transparency coating as the ways to monitor material below-bandgap radiation (light down conversion technique). When pumped with Nd-laser at a device temperature T<500C, nearly 20 mW output power of IR radiation could be achieved with 5 us rise-fall time. This represents the longer wavelengths, higher operating temperatures and output power from Si spontaneous emitters ever reported. The device application to the IR dynamic scene simulation as well as its pros and cons in respect to thermal emitters and conventional LEDs based on 111-Y compounds are also considered.

6368-04, Session 1

All optically driven MEMS deformable device via a photodetector array

J. Khoury, K. Vaccaro, C. L. Woods, Air Force Research Lab.; B. Haji-saeed, Univ. of Massachusetts/Lowell; S. K. Sengupta, Air Force Research Lab.; W. D. Goodhue, Univ. of Massachusetts/Lowell; J. Kierstead, Solid State Scientific Corp.; A. Davis, Air Force Research Lab.

Proof of concept of an all optically-driven-deformable-mirror-MEMS, actuated via an array of photodectors, was established by driving a deformable mirror cell with different types of photodetectors. It was possible to drive the MEMS optically with picowatt intensities using an avalanche photodetector.

6368-05, Session 1

Light down conversion process in Si with \>100% external efficiency

V. K. Malyutenko, V. V. Bogatyrenko, Institute of Semiconductor Physics (Ukraine)

We report on the basic principle and Si-based technology of linear all-optical light down conversion process. This fundamentally new approach is based on a possibility to enhance thermal emission power of a semiconductor in the spectral range of intraband electron transitions (mid- and long infrared, free carrier absorption band) through the shorter wavelength optical pumping (interband transitions, visible to near-infrared, fundamental absorption band). We theoretically show that at a certain conditions a number of low-energy all direction-emitting multiwavelength photons could drastically exceeds that of high-energy absorbed photons (\>10^3 % quantum efficiency). Moreover, we pointed out and experimentally realized conditions (1.15 um pump wavelength and 3 to 16 um emitting wavelengths, T\>200 deg. C) when this high-purity Si-based device demonstrates well above 100% external power efficiency. As a matter of fact, we come up with new concept for high-temperature incoherent light amplifier (optical transistor) based on the indirect bandgap semiconductors.

6368-06, Session 2

MOS Si/Ge photodetectors

C. Liu, C. Lin, National Taiwan Univ. (Taiwan)

The Si metal-oxide-semiconductor (MOS) photodetectors have been demonstrated for detection of lamp light and near infrared. The dark current at room temperature is significantly reduced with the oxide layer. With the photo excitation, the generation rate of electron-hole pairs in the inversion layer increases and thus the gate current increases.

The valence band offset between Si and Ge forms discrete quantum states in the Ge quantum dots. Hence, MOS Si/Ge quantum dot infrared photodetectors with boron delta-doping in the Si spacer can be used to detect mid- and far- infrared. One peak at 3.7-6 micrometer is due to the intersubband transition in the Ge quantum dot layers. The other peak at 6-16 micrometer mainly comes from the intraband transition in the boron delta-doping wells in the Si spacers.

The Ge-on-insulator (GOI) MOS photodetector adopts the technique of smart-cut. The higher-speed operation of GOI detectors can be expected due to its much thinner active region with respect to SOI devices. Besides, the near infrared at 1.3 micrometer and 1.55 micrometer used for optical communication can only be detected by GOI due to the limitation of bandgap of Si. We have measured the responsivity of GOI detectors operating at 850nm, 1.3 micrometer and 1.55 micrometer. The low-temperature process of GOI was as low as 150oC. To the best of our knowledge, this is the lowest process temperature for GOI technology.

6368-07, Session 2

Equalize APD-based receiver for ultrafast optical communication system

P. Sun, M. M. Hayat, The Univ. of New Mexico

Many modern high-speed optical receivers employ a PIN-EDFA combination for it high bandwidth and good SNR. However this combination is very costly and bulky. The avalanche photodiode (APD) offers a cost-effective alternative to the PIN-EDFA combination as it is capable of amplifying the photocurrent internally, without the need for optical preamplification. Unfortunately, this internal optoelectronic gain comes at the expense of an increase in APD's gain and buildup-time uncertainty. This results in a relatively slow response time for the APD (compared to a PIN) and introduces additional ISI. Although high-speed APDs are available which are suitable for transmission speeds up to 10 Gbps, their utility at higher speeds would result in significant ISI, which must be compensated for in the receiver. In this work, the APD-based receiver is viewed as a random linear channel whose impulse-response function is a stochastic process; the transversal equalizer (TE) and decision feedback equalization (DFE) are designed. The designs are based on the rigorous calculation of the mean and the correlation matrix of the receiver's random impulse response. These statistics are determined by utilizing a recently developed analytical model for the joint probability distribution of the gain and the buildup-time of thin APDs. It is shown that these equalizers can reduce the bit-error-rate significantly at high transmission rates, make the APD suitable for up to 40Gbps digital communication. Therefore, the equalized APD-based receiver has the potential to be a cost-effective alternative to the PIN-EDFA combination in ultra-fast optical communications.

6368-08, Session 2

Design and development of high quantum efficiency large area UV focal plane arrays for photon counting applications

E. J. Egerton, A. K. Sood, R. A. Bell, Y. R. Puri, Magnolia Optical Technologies, Inc.; T. A. Cook, Boston Univ.; J. Roginsky, Naval Surface Warfare Ctr.

In this paper we will present innovative design approach for UV Focal Plane Array for Photon Counting Applications. This Focal Plane includes the building a large area silicon micro-channel plate (MCP) using GaN photocathode.

In this paper, we will show the design and simulation of silicon micro-channel plate with GaN photocathode with large area array with 2 micron pores and 3 micron pitch.

We will also present results for the ICP-RIE process to fabricate 2 micron pores, and Growth of high conductivity GaN photo-cathodes using MOCVD to produce 40% QE.

We will also present the approach for development of readout architecture and circuit for Silicon based MCP 4096x4096 UV FPA. The readout architecture scheme uses a series of charge sensitive amplifiers (CSA) to boost the charge received on each anode. The signal from each CSA is then passed into a shaping amplifier (SA) that produces a smooth waveform. The peak of the smoothed waveform is captured by a sample and hold (S/H) circuit that holds the signal until an analog to digital (A/D) converter can sample it. Details of the ROIC circuit will be presented.

6368-09, Session 2

A method for measuring of modulation transfer function of HgCdTe infrared detector cell

L. Liu, Nanjing Univ. of Science & Technology (China)

The HgCdTe infrared thermal imaging system is a complicated optoelectronic system, which is composed of the optical system, scanner, infrared detector, electronic component and the display. For the infrared thermal imaging system, Modulation transfer function (MTF) is the primary parameter used for system design, analysis, and specifications. From it, not only the performance of the system estimated, but also some problems in the craft and materials of the detector can be found.

In this paper, firstly the physics meaning of the modulation transfer function is illustrated—MTF is the module of optical transfer function (OTF). Electronic circuitry also can be described by an MTF. The combination of the optical MTF and the electronic MTF creates the infrared thermal imaging system MTF.

Then a description of a test facility for testing and evaluating MTF is given. There are two general methods for determining the MTF: the direct method which is based on measuring the response to sinusoidal or bar targets and the indirect method, which is based upon computing the Fourier transform. Here we choose knife-edge target as a source to obtain MTF of HgCdTe infrared detector cell by our developed testing system.

At last, the result is analyzed and computed. The Pentium III computer system takes the charge of controlling and calculating.

6368-10, Session 3

Development of a new laser-surgery tool using high-brightness laser arrays and specially designed beam-shaping optics

F. Causa, Univ. of Bath (United Kingdom); S. Bonora, Univ. degli Studi di Padova (Italy); D. Masanotti, Univ. of Bath (United Kingdom); P. Villoresi, Univ. degli Studi di Padova (Italy)

The development of new medical tools for minimal-invasive surgery is essential for the reduction of pain, (post-treatment/operation) side-effects and hospitalisation costs.

The benefits of using optical methods in some procedures are now well recognised. In this context semiconductor optical sources offer the advantages of high efficiency, compactness, low cost, long lifetime, low power consumption and high reliability. The optical source presented in this paper comprises a phase-locked, high-power laser diode array and beam shaping optics designed to optimise the coupling to small-diameter optical fibres. The high-power, index-guided laser array used in this work has been developed to achieve high-brightness by adopting a specially designed optical cavity based on the parabolic taper for each individual element in the array. With this design the individual elements are phase-coherent and the fundamental mode of the array is dominant, thus achieving quasi-diffraction-limited operation without the use of external lenses. Compared to other high-brightness laser arrays, the parabolic bow-tie laser array used here offers the advantages of simple device fabrication, reduced costs and compactness. In this work, specially designed lenses are used to circularise the beam and, therefore, to focus the beam to a small spot-size to improve coupling to single mode fibres. Details of the device characteristics, with emphasis on beam quality and phase front, and of the design of anamorphic optics for beam shaping and focusing will be presented in the context of the integration of the high-brightness laser

array with the specially design optics to achieve optical power delivery exclusively where necessary via small-diameter optical fibres.

6368-11, Session 3

Microthermographic investigations of aging processes in diode lasers

A. Kozlowska, R. Kozlowski, M. Kozubal, P. Kaminski, A. Malag, P. Wawrzyniak, Instytut Technologii Materialów Elektronicznych (Poland); J. W. Tomm, M. Ziegler, Max-Born-Institut für Nichtlineare Optik und Kurzzeitspektroskopie (Germany)

The application of multi-spectral microthermography to the monitoring of aging processes in diode lasers is reported. We have found that an increase of the concentration of point defects during aging is correlated with an increased luminescence in near IR (1.5-2 micron range). This effect is monitored with a specially configured thermographic camera. Thus the set-up provides spatially resolved information about point defects along emitting area in the laser diodes facet plane. It allows also to distinguish between the emission that originates from radiative recombination at defect centers and the pure thermal emission.

The devices used in this study are emitting at 808 nm GaAsP/AlGaAs/GaAs diode lasers fabricated from a double-barrier separate confinement heterostructure. Wide-stripe diode laser devices of 1-mm cavity length have been fabricated using proton implantation for stripe definition. The devices are assembled in standard diode laser packages.

In order to elucidate the role of point defects in the aging process of diode laser complementary spectroscopic measurements are performed. Deep-level transient spectroscopy is used to determine the activation energies and the concentration of point defects. Changes of these parameters are monitored during the device aging. Photocurrent spectroscopy allows to examine the absorption properties of the structure. Activation energies of deep levels and their concentrations are determined for fresh as well for aged devices. A correlation between measurement results obtained using different methods is found, discussed and interpreted in detail.

6368-13, Session 3

Improvement of SLD efficiency by focussed ion beam post-fabrication processing

F. Causa, Univ. of Bath (United Kingdom); M. Milani, Univ. degli Studi di Milano-Bicocca (Italy); J. Sarma, Univ. of Bath (United Kingdom); L. Ferraro, Univ. degli Studi di Milano-Bicocca (Italy)

Super-Luminescent Diodes (SLDs) are high power semiconductor optical sources with relatively broad spectral linewidth increasingly used for a variety of applications such as optical coherence tomography, wavelength division multiplexing, fibre optic gyroscopes and short haul communications. The basic, crucial device feature needed to achieve high-power SLD operation is low facet reflectivity to prevent lasing and optical gain saturation. Results from theoretical calculations show that by appropriately designing the device length and output facet reflectivity a significant increase in optical output power and wall-plug efficiency can be obtained. This paper presents theoretical and experimental results indicating that it is possible to further improve the operational characteristics of SLDs and achieve high optical output power (well in excess of 1W) with extremely high conversion efficiency (40% predicted wall-plug efficiency). In this paper the control of the facet reflectivity and the device geometry are obtained by using Focused Ion Beam (FIB) post-fabrication processing with a FIB/SEM system. Facet reflectivity alteration using FIB is achieved by creating an amorphization pattern on a submicron scale with controlled depth (ranging from 10nm up to 1um) on the device facet. Imaging of the facet can be obtained in situ during device operation by electron or ion imaging. Results obtained using the alternative procedure of submicron-step, nanometric-size metal island deposition on the device facet will also be presented. Device operational characteristics obtained under both pulsed and CW operation will be discussed in the context of thermal dissipation and optical gain saturation.

6368-14, Session 3

Mid-infrared LEDs versus thermal emitters in IR dynamic scene simulation devices

V. K. Malyutenko, A. V. Zinovchuk, Institute of Semiconductor Physics (Ukraine)

One of important applications of mid-infrared (3-5 um) LEDs, but one which is rarely mentioned is that of infrared dynamic scene simulation devices (synthetic scene projectors). There are several reasons for market demand for these devices - high operation speed imaging (\> 20 kHz frame rate), multispectral imaging (several sub bands inside the mid-infrared atmospheric transparency window), and negative temperature background simulation (like winter or arctic scenes, and space background). Advanced MEMS-based IR scene simulators composed of thermal IR emitters satisfy none of these options.

In this report, design, technology, and parameters are presented for photonic emitters made of III-V narrow-band compounds with the wavelengths tuned by a device band gap and operated in forward (positive luminescence) and reverse (negative luminescence) bias modes. We show that \>1 mW emitting power or apparent radiation temperature of \>500 deg. C are easy to achieve in narrow spectral bands given that an active emitting area radiates uniformly and heat sink bottlenecks are eliminated. In the negative luminescence mode we demonstrate objects that are as cold as < -20 deg. C even though a device sits at room temperature. Finally, we report the test results of emitter arrays and bars and demonstrate some dynamic IR scenarios.

6368-15, Session 4

Plasmonics: the missing link between nano-electronics and microphotonics

M. L. Brongersma, Stanford Univ.

The enormous growth of the communication industry has increased the demand for new photonic functionality at a low cost. For this purpose, it would be highly desirable to have light sources, waveguides, amplifiers, and detectors that are monolithically fabricated on Si with CMOS technology. At first sight, it seems that the materials used in current CMOS integrated circuit technologies are chosen to optimize electronic performance. However, upon closer examination these materials are also suitable for generating, manipulating, and detecting optical signals. The unique properties of Si nanostructures such as nanoparticles and nanowires can be exploited to fabricate Si-based light sources and detectors. Si and SiO2 can be used to fabricate ultra-high quality factor micro-ring resonators for light modulation and generation. Metallic interconnects can serve as plasmonic waveguides and antennas that guide and manipulate light at the nanoscale. I will argue that if a number of key plasmonic elements can be realized on a Si chip, a tremendous synergy could be attained by integrating plasmonic, electronic, and conventional photonic devices by taking advantage of the strengths of each technology. I will discuss the efforts in our group in these areas and highlight the limitations and future possibilities for each technology.

6368-16, Session 4

Integrated photonic devices for FTTX applications

P. P. Xie, NeoPhotonics

In today's telecommunication market, especially in FTTH market, customers require good service at rock bottom cost with no compromise in product performance and quality. In this talk, I would like to elaborate on NEOPHOTONICS integration strategy to address these requirements. Specifically, we leverage our PLC integration platform to produce "system on a chip" type of devices at a fraction of the cost of traditional discrete optics. PLC devices integrating power splitting and WDM function are further integrated with EDFA as WDM Video Combiner module to be used in OLT. ONU PLC triplexer module using Hybrid integration of laser diode and photo diode on PLC chip with WDM function has also been demonstrated. Details and examples will be given at the talk.

6368-17, Session 4

Advanced photonic design automation (PDA) software for integrated optoelectronic devices

Z. Huang, RSoft Design Group, Inc.

No abstract available.

6368-18, Session 4

Reconfigurable all-optical universal logic gates

L. L. Goddard, J. S. Kallman, T. C. Bond, Lawrence Livermore National Lab.

We present simulations of several design layouts for a highly cascadable, reconfigurable, all-optical, universal logic gate. We will discuss the gate's expected performance, e.g. speed, fanout, and contrast ratio, as a function of the device layout and biasing conditions. The gate is a three terminal on-chip device that consists of: (1) the input optical port, (2) the gate selection port, and (3) the output optical port. The device can be built monolithically using a standard multiple quantum well graded index separate confinement heterostructure laser configuration. The gate can be rapidly and repeatedly reprogrammed to perform any of the basic digital logic operations by using an appropriate analog electrical or optical signal at the gate selection port. Specifically, the same gate can be selected to execute one of the 2 basic unary operations (NOT or COPY), or one of the 6 binary operations (OR, XOR, AND, NOR, XNOR, or NAND), or one of the many logic operations involving more than two inputs. The speed of the gate for logic operations as well as for reprogramming the function of the gate is primarily limited to the small signal modulation speed of a laser, which can be on the order of tens of GHz. The reprogrammable nature of the universal gate offers maximum flexibility and interchangeability for the end user since the entire application of a photonic integrated circuit built from cascaded universal logic gates can be changed simply by adjusting the gate selection port signals.

This work was performed under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

6368-19, Session 5

Negative index metamaterials in the optical range

A. Bratkovsky, Hewlett-Packard Labs.

We consider various effects and designs pertainig to the Veselago lens with negative refractive index that may operate at IR and optical frequencies (lambda < 3um). There are two general approaches to building the metamaterials that may exhibit: (i) using resonant elements, like split-ring resonators (SRR) or nanometallic resonant structures and (ii) metallic photonic crystals. Metamaterials with the resonant elements may have a relatively low bandwidth because of their very nature. Metallic crystals with nonresonant elements are more advantageous in this respect. The only requirement is to have an excitation branch with negative dispersion (dw/dk<0), and this may be engineered to occur in pretty wide frequency range. The main problem is in countering hefty losses of waves in metallic crystals, and to this end, a gain medium may be used. Pertaining results and problems will be discussed.

6368-20, Session 5

Advances in organic optoelectronic integration, packaging, and interconnects

L. A. Eldada, DuPont Photonics Technologies

Advances in organic optoelectronic integration, packaging, and interconnects.

6368-21, Session 5

High single-pass gain in Nd^{3+} doped ceramic material with side pumping

P. Huang, Wheaton College; J. Zhang, Boston Applied Technologies Inc.; X. Chen, Wheaton College; K. K. Li, R. Zhang, Q. Chen, Y. Wang, Y. K. Zou, H. Jiang, Boston Applied Technologies Inc.

Transparent ceramic laser materials have attracted a lot of attention because they are easy to make into large size and readily to dope with high rare earth ion concentrations, which can result in high power and high efficient lasers or microchip lasers for various important applications including efficient and multifunctional lasers and photonic devices. The electro-optical based, rare earth Nd3+ doped lanthanum-modified lead zirconate titanate (PLZT) ceramics have been fabricated and the related optical properties such as the absorption spectra and luminescence profiles have been investigated systematically.We measured the single-pass signal gain of Nd3+:PLZT at 0.5% and 1% of doping concentrations. With side-pumping approach, strong signal gain was observed in 1.0at. % and 0.5at. % Nd3+:PLZT by using 1064 nm solid state laser as the seed source and 802 nm diode laser as the pumping source at various pumping power ratios and angles. Utilizing a lock-in amplifier to modulate the source phase and detect the stimulated emission induced by the seed source, 1400% (11.0dB) single-pass gain was obtained in the 1.0at. % Nd3+: PLZT slab of 2.0mm in thickness, and 600% (8.0dB) in the 0.5at. % one with the same thickness. This is the highest small signal gain in this new material was achieved, to the best our knowledge. Our investigation has shown that the Nd3+:PLZT family have great potentials as gain medium of a tunable laser around 1064nm. This work has been supported in part by NSF grant DMI-0450547 and DOE grant DE-FG02-04ER83911.

6368-23, Session 6

Quantum information processing with nanophotonic structures

S. M. Spillane, R. G. Beausoleil, D. Fattal, M. Fiorentino, C. M. Santori, Hewlett-Packard Labs.

The application of nanophotonic technology to quantum information processing should provide a number of advantages, including increased performance and reduced size and cost. We will discuss some of the approaches we are undertaking at HP Labs to implementing optical quantum information processing using nanophotonic structures.

6368-24, Session 6

Carrier localization and enhanced spontaneous emission due to spontaneous plasma nanosheath formation in polar nanostructured materials

S. Riyopoulos, Science Applications International Corp.

The longitudinal component of the polarization field inherent in polar materials, combined with constrained carrier motion along the quantum wells, causes formation of equilibriumn plasma nano-sheaths at intersections of quantum wells. The induced short range (nm) potentials of peak voltages much larger than the thermal carrier energy cause wavefunction localization, which further reduces the dimensionality of the carrier behavior. The associated energy band-bending causes enhanced carrier accumulation at quantum wedges and quantum tips formed by intersecting quantum wells. In addition, the total carrier number over the QW length increases, manifesting spontaneous intrinsic pumping due to polarization. As a result, the spontaneous emission is localized at quantum wedges, and the total emission exceeds that from a flat quantum well of similar parameters, as experimentally observed. The sheath potentials are sufficiently high for 1-D or 0-D carrier localization at quantum wedges and quantum tips.

6368-25, Session 6

Carrier dynamics in active-region materials for diode laser applications

J. W. Tomm, V. Talalaev, Max-Born-Institut für Nichtlineare Optik und Kurzzeitspektroskopie (Germany)

For the practical application of novel micro- and nanostructures as the active device region, knowledge about their behavior at high non-equilibrium carrier densities as well as about the carrier dynamics within such complex systems is urgently required. Obtaining insight into these elementary processes allows for the estimation of potential application fields and perspectives of given structures and device concepts.

We report on a study of the transient photoluminescence (PL) behavior of such structures. Quasi-instantaneous excitation by femtosecond pulses and PL detection by a synchro-scan streak-camera allows for monitoring PL transients in the range between 7 ps and several ns.

The transient PL data is used as a monitor of the non-equilibrium carrier behavior. Several types of structures, namely InGaAs quantum wells and wires, InAs/GaAs quantum dots (QD) and vertically stacked InAs/GaAs QD-arrays are experimentally investigated. The data obtained is compared with the results of modeling work. For these model systems, we discuss the recombination behavior, aspects such as carrier trapping, and carrier localization as well as the carrier transfer between different parts of the structures. Special emphasis is placed on the kinetics of lateral (within single QD-planes) and vertical (within stacked QD-arrays) inter-QD carrier transfer.

Conclusions regarding relevant applications of the structures, e.g., as the optically active region material of semiconductor lasers are drawn.

6368-27, Session 7

Applications of reflective silicon substrates in optoelectronics and sensing

M. S. Unlu, Boston Univ.; M. K. Emsley, Analog Devices, Inc.; D. A. Bergstein, Boston Univ.

We present application of micro-resonators to resonant cavity enhanced (RCE) photodetectors and biological sensing techniques. Over the past decade a new family of optoelectronic devices has emerged whose performance is enhanced by placing the active device structure inside a Fabry-Perot resonant microcavity. In such structures, the device functions largely as before, but is subject to the effects of the cavity, mainly wavelength selectivity and a large enhancement of the resonant optical field. The increased optical field allows photodetectors to be made thinner and therefore faster, while simultaneously increasing the quantum efficiency at the resonant wavelengths. We have developed highly reflective Si substrates based on a repeated Silicon-on-Insulator process. These substrates enabled the development of high-speed RCE Si photodetectors operating at 850nm and Ge on Si photodiodes at 1550 nm.

We have also developed techniques in biological sensing and imaging using optical resonance. The Resonant Cavity Imaging Biosensor (RCIB) detects binding on a microarray surface and promises high-sensitivity as well as simultaneous imaging of very large arrays. Preliminary results on RCIB show promise towards label-free high-throughput DNA-DNA and DNA-protein microarray technologies.

6368-28, Session 7

THz oscillations from optically anisotropic planar microcavities and organic microcavity lasers

R. Gehlhaar, M. Swoboda, M. Sudzius, M. Hoffmann, H. Fröb, V. G. Lyssenko, K. Leo, Technische Univ. Dresden (Germany)

We present a study of time-resolved transmission and emission properties of birefringent planar microcavity structures. The structures consist of * /4-layers of SiO2 /TiO2 for the dielectric mirrors and a * /2-cavity-layer of either SiO2 or the organic dye composite AlQ3/DCM. For the SiO2 cavity, we observe a polarization splitting at normal incidence leading to terahertz oscillations of transmitted coherent light [1]. The polarization splitting is explained by an optical anisotropy of the dielectric layers caused by the fabrication process. The structures are produced by reactive electron-beam evaporation under high vacuum conditions. The samples are off-axially grown resulting in oblique columnar structures in the dielectric layers, which leads to optical anisotropy.

We apply an up-conversion setup for temporally and spectrally resolved transmission measurements and obtain a corresponding beating of 1.25 THz. Time resolved measurements yield a Q value of 1600, corresponding to cavity photon lifetime of 0.65 ps. We explain our observations with a transfer-matrix based numerical model and introduce a Fourier-transform based analytical algorithm. The cavity filled with the organic dye composite can act as an organic microcavity laser [2]. The birefringence of the distributed Bragg reflectors yields two perpendicularly polarized modes. Investigations of the ultrafast dynamics of this laser system show a phase coupling of the two modes leading to terahertz oscillations in a photomixing experiment. The oscillation frequencies can be widely tuned by variations in the fabrication process.

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6368-29, Session 7

Neodymium photoluminescence in whispering gallery modes of toroidal microcavities

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We report on light emission from high-Q neodymium-implanted silica microtoroids that are surface-tension-induced optical cavities sustaining whispering gallery modes (WGM) of high quality factor (Q ~ 10^8) and small modal volume (V < 100*lambda^3). Thus, they are well designed for Cavity Quantum Electrodynamics and Low Threshold Non Linear Optics experiments.

Fabrication of microtoroids is a two-step process involving silicium microelectronic technology and CO2-laser fusion of silica. Hence, it makes optronics integration easier.

We pumped neodymium ions by a tightly focused laser (lambda = 532 nm, pump waist ~ 4 μm) so that embedded neodymium ions emit in both the leaky modes of a microdisc and Whispering Gallery Modes of a microtoroid.

Effective detection of WGM is obtained by evanescent wave coupling using a phase-matched angle polished multi-mode fiber connected to the spectrograph. The results show the presence of WGM in microtoroids and observed Free Spectral Ranges are consistent with their diameters.

To improve emission in WGM, we are going to use a pump resonant with a WGM, thus exciting only the neodymium ions efficiently coupled to a cavity mode. This will be achieved by mastering of tapered fibre couplers, presently under progress in our laboratory.

The achievement of low threshold Nd-microlaser as an integrated version of an earlier reported work on microspheres will be discussed.

6368-30, Session 7

Microstructures for enhanced light-matter interactions: light trapping and controlled emissions

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Our focus is on the potential of enhancing light-matter interactions by using microstructures. It has been proven that microstructures of composite materials (MCMs) are versatile means for passive optical functional integration. Here we elaborate on some motivations and preliminary results for using MCMs on active devices. Structures for light trapping at UV-VIS (e.g., solar cells) and controlled emission (e.g., VCSEL) at infrared wavelengths are discussed.

6368-31, Session 8

Simulating the gain flattening filter for EDFA

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In this paper we report the experimental study of gain of telecommunication Erbium Doped Fiber Amplifier (EDFA). For particular pump power, the gain of Erbium Doped Fiber Amplifier for the wavelength range of 1529 nm - 1559 nm was measured and found that the gain of the Erbium Doped Fiber Amplifier is very uneven exhibiting peaks with different widths around 1532 nm and 1550 nm . On analysis of the results, we have simulated the filter of desired characteristic which could support for flattening the gain of EDFA for fixed pump power, so that the EDFA could be used for WDM applications .We have flattened the gain spectrum of a commercial Erbium-doped fiber amplifier, obtaining a curve with approximately + 1.05dB of ripple, from 1530.1 nm to 1557 nm, using five bragg gratings in equalizing optical filter.

6368-34, Session 8

Characteristics of triple-cladding long-period optical fiber grating with refractive index modulation

X. Zhao, Z. Gu, Univ. of Shanghai for Science and Technology (China)

The characteristics of long-period fiber grating have been mainly studied based on the simplified model in recent years, in which the modulation of the refractive index was replaced with the average refractive index modulation. Obviously, this model is not perfect. In this paper, a rigorous model of refractive index modulation is considered. With this model, the eigenvalue equation, the field distribution, the local intensity and transmission spectra are studied on the film coated long-period fiber grating based on the method of transfer matrix. Through rigorous vector-field analysis, the characteristics of triple-clad long-period fiber grating are acquired. Firstly, the vector components of the electric field for the HE cladding mode are plotted to study the field distribution of the cladding mode, and the local intensity curves of the first six l = 1 cladding modes are also given. It is found that the low-order HE modes have a larger proportion of intensity localized in the core than the low-order EH modes, just like the double-clad LPFG. In addition, the coupling constant between the core mode and the cladding mode is analyzed. The results show that the coupling constant of the low-order HE increases monotonously when the mode number becomes larger, and it varies monotonously with the film thickness except for a certain specified region. Furthermore, the relation between the sensitivity to the film refractive index and the film optical parameters and the fiber grating parameters is analyzed. Data simulation shows that the sensitivity to the film refractive index is to be more than 104, accordingly the measurement resolution is less than 10-8. It provides a important theoretical guide to the optimization of the design of LPFG sensor.

6368-53, Session 8

An electro-optically tunable optical filter with an ultra-large wavelength tuning range

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We present an electro-optically (EO) tunable filter design. The EO tunable filter is capable of nanosecond wavelength tuning across the whole C band with a narrow pass band of <0.4nm and a low channel cross-talk of <-30dB. This EO filter can be used in dynamic WDM networks for fast wavelength scanning/selection, communication channel reconfiguration, and optical switching.

6368-22, Poster Session

Femtosecond dynamics and optical properties of TbDyFe thin film

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Giant magnetostrictive thin films (GMFs) exhibit large magnetostriction strains and non-contact driving power at low magnetic fields, which is a rather new material with a great potential for development in the coming years. For investigate the optical and dynamics properties of GMFs, a femtosecond laser pump-probe test device was designed and Tb0.3Dy0.7 Fe2 thin film was prepared by RF magnetron sputtering as the sample in this work. The Tb0.3Dy0.7 Fe2 alloy (99.9%) was used as target and the substrates was glass slice with thickness of 0.5mm. Under the condition of vacuum degree, 10-5 Pa; PAr, 0.4~0.8 Pa; sputtering power, 100W and sputtering rate is 0.06nm/s, the thin film with the thickness of 1.2 was obtained. Then experiment were carried out by using Ti:sapphire laser system, with pulse duration of 30fs; output power, 560mW; signal pulse energy, 6nJ and central wavelength is 798 nm. The high repetition rate (82 MHz) allowed the use of a photoelastic modulator (PEM), which highly increased the signal to noise ratio in magnetic measurements. Time-resolved reflectivity and transmissivity of this thin film have been measured at different pump fluences and wavelengths. With a new testing method, real and imaginary part of dielectric constant can be measured directly and independent of Kramers-Kronig integration. Experimental results demonstrate that the transient reflectivity was strongly affected by the pump pulse fluence and wavelength, but dielectric constant was influenced by photon energy. Terahertz (THz) dynamics response contains an ultrafast decay component of about 1.5 ps is also observed.

6368-36, Poster Session

A modified full-vectorial finite-difference beam propagation method based on H-fields for optical waveguides with step-index profiles

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A modified full-vectorial finite-difference beam propagation method based on H-fields in solving the guided-modes for optical waveguides with step-index profiles is described. The propagation is split into two substeps. In the first substep, the field propagates in the absence of the cross-coupling terms, and then they are evaluated and double used in the second substep. The order of two substeps is reversed for each polarized field component so that the CCTs are always expressed in implicit form. Therefore, the calculation is stable. Moreover, the resulted matrix is tridiagonal, thus the calculation is efficient. An improved six-point finite-difference scheme with high accuracy is constructed to approximate the cross-coupling terms along the transverse directions. By using the imaginary-distance procedure, the filed patterns and the normalized propagation constants of the fundamental modes for a buried rectangular waveguide and rib waveguide are presented, and the hybrid nature of the full-vectorial guided-modes is demonstrated. Solutions are in good agreement with the benchmark results from film mode matching method, which tests the validity and utility of the present method.

6368-39, Poster Session

Analysis of the mode structure in high-power diode lasers based on a double barrier separate confinement heterostructure

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The low beam quality of high power diode lasers, manifesting among the others in high fast-axis beam divergence, presents a serious drawback for many applications of these devices. Among the most important beneficiaries of low beam divergence are optical pumping applications since the beam focusing capability strongly depends on the beam quality. A decrease of beam divergence and an increase of catastrophic optical damage level can be achieved by modifying a conventional separate confinement heterostructure. A proposed design, the double barrier separate confinement heterostructure (DBSCH) contains thin, wide-gap barrier layers at the interfaces between waveguide and cladding layers that cause a local guiding / antiguiding competition and allow for optical confinement control, thereby increasing the radiation spot size at the laser facet and, concomitantly, decreasing the beam divergence.

In present paper we present an analysis of mode structure of high-power DBSCH diode lasers. The devices are characterized by very low fast-axis beam divergence (13 - 15 deg, depending on the design version). Modeling of fundamental mode distribution for three different design versions of DBSCH diode lasers is presented. Electro-optical characteristics of the devices such as light-current curves and far-field distributions are shown. Complementary measurements of the near field distribution in diode lasers is preformed by employing a Near -field Scanning Optical Microscopy in collection mode. The mode structure of diode lasers is directly visualized giving indications about the heterostructure construction.

6368-40, Poster Session

Analysis of mechanical strain and temperature profiling in high-brightness parabolic bow-tie laser arrays

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With the widespread use of laser diodes in modern industry there has been an increasing demand for high optical output power devices with good beam quality and, ideally, low production and packaging costs. Reliability and long lifetime are essential requirements since they determine the extent to which such sources will be utilised. The devices of interest here are arrays of parabolic bow-tie lasers which

have been specially designed to achieve high power with high brightness without the need for re-growth or sophisticated device fabrication. In the purpose-designed index-guided tapered-geometry optical cavity the inter-element coupling is longitudinally non-uniform, favouring stable, quasi-diffraction-limited operation.

This paper presents a comparative study involving arrays with different numbers of elements and different geometries of the individual element (stripe, linear and parabolic tapers) to investigate the effects of scaling and geometry (which affect the array phase coherence) on degradation and ageing. Temperature profiles at the array facets have been obtained using a thermal imaging system, whereby quantitative data are obtained with respect to carefully detected calibration curves. The HgCdTe-based detector operates in the 3-5.5um wavelength range; the estimated spatial resolution is approximately 5um/pixel. The results obtained so far indicate a slight increase in temperature (2-5oC) in uncoupled arrays with respect to phase-coherent arrays and a considerable increase in temperature with increasing number of elements in the array. Such considerations are essential to properly manage thermal dissipation and improve the operational characteristics of such devices.

6368-41, Poster Session

Analysis of noise properties in a violet laser diode and its frequency stabilization based on Fabry-Perrot resonators

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We have demonstrated for the first time the analysis of noise properties in a 65mW, 400nm violet laser diode and also stabilized its frequency fluctuations as low as hyper coherent level. We measured the longitudinal mode behavior in some operation conditions, including the ambient temperature and optical feedback amount and so on. With some optical feedback amounts usually seen in typical optical pick-up systems, we have confirmed that the average relative intensity noise (RIN) value measures up to about -125dB, while the external cavity length dependences of the RIN show maximal and minimal spikes repeatedly at certain points where the external cavity length coincides with integral multiples of the half of the effective internal cavity length of our sample LD. Under such circumstances, we have achieved the suppression of the optical feedback noise to about -132dB by selecting the polarization of the feedback light. Moreover, we have proved the measured 65mW, 400nm violet laser diode sample tends to oscillate in multiple modes, so that we should carry out the single longitudinal mode operation by controlling the ambient temperature about 15 degrees. Thus, we have finally attained the frequency stabilization of the violet laser diode

using a reference Fabry-Perrot cavity based on the Pound-Drever-Hall method. As a result, we have achieved for the first time the frequency stability less than 10E-11 of the minimum square root of Allan variance in a 400nm type violet laser diode.

6368-42, Poster Session

Study on the spatial resolution and microstructure fabrication of two-photon polymerization technique

Y. Haifeng, JiangSu Univ. (China)

Laser micro-fabrication using femtosecond laser pulses has gained much attention in recent years for the pulse energy concentration in time and space. One promising possibility for the fabrication of micro-structures is provided by two-photon absorption photo-polymerization(TPP). Effective threshold property for TPP of resins is investigated. Based on the distribution function of Gauss laser and critical concentration of free radical, expression of lateral resolution and polymeric threshold of photosensitive resin are deduced. Through the analysis using MATLAB, we found that the scanning speed is in direct proportion to the spatial resolution, while laser power is reverse to it. Meanwhile, adopting objective lens with NA as high as possible to focus the irradiating laser improve the spatial resolution of TPP. By designing relevant experiments, this theory has been testified. Under the optimized condition, we obtain the minimum line width of 0.40μm, which has broken the diffraction limit. Therefore, the process of TPP can be employed as a basis for a promising new technology for the fabrication of three-dimensional micro- and nanostructures. Finally, we have depicted some microstructures, including micro-impeller, micro-chain and photonic crystal, fabricated by this method, which illustrated TPP is a much promise method for the fabrication of three-dimensional micro- and nanostructures.

6368-43, Poster Session

Optimal tolerance allocation in the optical head of near-field recording system

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In this paper, error analysis and tolerance allocation methods for the optical head of NFR (Near Field Recording) system are presented. Using optical systems analysis tool - CODEV, the NFR system are designed. After design, we fabricate the NFR system and test the reading & writing performance of the NFR system. The test results show that the reading & writing performance is not good enough. In order to find the cause of the performance drop in the NFR system, assembly and manufacturing tolerances of the optical head of NFR system are simulated. The tolerances analysis result indicates that the optical direction tolerance is very tight. It needs to allocate and compensate the tolerances of the optical head of NFR system.

So we proposed optimal compound tolerance allocation method using SUM (summation) method, WOW (worst on worst) method, RSS (root sum square) method, and Monte-Carlo method. We used four tolerance allocation methods to allocate the tolerance of the optical head of NFR system. The results of the four tolerance allocation methods are compared. In order to test the performance of the optical head and the tolerance allocation method which we proposed, we designed and fabricated a tolerance allocation evaluation system for the optical head of NFR system using interferometer which can detect the RMS wavefront aberration of the optical head. Using the system, we evaluated tilt, decenter and defocus tolerances in the optical head of the NFR system. And show the RMS wavefront aberration characteristics of the optical head of the NFR system.

6368-45, Poster Session

Numerical simulation of InAlGaN ultraviolet light-emitting diodes

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High-efficiency ultraviolet light-emitting diodes (UV LEDs) have received much attention due to their promising applications in illumination system, medicine, and biochemical applications. The advantages for using InAlGaN quaternary material as active region include less dislocations and lattice match to the substrate. In this work, the optical properties of the InAlGaN/InAlGaN multiple quantum-well (MQW) UV LEDs are numerically investigated with a self-consistent APSYS (Advanced Physical Models of Semiconductor Devices) simulation program. The results obtained from the numerical simulation are compared to those obtained experimentally by Wang et al. (J. Crystal Growth, vol. 287, pp. 582-585, 2006). Specifically, the characteristics of the UV LEDs with various p-AlGaN electronic blocking layers of different aluminum compositions and doping concentrations are studied. Optimization of the UV LED structure under study will be attempted. On the other hand, since the use of AlGaN electronic blocking layer may induce strain and defect as a result of the lattice mismatch to InGaN or GaN layers, the use of a lattice-matched InAlGaN as electronic blocking layer in UV LEDs may be beneficial owing to the reduced piezoelectric polarization. The optical properties of the InAlGaN/InAlGaN MQW UV LEDs with a quaternary InAlGaN electronic blocking layer will be investigated.

6368-46, Poster Session

Effects of built-in polarization and carrier overflow on InGaN quantum-well lasers with AlGaN or InAlGaN electronic blocking layers

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The optical and electronic properties of InGaN quantum-well lasers with an AlGaN or InAlGaN electronic blocking layer (EBL) are investigated by means of an advanced laser simulation software, LASTIP (LASer Technology Integrated Program). The conventional

material of EBL in InGaN quantum-well lasers is the AlGaN which can prevent indium from dissociation out of the active layer during subsequent high-temperature growth of p-type layers and has a high bandgap that can prevent electron overflow from the active region. However, the AlGaN EBL may induce strain and defect as a result of the lattice mismatch to InGaN or GaN layers. Moreover, Piprek et al. (IEEE Photon. Technol. Lett. 18, 7, 2006) showed that the built-in polarization between the interface of InGaN barrier layer and AlGaN EBL reduces the energy barrier in conduction band and attracts a high electron density. Under this circumstance, the threshold current increases because of the enhancement of leakage current. Therefore, we will employ a lattice-matched InAlGaN as EBL in InGaN quantum-well lasers to reduce the built-in polarization in the interface of barrier layer and EBL. By employing a lattice-matched InAlGaN EBL, the piezoelectric polarization can be reduced. Furthermore, spontaneous polarization can be reduced by choosing appropriate aluminum and indium compositions as well. The effects of built-in polarization and carrier overflow on laser performance of InGaN quantum-well lasers with AlGaN or InAlGaN EBL will be compared in detail. Finally, optimization of EBL for InGaN quantum-well lasers will be attempted.

6368-47, Poster Session

Numerical study for 1.55-μm AlGaInAs/InP semiconductor lasers with compensated tensile strain in barriers

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Semiconductor lasers emitting at 1.55 μm are of interest for optical interconnections and optical fiber communications. The AlGaInAs/InP material system has received much attention due to their relatively high band-offset ratio. In order to reduce the current leakage and enhance the laser performance, p-type AlInAs electron stopper layer used in AlGaInAs/InP semiconductor laser structure has been proposed by Takemasa et al. (IEEE Photon. Technol. Lett., vol. 10, pp. 495 * 497, 1998). In this work, the AlGaInAs/InP semiconductor laser structure is numerically investigated by using LASTIP (abbreviation of LASer Technology Integrated Program) simulation program. The initial simulation results suggest that the well with a certain amount of compressive strain and the barrier of active layer with a certain amount of compensated tensile strain can improve the laser performance. The barrier with various compensated tensile strains influences on radiative and non-radiative recombination currents will be studied in this work. Furthermore, we will attempt to find the optimization of active layer for 1.55-μm AlGaInAs/InP semiconductor lasers. In addition, a n-type AlInAs hole stopper layer located between the active region and the n-type graded-index separate confinement heterostructure (GRINSCH) layer will be adopted to obtain higher characteristic temperature among different operating temperature ranges, 288~358K, 288~318K, and 318~358K. Finally, the performance of laser with the AlInAs hole stopper layer for different n-doping concentrations will be discussed and compared.

6368-49, Poster Session

A multimode thermooptic beam steering switch

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Thermooptic switches are valuable active devices for rapidly and reliably switching and routing optical signals in planar lightwave circuits. We present modeling and fabrication of a thermooptic switch made of the polymer SU-8, an epoxy resin commonly used as a MEMS structural material. SU-8 is a good candidate material for use in planar waveguides due to its high refractive index, good transmission properties in the visible and infrared, and excellent thermal and mechanical stability. Furthermore, it has great advantages in fabrication since it is used as a negative photoresist, and so can be patterned directly using photolithography. Light is guided by a refractive index gradient generated by embedded MEMS microheaters, which activate the thermal nonlinearity of the polymer. The thermooptic change in refractive index imparts an inhomogeneous phase shift to the beam in the waveguide, which guides input into one of two or more outputs. Besides experimental characterization of the switches, we use a novel 3D beam propagation method, along with finite element modeling of the temperature profile, to simulate the switching behavior. The theoretical results are compared to actual switch outputs.

6368-50, Poster Session

Antireflection coating for photo-pumped IV-VI semiconductor light-emitting devices

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An antireflection coating material for optically pumped group IV-VI lead-chalcogenide semiconductor light emitting devices has been proposed. The pumping source, usually taken for these optically pumped devices are low cost, compact, high power III-V diode lasers emitting in the 980nm-1μm wavelength region. Lead-chalcogenide semiconductor materials having higher refractive indices in this wavelength region, reflects back almost (40-42) % of the incident pumping light into the ambience, allowing only a smaller fraction of pump-light to enter the high-index semiconductor. So there is a need to minimize the reflectance of the light-receiving surface in order to boost the pumping efficiency and increase the generation of photons in the semiconductor material. The coating has been used to increase the photo-pumping efficiency. Theoretical model showed that with the proposed AR coating with a quarter wavelength thickness, 0.008% reflectivity could be achieved in the 980nm-982nm wavelength region. The antireflection property of the coated film was investigated by FTIR-spectroscopic reflectance measurement. Room temperature continuous wave (CW) mid-infrared photoluminescence (PL) of the diode pumped IV-VI semiconductor multiple quantum well (MQW) structure was studied before and after coating the antireflection material. The mid-infrared photoluminescence from the coated structure was increased up to 4-times when compared with uncoated structure.

6368-51, Poster Session

ZnCdSeTe radiation detectors

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Group II-VI semiconductor compounds CdTe, ZnCdTe and CdSeTe are known as suitable materials for the room temperature γ- and X-ray detectors. In this work, our aim was to investigate properties of a quadrupole compound ZnCdSeTe. We selected a suitable host composition to keep a hexagonal crystal structure which enables to optimize the detector properties. Copper, chlorine and oxygen dopants were used to form a high resistivity and radiation sensitivity. Precautions were applied to achieve an uniform doping, high quality of crystal surfaces, and to remove the flux and other residues after the thermal treatments. Controllers with high accuracy were used to hold calculated temperatures in the furnace zones. Fabricated samples showed a high radiation sensitivity from NIR via VIS and UV to X-ray band. Very good linearity, stability and performance of samples was measured using a X-ray source with Cu-anode, at 40 keV. Application of ZnCdSeTe radiation detectors is possible in industry, for radiation monitoring in nuclear medicine, in automatic systems, in test and measuring equipment etc.

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Part of Proceedings of SPIE Vol. 6369 Photonic Crystals and Photonic Crystal Fibers for Sensing Applications II

6369-01, Session 1

Microstructured optical fibers, fundamental properties, and biosensor applications

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Microstructured Optical Fibers (MOFs) are characterized by having a pattern of air holes that run along the entire length of the fiber. The optical properties of such fibers are primarily determined by the position, shape and size of the air holes. Current fabrication techniques offer a large degree of freedom in the design of the air hole pattern thereby making it possible to produce MOFs with a large variety of optical properties. This includes high nonlinearity, endlessly single mode guidance, low dispersion over a wide wavelength range, and guidance in hollow cores. Among the many potential applications of MOFs there are a few that presently receives much attention: high power fiber lasers, light sources for biomedical systems, non-linear effects for optical communication systems, and biosensors.

MOF based biosensors take advantage of the unique possibility to position a given sample inside the air holes, where it can be analyzed by evanescent-wave interaction. The fibers can be functionalized towards specific capture of e.g. single stranded DNA strings or antibodies by immobilizing a sensor layer on the side walls of the air holes. Most real-life applications of MOFs within biosensing require robust easy-to-use components allowing for simultaneous coupling of light and samples into the fiber. This can be realized by integrating the fiber in a low-cost polymer chip or optic-fluidic coupler.

In addition to giving an overview of the present state-of-the-art within the field of silica and polymer based MOFs and the application of these, the talk will address recent results on MOF based biosensors.

6369-02, Session 1

Tapered photonic crystal fibers

R. Albandakji, A. Safaai-Jazi, R. H. Stolen, Virginia Polytechnic Institute and State Univ.

Recently, tapered photonic crystal fibers (PCFs) have attracted interests for a number of reasons. First, output spot sizes can be increased or decreased by up or down tapering, respectively. The fiber numerical aperture can also be modified in a similar way. The commensurate rise in optical intensity possible in a tapered fiber leads to greater efficiency in the nonlinear processes typically associated with super-continuum generation. Efficient coupling of power from large core PCFs to small core nonlinear fibers can be achieved using PCF tapers. Tapering has also allowed for the fabrication of compact bandgap structures within relatively small fiber structures, approaching a first-order photonic bandgap structure that has not yet been demonstrated.

The method used to analyze the PCF taper is based on approximating the tapered section as a series of uniform sections along the axial direction. Using this approach, the index profile becomes independent of the axial direction within each section; therefore, we can approximate the modes within the finite section by the modes of an infinitely long fiber. These modes are the so-called local modes, which are considered to be an excellent approximation for slowly varying fibers. Then, the conventional coupled mode theory is used to study the coupling of local modes among each other.

Tapered PCFs, similar to tapered conventional fibers, can be either adiabatic or nonadiabatic. Using the method of analysis discussed above, we examine the adiabaticity of the taper and obtain three-dimensional plots showing the evolution of the total electric field propagating inside the tapered fiber. Also, we analyze different taper shapes, such as the linear taper, raised-cosine taper, and the modified exponential taper. Other factors, such as the taper length and the number of air hole rings are also studied.

6369-03, Session 1

Fabrication and characterization of solid-core microstructured optical fiber with steering-wheel air cladding for sensor applications

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Microstructured optical fibers (MOFs) with solid core and tiny silica-air capillaries running along their axis form a very promising detection platform since MOFs can provide strong evanescent-wave overlapped with air holes near core over a long optical path. Furthermore, due to the design flexibility and versatile functionality, robust sensing scheme can be achieved through the modification of inner surface of the holes. In this paper, we describe a new type of solid-core MOF with steering-wheel air cladding (called SW-MOF) for evanescent-field sensor application. Specifically, SW-MOF was fabricated using sol-gel casting technique. To avoid loss induced by air-hole roughness attributable to the surface modes, a plasma healing process was employed after sintering the preform. The SW-MOF was drawn into fibers with core and fiber diameters of 2.3 micrometer and 125 micrometer, respectively. The steering-wheel pattern of air holes has a web thickness of 1.25 micrometer and an elongated air hole diameter of 22 micrometer in the long axis. Attenuation measurements showed a fiber loss of 0.13dB/m at 785 nm while the cut-off wavelength for single mode operation is 683 nm. Near-field mode imaging was used for the determination of mode-intensity overlap and mode-field diameter, with which the numerical aperture can be derived. With low loss and high power fraction in air holes as well as large hole diameter, SW-PCF is well suited for evanescent-field sensing and detection of chemical and biological species.

6369-04, Session 1

Characterization of photonic crystal fibers by using a full-vectorial finite element method

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Photonic crystal fiber (PCF), which is also known as holey fiber, is a micro-structured fiber, where arrays of holes running along the waveguide length and have more controllable fabrication parameters than standard single mode fiber. Increasing interest is being shown in such PCFs for a range of applications in optical communications, sensing and signal processing. This has included the control and guidance of optical beams, taking advantage of their unique transmission characteristics which include being continuously single-moded, with controllable spot-sizes offering large spot size for high power delivery and small spot size for intense nonlinear activities. The fibers also allow tailored group velocity dispersion characteristics for various linear and nonlinear device applications.

To date, most of the research into these fibers has had a strong experimental basis [1], which has recently been complemented by various modal solution approaches to their characterization, this having mostly been using scalar formulations or being limited to specific types of structures. The modal solution approach based on the powerful finite-element method (FEM) [2] is more flexible, can represent any arbitrary cross-section more accurately and has been widely used to find the modal solutions of a wide range of optical waveguides [2]. The flexibility of the FEM to represent a cross-section of a holey fiber, with its arbitrary hole sizes, materials, shapes, and their placement, makes it a powerful approach where many other simpler and semi-analytical approaches are proven to be unsatisfactory. The optical modes in a high-index contrast PCF with two-dimensional optical confinement are also hybrid in nature, with all six components of the E and H fields being present. To characterize accurately such fibers, a full-vectorial approach is necessary and such a H-field based full vectorial approach [2] has recently been extended to study the polarization issues in PCFs.

Modal solutions for the fundamental and higher order TE and TM

polarized modes have been obtained including the variation of the propagation properties, single-mode operation, the modal field profiles, the spot-size, the power confinement, the modal hybridism and the bending loss. An asymmetric air-hole has been introduced into the designs to enhance the modal birefringence and to create a single polarization PCF. The effect of material nonlinearity has also been studied and results on these activities will be presented.

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6369-05, Session 2

Surface functionalization of photonic crystal fibers for SERS-based water monitoring

S. A. Sukhishvili, Stevens Institute of Technology

We report several strategies to design highly SERS-active surfaces for sensing of anionic species and/or biological molecules in aqueous environment. The strategies involve the use of polyelectrolytes and allow facile, environmentally benign and robust engineering of interfaces with tunable charge and polymer conformations for subsequent SERS-based sensing. The first route involves reduction of silver nitrate using a combination of branched polyethyleneimine (BPEI) and N-(2-hydroxyethyl)piperazine-N'-2-ethanesulfonic acid (HEPES). The procedure yields monodisperse positively charged silver nanoparticles whose size could be tuned in the range from 15 to 50 nm by varying the BPEI to HEPES molar ratio. The BPEI-templated Ag nanoparticles can be easily immobilized at negatively charged surfaces, producing substrates which exhibit exceptional affinity to anions. The demonstrated capability of such substrates to perchlorate and cyanide anion detection was about 10 ppb using 930 cm-1 and 2210 cm-1 bands, respectively. In the second strategy, we use positively charged polyelectrolytes to produce Ag-nanoparticle-based substrates which are designed to resist non-specific adsorption of biological molecules, such as proteins. Protein adsorption properties of the substrates are supplied by a range of polyelectrolyte chain conformations achieved through various history-dependent polymer adsorption routes. Finally, we will discuss the application of these procedures to produce nanoparticle-functionalized photonic crystal fibers for SERS-based sensing.

6369-06, Session 2

Surface enhanced Raman scattering using metal modified microstructured optical fibre substrates

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Synthesis of metamaterials using micro/nanostructured scaffolds as templates is a powerful means to create 3D structures with appropriate nanoscale architecture. Microstructured optical fibres (MOFs) combine very large surface areas and aspect ratios with outstanding mechanical properties that serve as excellent 3D templates. MOFs are a special class of optical fibres whose guiding properties rely either on modified total internal reflection or on the existence of photonic bandgaps. In MOFs, the aperiodic or periodic arrangement of holes can be tightly controlled during the fabrication process and by choosing an appropriate structure, the spectral and temporal characteristics of light propagating through them can be carefully engineered. A further advancement in the functionalization of MOFs is the inner modification and filling of their capillary holes. The deposition of useful materials inside the fibre's voids has the potential to explore new directions in micro/nanomaterials technology and allow for long interaction length between the fibres guided modes and the infiltrated materials. Here we report the growth of silver granular layers inside the MOF holes by high pressure chemical deposition techniques. The resulting metal-dielectric MOFs serve as exceptional substrates for surface enhance Raman spectroscopy allowing for very long interaction lengths between the fibre's optical guided modes and plasmonic resonances of the silver nanoparticles with benzenethiol molecules used as the analyte.

6369-07, Session 2

Absorption measurement in the near-infrared using solid-core microstructured and hollow optical fibers

A. S. Raspopin, Y. Zhu, H. H. Du, Stevens Institute of Technology

It is theoretically well founded that the detection of molecular species can be implemented by evanescent-wave absorption. The technique is based on the fundamental overtone and combination vibrational absorption of analytes in the infrared (IR) and/or the near-IR regions. Additionally, the absorption measurement with near-IR spectroscopy is a non-destructive method of molecular analysis, providing perfect data collection and requiring no sample preparation However, the sensitivity of evanescent-wave absorption is strongly related to the power fraction carried in the evanescent-field itself, which is inherently low.

In this paper, we report the use of several platforms for evanescent-field measurements: a solid-core photonic crystal fiber (PCF) with steering-wheel pattern of large holes in cladding; a high non-linearity photonic crystal fiber (HNL-PCF); and hollow optical fibers with varying hole diameters. To avoid the light focusing and collimation, a tungsten white light source is directly coupled to the fiber in our simple experimental setup, through which the feeble light is captured by a near-IR spectrometer for analysis. First, we have measured the transmission spectrum with a long-period grating written in a single mode PCF in the near-IR and clearly seen the resonance wavelengths of three notches, induced by the core-cladding mode couplings of LP01-LP02, LP01-LP03, and LP01-LP04 with high resolution of 10 pm. The high-order harmonic coupling between the core and cladding modes are also detected. Second, we have detected the plasmon peaks of various metallic colloids and nanoshells immobilized on PCF cladding, necessary for realization of SERS-active PCF. In addition, the absorptions of non-hydrogen bonded SiOH and hydrogen bonded SiOH are traced in HNL-PCF treated with water using our near-IR spectrometer. Finally, the advantages of this scheme are described, and the near-IR spectroscopy applications are discussed.

6369-08, Session 2

A high-resolution refractometer using long-period grating induced by mechanical stress relaxation in photonic crystal fibers

Y. Zhu, Z. He, H. Du, Stevens Institute of Technology; R. Bise, OFS Fitel, LLC

Periodic modulation of refractive index in a fiber core and/or cladding induces a fundamental guided mode to couple a sequence of forward propagating cladding leaky modes, producing one or more resonances at discrete wavelengths in the transmission spectrum. The basic condition for the core-cladding mode coupling is that both phase-matching between modes and strong overlap of mode profiles are satisfied. The interrogation of either peak resonant wavelength shift with constant amplitude or coupling strength change at fixed wavelength, which are affected by surrounding medium of cladding surface, is an important application of long-period gratings (LPGs) in physical sensing domain. For chemical and environmental sensing, large shifts in resonance wavelength with the change of external refractive index are desirable for high sensitivity. In this paper, we present photonic crystal fiber (PCF)-based LPG refractometer with ultra-sensitivity, compared to that of normal fiber LPG. Mechanical stress relaxation is employed to realize LPGs in endlessly single mode photonic crystal fiber (ESM-PCF) and SMF-28 conventional optical fiber using a CO2 laser and point-by-point technique. Different concentrations of glycerin with indices of refraction from 1.37740 to 1.45085 were experimentally measured with the two types of fiber. It is important to note that the resonance wavelength shifts of LPGs in ESM-PCF and SMF-28 are about 3.1 pm and - 0.72 pm, respectively, for 1 x 10-5 change in the refractive index as it was reported that the Bragg wavelength shift in an etched fiber Bragg grating (FBG) is only about - 0.083 pm under similar condition. The ESM-PCF based LPG exhibits high resolution. It is also found for the first time that, contrary to the LPG in the normal fiber, the resonance wavelength of the LPG in

ESM-PCF shifts toward longer wavelength by increasing the external refractive index. This unique feature can be theoretically interpreted by phase-marching condition combined with modified transfer matrix equation. Characterization at medium temperatures from 25 0C to 200 0C shows 8.8 pm/0C and 117 pm/0C of thermal dependency of the resonance wavelength for ESM-PCF LPG and SMF LPG, respectively. The advantages of ESM-PCF-LPG are ultra-compact, temperature insensitive, high resolution, and system compatibility. As such, the refractometer we report on can be easily implemented for practice sensing applications.

6369-09, Session 3

Optical properties and microstructures of colloidal crystalline arrays composed of titania nanosheets coated core-shell structured spheres

H. Nakamura, Toyota Central Research and Development Labs., Inc. (Japan)

Colloidal crystalline arrays are three dimensionally periodic lattices of self-assembled monodisperse colloidal spheres. These periodic structures have been actively explored as functional components in fabricating new types of diffractive devices such as optical filters and chemical sensors, mechanical sensors, and photonic bandgap structures. We have demonstrated the synthesis of silica or polystyrene spheres uniformly coated with titania nanosheets and the fabrication of these spheres into close-packed colloidal crystalline arrays. We have also reported on the optical properties and microstructures of the colloidal crystalline array estimated by angle-resolved reflection spectra measurements. The titania nanosheets were synthesized by delamination of layered titanate crystallites. The titania nanosheets coated spheres were prepared by the LBL (Layer-By-Layer) assembly coating process, which consisted of alternately laminating cationic polyelectrolyte and anionic titania nanosheets on monodisperse silica or polystyrene spheres. The close-packed colloidal crystalline array was fabricated in the glass cell by drying process of the aqueous dispersion of the spheres. The Bragg diffraction peak of the colloidal crystalline array shifted to longer wavelengths with increasing thickness of titania nanosheets layers. Angle-resolved reflection spectra measurements showed that this red shift was caused by increasing the mean effective refractive index neff of this crystalline lattice without changing interplanar spacing d111 with increasing thickness of titania nanosheets layers. Since a wide range of coated colloids of different size, composition, and optical properties can be prepared via the LBL coating, the current work suggests new possibilities for the creation of advanced colloidal crystalline arrays with tunable optical properties.

Colloidal crystalline array, Titania nanosheet, Core-shell structured sphere, Layer-By-Layer assembly process, Bragg diffraction, Angle-resolved reflection spectra measurement, Refractive index,

6369-10, Session 3

Mesoporous photonic crystals for sensor applications

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Artificial structures composed of closely packed monodispersive SiO2 (silica) spherical particles, which are synthetic opals and opal thin films, are used as representatives of 3D photonic crystals (PCs). Optical properties of PCs depend on the state of polarization and direction of light propagation in them. Moreover, by varying the size of silica sphere and the dielectric contrast in 3D PCs, the photonic band structure can be realized in the infrared range and cover all visible spectral range. It was demonstrated that 3D PCs based on opal thin films of thickness of 10 close-packed layers show intensive stop bands and, also, can be used to fabricate magnetophotonic crystals by incorporating magneto-optical planar defect in 3D PCs and therefore to observe magneto-optical effects at specific resonant frequencies.

In this work, we show that optical properties of mesoporous 3D PCs are extremely sensitive to the external conditions of experiment, and in the first turn, to a humidity of surrounding media. This is due to inherent to mesoporous PCs microstructure. In fact, both an opal film itself and the internal structure of a single sphere have high porosity, uniform pore size distribution and, also, specific pore arrangement. Therefore dielectric permittivity of mesoporous PCs strongly depends on humidity that can be easily detected by optical or magneto-optical means. High sensitivity, quick response and possibility of contactless measurements makes sensors based on optical and magneto-optical effects in mesoporous PCs very promising. It concerns not only humidity sensors, but also sensors of various gases, temperature, deformation and so on.

6369-11, Session 3

Structural colored gel

Y. Takeoka, Nagoya Univ. (Japan)

Here, I report that the structural colored gel by the use of a closest packing colloidal crystal as template. My work aims to establish how gels of desired optical performance can be obtained.

6369-12, Session 3

Tuning stop band of soft opal film by deformation for strain sensing applications

H. Fudouzi, T. Sawada, National Institute for Materials Science (Japan)

We will report colloidal crystal composite with tunable stop band for the strain sensing applications. The colloidal crystal made of a thin layer of cubic close packed, ccp, colloidal particles embedded in poly (dimethylsiloxane), PDMS, elastomer: i.e. “soft opal”. The array of ccp (111) planes diffracts light of selective wavelengths according to Bragg’s law. Here two types of sheet were used as substrate. One is an elastic rubber. Soft opal film was coated on the sheet. When the elastic rubber sheet was stretched in the horizontal direction, it reduced in size in the vertical direction. As a result, the lattice distance of ccp (111) planes decreased and the reflected wavelength of light shifted to shorter wavelengths. After the mechanical strain on the elastic rubber sheet was released, the peak returned to its original position. Changing structural color of the sheet, i.e. Photonic rubber sheet, is a reversible and repeatable process.

On the other hand, soft opal film was coated on a PVC sheet. When the plastic deformation of the PVC sheet, the local strain of the sheet caused the tuning stop band of soft opal film. We can see the strain map image of the plastic deformation by naked eyes. The soft opal film has a potential to be applied for mechanical strain sensing and mapping.

6369-13, Session 3

Stimulated globular scattering in photonic crystals

A. D. Kudryavtseva, V. S. Gorelik, N. V. Tcherniega, P.N. Lebedev Physical Institute (Russia)

Stimulated Globe Scattering (SGS) has been for the first time experimentally observed in 3-D photonic crystal - artificial opal.Ruby laser giant pulse (694.3 nm, pulse duration 20 ns, maximum energy 0.3 J)has been used as a source of excitation. SGS effect consisted in the appearance of two Stokes components with frequency shifts 0.4 and 0.6 cm-1. Observed frequency shifts correspond to the vibration modes of spherical amorphous SiO2 particles (globes), of which the crystal consists. The values of the frequency shifts are defined by the globes size and properties of the material. Threshold of the effect and conversion efficiency of the pump wave into the SGS wave have been found. Spatial distribution of the scattered wave has been studied.Investigations have been fulfilled in two geometries: forward and backward. Both pure opal crystals, consisting of the dense packed amorphous globes with diameter 200 nm and crystal with pores filled with molecular liquids have been studied.Fabry-Perot interferometer was used for spectral structure investigations. SGS in pure crystal was observed in backward direction (opposite to the initial pumping beam) and its frequency shift was 0.44 cm-1. SGS in the opal crystals filled with liquids (acetone and ethanol) has been observed both in backward and forward direction. Its first Stokes component frequency shift was a little smaller than the frequency shift in the pure crystal. In backward

direction for crystal filled with liquids we observed also second component with frequency shift 0.65 cm-1 for acetone and 0.63 cm-1 for ethanol.

6369-14, Session 3

Rapid fabrication of large-area photonic crystals containing well-defined defects by two-photon photopolymerization

J. Kong, JiangSu Univ. (China)

We demonstrate a promising method to fabricate large-area three-dimensional photonic crystals woodpile structures with desired defects by two-photon photopolymerization in a liquid resin. Photoresists (ORMOCERandSU-8) are used to form square three-dimensional photonic crystals. Desired defects are introduced in these structures easily .A 1mm- ∗ 1mm woodpile structure with the lattice constant as small as 600nm embedding several kinds of defect, such as waveguide or microcavity, has been obtained by employing this technique. We fabricate three-dimensional photonic crystals structure with cross-waveguide or micro-laser in it

Three-dimensional photonic crystals with band gaps of 1.3- 2.5μm in wavelength and with gap/mid gap ratios of as much as 18% have been generated efficiently by two-photon photopolymerization. From femtosecond-pulsed 796-nm light with the scanning power 35-100mW, woodpile structures consisting of 40 layers of elliptically shaped rods spaced at 600-1000nm have been fabricated by focusing with a 1.35-N.A. objective. The high degree of correlation in these structures allows the suppression of infrared transmission by as much as 50% as well as the observation of higher-order band gaps. We currently invert these three-dimensional photonic crystals (PC)by a two step process: In the first step, the PC is infiltrated with SiO2,followed by subsequent removal of the SU-8.In a second inversion step, silicon is infiltrated and the SiO2 etched away. This results in a positive replica with complete photonic band gaps of the polymer PC. We also investigate the decrease in the gap wavelength on reduction of layer spacing, in-plane rod spacing, and rod size. The combination with two-photon photopolymerization facilitates the rapid, flexible and cheap fabrication of large-area three-dimensional PCs, as well as the controlled incorporation of defects and waveguides.

6369-15, Session 4

Optimizing surface-enhanced Raman scattering with resonant localized plasmons

J. J. Baumberg, Y. Sugawara, N. M. B. Perney, Univ. of Southampton (United Kingdom); M. E. Zoorob, M. D. B. Charlton, C. M. Netti, Mesophotonics Ltd. (United Kingdom)

Localized plasmon modes are highly suited for use in optical field-based sensor applications such as surface-enhanced Raman scattering (SERS). We demonstrate here how localized plasmon modes can be designed in pyramidal and hemispherical pits (of aperture dimension 400-2000nm), using geometry to tune the resonant plasmon wavelengths [1,2]. We confirm that diffraction features play no role in the plasmon localization process. It is well known that plasmons are effective for transducting incident electromagnetic radiation into molecules, enhancing the Raman scattering process by many orders of magnitude. Here, we demonstrate how the SERS of a monolayer of Benzenethiol can be optimized through plasmon engineering, and how the SERS is strongly correlated to plasmon absorption at the wavelength of excitation. We develop a simple plasmonic cavity model of the coupling which provides a good account of the data, and is predictive. In particular we see a resonant enhancement for different orders of localized plasmons and show how the electric field on the surface in the vicinity of the molecules is modified. The reproducibility of these SERS substrates was found to be better than 10% point to point and sample to sample, as the enhancement mechanism is not reliant on “hot spots”. These substrates are now in trial for a variety of chemical sensing and healthcare mass screening applications.

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6369-18, Session 4

Flexible bandwidth control of the single-mode guided band in a 2D photonic crystal coupled-cavity waveguide

J. J. Hu, Nanyang Technological Univ. (Singapore); X. Chen, Minjiang Univ. (China); P. Shum, X. Yu, Nanyang Technological Univ. (Singapore)

We proposed flexible bandwidth control for a two-dimensional photonic crystal coupled-cavity waveguide. The two-dimensional waveguide is designed to operate in single-mode. To keep the signal pulse shape along the single-mode waveguide, minimized dispersion within a wide bandwidth is required for the design. Moreover, research in enlargement and precise controlling of bandwidth are of great importance for waveguide structure design based on photonic crystals. In this work, the large bandwidth-tuning for single-mode guided band with fixed center frequency is realized by changing two configuration parameters, namely defect radius and defect width. In our previous studies we used these two parameters to control the upper and lower cut off frequencies of the guided band both independently and simultaneously. Plane wave expansion method is utilized for calculation. The largest bandwidth tuning range up to 50.7% of photonic bandgap is achieved for normalized center frequency at 0.377. We also calculate the dispersion relation for several single-mode guided bands with different center frequencies. Furthermore, for different bandwidths and different center frequencies, we investigate the relations of group velocities and wave vectors, which are crucial to engineer the group velocity dispersion in the waveguide. Our results demonstrate the possibility of large bandwidth tuning while single-mode operation is maintained, which could be extended to photonic crystal slab waveguide with some modifications. We believe this work will contribute to the design of integrated optical devices based on photonic crystal waveguides, such as multiplexers and de-multiplexers which make use of the flexible bandwidth control capabilities.

6369-20, Session 4

Single quantum dot inside a high-Q photonic crystal cavity

G. Shan, S. Bao, Fudan Univ. (China)

We here investigate the photon properties of a functionalized quantum dot inside a photonic crystal cavity, incoherently driven by an external laser field, theoretically. The novel photonic crystal cavity confines the optical field well and in a small volume, and engineers the strength of coupling between a discrete quantum dot (QD) transition and an electromagnetic mode of the cavity thus maximizing the strength of coupling with the quantum dot. And we analyze the spectral response properties of the present system. The useful photonic crystal cavity confines the optical field well and in a small volume, thus maximizing the strength of coupling with the quantum dot that are strategically embedded within the cavity. This, in turn, has important implications for a variety of optical phenomena, such as cavity QED, and many important applications for quantum communications and computing.

6369-21, Poster Session

Investigation of photonic crystal fiber based long-period gratings with aqueous solution inclusions

X. Yu, P. Shum, P. Xie, Nanyang Technological Univ. (Singapore)

Photonic crystal fiber (PCF) has been studied intensively in the past decade owing to its potential in fiber optic communication and sensing applications. Many research interests have been attracted to the long period gratings (LPGs) and LPG based devices in PCFs in recent years. Because of the microstructured air holes, the effective modal index shows strong wavelength dependence, which will result some anomalous properties in such gratings distinguished with conventional fiber. However, the mode coupling characteristics have not been investigated in details and the systematic comparison with the single mode fiber (SMF) based LPGs have not been analyzed yet. Moreover, because of the existence of the air holes in the cladding, we can include different aqueous solutions in such holey structure, such as pure water or sugar solutions. Meanwhile, the refractive index of these inclusions can be easily tuned by changing the temperatures, which will

result in an evolution of the cladding modes. So some interesting coupling effects can be expected between the core and cladding modes. In this paper, the evolution of mode coupling with the structure change is discussed firstly. Then the attention is focused to investigate the PCF based mechanical LPGs with aqueous solution inclusions. The shift of resonance wavelength with the solution brix and the temperature is evaluated both theoretically and experimentally. This grating device offers the unique advantages of being tunable, removable, reconfigurable and strain-stable. These properties guarantee it to be utilized as a stable candidate for temperature and refractive index sensing.

6369-23, Poster Session

Magnetic field sensors using magnetophotonic crystals

R. Fujikawa, K. Tanizaki, A. V. Baryshev, K. Shin, P. Lim, H. Uchida, M. Inoue, Toyohashi Univ. of Technology (Japan)

Magnetophotonic crystals (MPCs), combination of photonic crystal (PC) and magnetic materials, are paid much attention due to huge enhancement of magneto-optical effect. Bismuth substituted yttrium iron garnet (Bi:YIG) is well known as the magnetic material with effective magneto-optical properties, even if Bi:YIG is polycrystal. We have investigated one-dimensional magnetophotonic crystals (1D-MPCs), composed multi layers of SiO2 and Ta2O5 with Bi:YIG film as a defect layer. Due to their magnetic defect layer, Faraday rotation angle could be enhanced in the localize mode.

In this work, we investigated the possibility of application of magnetophotonic crystals as the wireless magnetic field sensor, especially for dangerous places like vicinity of high voltage wires. The structure of 1D-MPC was (Ta2O5/SiO2)5/Bi:YIG/(Ta2O5/SiO2)5 on a fused quarts substrate. The localize mode appeared at the wavelength of 884 nm, which is tunable by the thickness of multi layers or defect layer. Faraday rotation angle at the localize mode was 1.5 degrees, this is one hundred times larger than single Bi:YIG polycrystal film. Considering about the magnetic properties, this rotation of polarization changes -1.5 degrees to 1.5 degrees almost linearly, according to applying magnetic field -0.75 kOe to 0.75 kOe. In this case, intensity of transparent light might be change from 67% to 70%, when polarizers placed before and behind of 1D-MPC were rotated 45 degrees. Novel wireless magnetic field sensors based on magneto-optical effect in 1D-MPC is promising.

6369-24, Poster Session

Exact analytical solutions of planar photonic crystal waveguides

A. Safaai-Jazi, R. Albandakji, S. Mirlohi, Virginia Polytechnic Institute and State Univ.

In conventional dielectric waveguides, light guidance occurs due to the total internal reflection phenomenon. In photonic crystal waveguides, however, two mechanisms can contribute to light guidance; the total internal reflection as well as the photonic crystal effect. While extensive experimental and numerical investigations of light propagation in photonic crystal waveguides have been presented during the past decade, few analytical studies of these waveguides, particularly with regard to photonic crystal modes, are available in the literature. The purpose of this work is to present a theoretical investigation of one-dimensional planar photonic crystal waveguides. Using a novel approach, exact analytical solutions for guided modes in such waveguides are presented. These rigorous solutions allow one to distinguish clearly between the index-guiding regime and guidance due to the photonic crystal effect. In this study, the dispersion characteristics and modal field distributions in one-dimensional planar photonic crystal waveguides are considered.

The geometry of these waveguides consists of a dielectric layer of refractive index sandwiched between two semi-infinite periodic dielectric structures for which the refractive index alternates between and . Exact analytical expressions for dispersion relations, from which propagation constants of guided modes can be calculated, are obtained using a novel impedance technique in conjunction with the transverse resonance condition in the core layer of the photonic crystal waveguide. Then, solutions for electromagnetic fields of these modes are derived in each layer from the wave equation. Both TE (transverse electric) and TM (transverse magnetic) modes are examined. Numerical results for the propagation constant and field distributions of several lower-order modes are presented for an example case. The solutions unique to photonic crystal waveguides are emphasized.

Sunday-Wednesday 1-4 October 2006

Part of Proceedings of SPIE Vol. 6370 Nanomaterial Synthesis and Integration for Sensors, Electronics, Photonics, and Electro-Optics

6370-01, Session 1

Transport, assembly, and rotation of nanowires in suspension

D. Fan, F. Q. Zhu, R. C. Cammarata, C. Chein, Johns Hopkins Univ.

Nanowires are potential building blocks for a variety of nanoscale devices, including those integrating nanophotonics, MEMS, and other sensors. Using AC electric fields applied to strategically designed microelectrodes, we have designed a system in which nanowires in suspension can be driven to align, to chain, to accelerate in directions parallel and perpendicular to its orientation, to concentrate onto designated places, and to disperse in a controlled manner with high efficiency despite an extremely low Reynolds number (10-5). Randomly oriented nanowires in suspension can be rapidly assembled into extended nonlinear structures within seconds. We show that both the electric field and its gradient play essential roles in the aligning and transporting of nanowires into scaffolds according to the electric field distributions associated with the geometry of the microelectrodes. In addition, a novel system has been developed that allows for the rotation of nanowires by AC electric fields applied to strategically designed electrodes. The rotation of the nanowires can be instantly switched on or off with precisely controlled rotation speed (to at least 15,000 rpm), definite chirality, and total angle of rotation. This new method has been used to controllably rotate magnetic and non-magnetic nanowires as well as carbon nanotubes. We have also produced a micromotor using a rotating nanowire that drives particles into circular motion. This has application to microstirrers, MEMS, microfluidic devices. All of the features discussed offer great promise and flexibility with regard to producing a variety of nanoscale assemblies involving metallic, semiconductor, and biological materials with multifunctional applications.

6370-02, Session 1

A nanotube-on-insulator (NOI) approach toward scalable and integratable nanotube devices on sapphire

C. Zhou, Univ. of Southern California

We will present our recent experimental and theoretical studies on synthesis of massively aligned single-walled carbon nanotubes on sapphire, which form the basis of a novel nanotube-on-insulator (NOI) approach to produce high-yield integratable nanotube devices. We will discuss various aspects of the synthesis, including the effects of the crystalline substrates and the catalyst diameter. Based on the nanotube arrays, we demonstrated registration-free fabrication of both top-gated and polymer-electrolyte-gated field-effect transistors with minimized parasitic capacitance. In addition, we have successfully developed a way to transfer these aligned nanotube arrays to flexible substrates. Our approach has great potential for high-density, large-scale integrated systems based on carbon nanotubes for both micro- and flexible electronics.

6370-03, Session 1

Luminescent quantum dots for cellular analysis

Z. Rosenzweig, L. Shi, N. Rosenzweig, Univ. of New Orleans

The presentation will describe the development of FRET active quantum dot based sensors and their use in cellular studies. The synthesis and characterization of these nanoparticles and optimization studies that were designed to realize maximum FRET efficiency between quantum dot-based donors and molecular acceptors will be discussed. Various applications of these FRET active quantum dots will be described. These include their use for the analysis of intracellular and extracellular proteolytic activity, their application in protease inhibitors screening assays and their employment as probes of cellular membrane dynamics.

6370-04, Session 1

Self-assembly for nanointegration *(Tutorial)*

Y. Cui, Stanford Univ.

Integration of nanoscale components into functional devices requires new strategies. Self-assembly is one of most important concepts in realizing the nanointegration. Here I give an overview on the recent development of self-assembled nanocrystals, nanowires, nanotubes and biomolecules. Both principles and devices will be discussed.

6370-05, Session 2

Nanodevices and electric nanogenerators based on ZnO nanobelts and nanowires

Z. L. Wang, Georgia Institute of Technology

One-dimensional (1D) nanostructures (nanowires, nanobelts and nanorods) are the forefront nanomateirals for nanotechnology. Oxide nanostructures have been synthesized for a wide range of semiconducting oxides [1] that are potential building blocks for constructing numerous nanodevices. Field effect transistors [2], ultra-sensitive nano-size gas sensors [3], nanoresonators and nanocantilevers [4] have been fabricated using nanobelts. Among all of the oxide nanostructures we have investigated, ZnO is very unusual. The two important characteristics of the wurtzite structured ZnO are the non-central symmetry and the polar surfaces. The polar surfaces give raise a few interesting growth features, such as the formations of nanosprings [5], nanorings [6], nanobows [7] and nanohelices [8]. These nanostructure are semiconductive and piezoelectric and have potential applications as nano-scale sensors, traducers, and actuators.

This presentation will be focus on the synthesis, characterization, bio-compatibility and potential applications of these novel nanostructures as biosensors and electric generators for self-powering nano- and bio-technology [9, 10]. I will demonstrate a technology that has the potential of converting mechanical movement energy (such as body movement, muscle stretching, blood pressure), vibration energy (such as acoustic/ultrasonic wave), and hydraulic energy (such as flow of body fluid, blood flow, contraction of blood vessel) into electric energy that may be sufficient for self-powering nanodevices and nanosystems. The nano-generator discovered by us could be the foundation for exploring new self-powering technology for in-situ, real-time and implantable biosensing, biomedical monitoring and biodetection.

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6370-06, Session 2

Germanium nanowire based devices

S. Guha, E. Tutuc, IBM Thomas J. Watson Research Ctr.

Semiconductor nanowires offer interesting possibilities for integration onto a silicon platform for devices that benefit from a high surface area to volume. These include MOSFETs with high, wraparound gate capacitance, capacitors with high surface area, and sensors. We will describe some of our recent results on the growth and characterization

of germanium and silicon nanowires. In particular we will discuss the difficulties with the doping of germanium nanowires due to radial wire growth rates that depend upon the type of dopant present; and the realization of lateral p-n junctions in single Ge nanowires. We will also discuss some of the approaches for incorporating nanowire structures into exisiting, planar, semiconductor process flows.

6370-07, Session 2

Epitaxial III-V nanowires on a Si substrate

L. C. Chuang, M. J. Moewe, S. M. Crankshaw, N. P. Kobayashi, C. C. Chang, C. J. Chang-Hasnain, Univ. of California/Berkeley

Compound semiconductor nanowires (NWs) are of great interests because they are promising new materials for optoelectronic and electronic devices. Using the vapor-liquid-solid (VLS) growth mechanism, III-V NWs have been grown on substrates with large lattice mismatches [1]. This brings about the potential for integrating III-V active materials on Si substrates. In addition, quantization effects for small diameter NWs have been reported [2]. The 2D electron confinement is promising for a variety of tailored optical and electrical properties, including high optical gain and low threshold current - similar to those of quantum wells (QWs) and dots (QDs). To realize these promises, however, the control of NW diameters is critical, but remains absent to-date.

In this paper, we exhibit the experimental upper limit of coherent, epitaxial NWs, referred herein as critical diameter (CD). The critical diameter is limited by the lattice mismatch between NW material and the substrate. Although the CD concept is straightforward, similar to that of strained QW critical thickness, it has only been theoretically calculated [3]. Here, different combinations of NWs and substrates are used to provide different lattice mismatches. Uniform, well-aligned NWs are achieved using wafer-scale MOCVD and colloidal Au nanoparticles as catalysts. In addition, we also report a very narrow photoluminescence (PL) emission of 1.7 meV from InP NWs on Si. Comparing to the bulk InP peak (~875nm), the NWs show a large blue shift, ranging from 50~200 meV, due to strong quantum confinement. The sharp PL peak with a small FWHM indicates high quality optical material is obtained. Detailed material growth and characterization will be discussed at the meeting.

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6370-08, Session 2

A physics based model for transport in semiconductor nanowires

M. S. Islam, I. Kimukin, Univ. of California/Davis; M. Anwar, Univ. of Connecticut

A physics based model to explain the measured resistance of Silicon NanoWire (SNW) is presented. The resistance of SNW is modeled as a parallel combination of the highly resistive depleted region surrounding the conducting core. The model suggests that for all practical purpose the diameter of the conducting core is roughly one third of the total diameter of the SNW. Moreover, the formulation suggests an upper and a lower bound for the product of doping concentration and mobility of the core. For the p-type SNW under consideration this provides an estimate of the resistivity of the conducting core. Moreover, by utilizing the measured resistance data before and after isotropic etch is was estimated that the surface doping concentration is of the order of 2.8x1018 cm^-3 with a N_d(x)=7.034*10^17*e^(1.387*10^7x(nm)) position dependence.

6370-09, Session 2

Semiconductor nanowires for electronics: hierarchical growth and applications

D. Wang, Univ. of California/San Diego

Semiconductor nanowires has been broadly researched as building blocks for assembly of a wide range of nanodevices for electronics and photonics. The precise control of synthesis and hierarchical arrangement of nanoscale components is essential to successful manufacture of nanoelectronics and photonic devices and systems. Herein we report the growth of well-aligned vertical arrays and 3D nanowire networks and the diverse potential applications.

6370-10, Session 3

Polar-surface induced novel growth configurations of piezoelectric nanobelts

Z. L. Wang, Georgia Institute of Technology

The wurtzite structure family has a few important members, such as ZnO, GaN, AlN, ZnS and CdSe, which are important materials for applications in optoelectronics, lasing and piezoelectricity. The two important characteristics of the wurtzite structure are the non-central symmetry and the polar surfaces. The structure of ZnO, for example, can be described as a number of alternating planes composed of tetrahedrally coordinated O2- and Zn2+ ions, stacked alternatively along the c-axis. The oppositely charged ions produce positively charged (0001)-Zn and negatively charged (000-1)-O polar surfaces, resulting in a normal dipole moment and spontaneous polarization along the c-axis. This polar surface gives rise a few interesting growth features. In this presentation, we will focus on a few growth phenomena that are closely related to the polar surface. Some details will be given about the analysis of the nanobelt based materials.

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6370-11, Session 3

Catalyst-free selective-area MOVPE of semiconductor nanowires

J. Motohisa, T. Fukui, Hokkaido Univ. (Japan)

Recently, semiconductor nanowires have been attracting interest as one of a new class of building blocks for nanoscale electronics and photonics in the bottom-up approach. We here report on the systematically controlled growth of various kinds of semiconductor nanowire arrays, such as GaAs, AlGaAs, InAs, InP and their heterostructures by catalyst-free selective-area metalorganic vapor phase epitaxy (SA-MOVPE). The growth of nanowires started with preparation of partially masked GaAs (111)B (or InP (111)A) where array of circular opening in the SiO$_2$ mask was defined. Then the MOVPE growth was carried out selectively in the mask openings. Due to the crystallographic nature of GaAs-based or InP-based III-V semiconductors, vertically standing nanowires were formed without any aid of catalysts. The cross section of the nanowires were hexagonal, indicated that they were surrounded by six $¥{110¥}$ sidewall facets vertical to the (111) plane. The length, diameter, shape and position of the nanowires were precisely controlled by careful choice of the growth conditions and mask patterning. Manipulation of the growth conditions also enabled us to deliberately define the nanowire growth along either the axial or the radial direction, which has significant potential for the realization of novel nanostructures. We already fabricated AlGaAs/GaAs core-shell nanowires, InP/InAs/InP multi-core-shell nanowires and AlGaAs, InAs nanotubes. Transmission electron microscopy studies revealed that these nanowires were single-crystalline with zincbrende (GaAs) or wurtzite (InP) crystal structures. Their unique optical and transport properties will also be reported.

6370-12, Session 3

Magnetically assembled and magneto-transport studies of single ferromagnetic nanowires

N. V. Myung, B. Yoo, Y. Rheem, W. Beyermann, Univ. of California/Riverside

Facile, cost-effective, and manufacturable techniques to create single nanowire based devices with good electrical interconnects is demonstrated by combining template-directed electrodeposition, magnetic assembly, and a post-anneal in a reducing environment. Various ferroamgnetic nanowires with a diameter of approximately 30 nm were electrodeposited at room temperature using in-house made anodized alumina as a nanotemplate. After electrodeposition, nanowires were released from the template, precisely positioned, trapped, and assembled on ferromagnetic electrodes using the magnetic interaction between the nanowires and the electrodes. By annealing the interconnect in a reducing environment, the interconnect's resistance was dramatically reduced from \>10 Mohms to 835 ∗ ohms. Magneto-transport studies of a single ferromagnetic interconnect with diameters ranging from 30 nm to 200 nm show a strong diameter and temperature dependent magnetoresistance, which might be attributed to different domain structure within the interconnect.

6370-13, Session 3

Laser nanoprocessing using near-field probes

C. P. Grigoropoulos, Univ. of California/Berkeley

Recent research results on the nanoscale laser-induced surface modification will be presented. Ultra-fast and nanosecond pulsed lasers have been coupled to near-field-scanning optical microscopes (NSOMs) in apertureless configurations as well as through apertured bent cantilever fiber probes. The feature size depends on the pulse length, and the near-field absorption distribution. Experiments have been conducted on the surface modification of metals, polymers and semiconductor materials in both ambient air and controlled gas environments. Nanolithogrpahy schemes are presented. Confinement of laser-induced crystallization to nanometric scales has also been shown. Laser Chemical Vapor Deposition (LCVD) has been utilized to deposit nanoscale metal and semiconductor patterns. Experiments have been conducted on the pulsed laser-induced functionalization of monolayer coatings. Work on the nanoscale chemical analysis of materials via laser-induced breakdown spectroscopy and on nano-photo-electron emission spectroscopy is presented.

6370-14, Session 4

A modified high-resolution TEM for thermoelectric properties measurements of nanowires and nanotubes

C. Dames, Massachusetts Institute of Technology; S. Chen, Boston College; C. T. Harris, Massachusetts Institute of Technology; J. Huang, Z. Ren, Boston College; M. S. Dresselhaus, G. Chen, Massachusetts Institute of Technology

Nanowires are interesting candidates for thermoelectric applications because of their potentially low thermal conductivity and high power factor. However, measurements at the single-wire level are challenging and tend to lack detailed information about the atomic-level structure of the sample and contacts. We are modifying a high-resolution transmission electron microscope (HRTEM) with integrated scanning tunneling microscope (STM) for in-situ measurements of the thermoelectric properties of individual nanowires and nanotubes. A slender hot-wire probe is used to make electrical and thermal contact to the free end of a nanowire or nanotube. The electrical conductance of the nanowire/nanotube can be measured with the usual STM mode of operation. The Seebeck coefficient can be extracted from the transient response to a step change in the joule heating of the hot-wire probe. The thermal conductance can be calculated from the temperature and heat leakage of the hot-wire probe. These measurements are combined with detailed HRTEM observations.

6370-15, Session 4

Electrical properties of single-walled carbon nanotube films

A. Ural, Univ. of Florida

Single-walled carbon nanotubes have attracted a significant amount of research attention in the last decade because of their remarkable physical and electronic properties, such as high mobility and current density. Despite these outstanding properties, however, controlling the diameter, chirality, origin, and direction of individual nanotubes has proven very challenging. Recently, there has been a growing interest in using two-dimensional nanotube networks and three-dimensional nanotube films as a new class of materials based on single-walled carbon nanotubes, in which individual variations in diameter and chirality are ensemble averaged to yield uniform physical and electronic properties. Several applications of SWNT networks and films have recently been demonstrated, such as thin film transistors, flexible electronics, sensors, and transparent and conductive electrodes for optoelectronics. In this talk, I will present our recent measurements of the electrical properties of single-walled nanotube films, and discuss their significance for potential device applications.

6370-16, Session 4

A computational study of carbon nanotube optoelectronic devices

Y. Yoon, Univ. of Florida; M. Alam, Purdue Univ.; J. Guo, Univ. of Florida

Significant advances have been made on carbon nanotube optoelectronic devices recetnly. We have developed a simulation framework for carbon nanotube infrared emitters and for carbon nanotube phtotodetectors. A self-consistent simulation, which couples a quantum treatment of the metal-CNT contacts to a semiclassical treatment of the channel, is performed to understand carrier transport and light emission in a CNT infrared emitter. The results show that when the channel is long, light emission significantly affects carrier transport, and reduces the source-drain current by a factor of 2 in ambipolar transport regime. The experimentally observed light-spot movement along the channel can be mostly understood and explained by a simple, semiclassical picture. Furthermore, the photoconductivity of carbon nanotube (CNT) Schottky barrier transistors is studied by solving the 3D Poisson equation with the non-equilibrium Green's function transport equation. Electron-photon coupling and electron-phonon coupling are treated using the self-consistent Born approximation. The photocurrent shows peaks at photon energies near the subband gaps, which can be engineered by controlling the CNT diameter. Electron-phonon coupling (i) slightly broadens the peaks, (ii) leads to phonon-assisted photocurrent at certain energy ranges, and (iii) changes the energy-resolved photocurrent. We also show that the metal/CNT barrier height has a much smaller effect on the photocurrent than on the dark current.

6370-17, Session 4

Structure and property studies on carbon nanotubes

Z. Ren, S. Chen, J. Huang, Z. Wang, Boston College; G. Chen, M. S. Dresselhaus, Massachusetts Institute of Technology

Normally, the atomic scale structures of carbon nanotubes (CNTs) are studied by a transmission electron microscope (TEM) without knowing the electric transport properties, whereas the electric transport properties are studied by a four-probe technique without knowing the structure due to the limit of the experimental tools. However, it is absolutely necessary to know the corresponding electric properties of a specific structure so that a required structure can be built to satisfy the property requirements for a specific application. Now it is possible to do so by combining a scanning electron microscope (STM) probe with a TEM sample holder to measure the electric transport property while the structure is recorded. In this report, I will discuss 1) the electric breakdown of carbon nanotubes contacted either on the side or at the end under high bias voltage and the corresponding electric properties during the whole process, 2) super-elongation of CNTs under a constant bias voltage and the corresponding electric properties, and 3) formation of CNTs from amorphous carbon layer or fiber.

6370-18, Session 5

Analysis and design of key phenomena in electronics: integrated circuits, devices and nanostructures

N. Goldsman, Univ. of Maryland/College Park

Novel methods of modeling key phenomena in semiconductor physics that are very important now, or that are likely to be critical as we progress in nanotechnology, will be discussed. Key results and predictions that are obtained from performing these analyses will be presented. The presentation will start from the chip level where we will show how we predict power dissipation, and resulting temperature distributions within an integrated circuit. Investigations indicate that power densities in high performance integrated circuits are approaching those found in nuclear reactors. These calculations are coupled to the performance of individual devices and circuits. Methods for modeling the effect of temperature on nanoscale MOSFET performance will then presented, while also accounting for phenomena affecting ultra-small MOSFETs including quantum confinement. In the last part of the presentation, very recent results on future aspects of electronics will be presented. This last part of the talk will focus on the incorporation of Carbon Nanotubes into electronic devices, and possible application of Carbon Nanotubes to terahertz electronics.

6370-19, Session 5

Carbon nanotube-based electronics and sensors: opportunities and challenges

S. P. Karna, U.S. Army Research Lab.

Carbon nanotubes (CNT) are arguably the most promising of nano-scale materials for technological applications due to their unique chemical and physical properties. Of particular interest has been their application in electronics and sensors technologies. Recent breakthroughs in growth, purification, assembly in useful device geometries of CNTs, and observations of their novel response properties have further intensified research efforts world-wide toward CNT-based electronics and sensors technologies. Yet, the electronics and sensors applications of CNT face a number of challenges, especially those related to materials growth, purity, uniformity, and integration. In this talk, I shall provide a brief overview of recent advances in CNT-based electronics and chemical sensors. Selected results from the experiments performed by our group at the Army Research Laboratory and by others that show promises for surmounting some of the materials-related challenges will also be presented.

6370-20, Session 5

Manufacturable biosensors based on carbon nanotubes and In_2O_3 nanowires

C. Zhou, Univ. of Southern California

We report our progress toward manufacturable and disposable biosensors based on carbon nanotubes and In2O3 nanowires. Our approach employs room-temperature processing and inexpensive fabrication to produce large numbers of biosensors with high uniformity and good reproducibility. These devices were covalently functionalized with antibodies and then used for the detection of a variety of proteins, including prostate specific antigen (PSA). Electronic measurements under dry conditions revealed complementary response for In2O3 nanowire and carbon nanotube devices after the binding of PSA. Real time detection in solution has also been demonstrated for PSA down to 5 ng/mL. Further improvement of the sensitivity will also be discussed.

6370-21, Session 5

Advances in carbon nanotube-based chemical sensors

F. K. Perkins, E. S. Snow, J. A. Robinson, Naval Research Lab.

In this presentation I will describe our efforts at NRL to develop a chemical sensor technology based on single-walled carbon nanotubes (SWNTs). SWNTs possess many unique properties that make them well suited for the direct electronic detection of trace chemical vapors. For example, a surface-to-volume ratio that is essentially infinite produces a high sensitivity to its local chemical environment. Electron transport that is nearly ballistic provides an efficient electrical conduit for transmission of changes in electrical properties caused by the presence of a chemical adsorbate. Finally, the graphitic surface of SWNTs is almost chemically inert, allowing reliable and stable operation as a chemical sensor. However, there are a number of technical issues that must be addressed before one can incorporate SWNTs into a commercial chemical detection system. These issues include the development of an inexpensive, high-yield fabrication procedure, reduction of 1/f noise and understanding of other inherent noise sources, optimization of the electronic transduction mechanism, and provision of chemical specificity. In this presentation I will describe our approach to addressing each of these issues, and I will update our progress toward developing a SWNT-based trace chemical detection system for toxic industrial chemicals, chemical warfare agents, and explosives.

6370-22, Session 6

Nanowire based chemical and biosensors *(Tutorial)*

C. Zhou, Univ. of Southern California

This tutorial will present an overview on chemical and biosensors based on various nanowire structures. The success of nanowire sensing stems from the successful synthesis of various nanowires, including silicon, ZnO, In2O3 and many other materials. These nanowires, due to their enormous surface-to-volume ratios, have been utilized as high-performance chemical sensors for gases such as NO2, NH3, H2 and CO at both room temperature and elevated temperatures. In addition, high-performance biosensing has also been demonstrated with these nanowires by many groups. The detected bio species cover a wide spectrum, including influenze virus, straptavidin, prostate specific antigen and many other proteins.

6370-23, Session 6

Synthesis, characterization, and physical properties of transition metal silicide nanowires

S. Jin, Univ. of Wisconsin/Madison

We develop rational chemical strategies to synthesize novel one-dimensional nanowire materials of transition metal silicides, investigate their physical properties, and use them as nanoscale building blocks for the bottom-up assembly of integrated photonic, electronic, and spintronic nanosystems. Transition metal silicides are extremely important to microelectronics because of the ohmic contact and interconnect many silicides (NiSi, CoSi2, and TiSi2) provide. Furthermore, many silicides are direct bandgap semiconductors (CrSi2, β-FeSi2) and are promising for silicon-based photonics. The recent discovery of FexCo1-xSi alloys as ferromagnetic semiconductors make them promising for spintronic applications as well. We have developed general and rational synthetic approaches to family of transition silicide nanowires and their heterostructures. Our first approach utilizes CVD of metal carbonyl-sillyl single source precursor complexes to synthesize single crystal FeSi and CoSi nanowires via CVD without any catalyst seeds. We believe have observed a new nanowire growth mechanism that is generally applicable to silicide nanowire formation. We are extending such approaches to semiconducting silicide nanowires. We use a complimentary method of chemical vapor transport (CVT) for those transition metals that analogous organometallic complexes do not exist to prepare, for example, semiconducting CrSi2 nanowires. We have also developed a facile method to pattern the locations of nanowire growth. We will report the preliminary results on the physical properties of these new silicide nanowires.

6370-24, Session 6

A novel technique for precise positioning of metal-catalyzed semiconductor nanowires

C. W. Edgar, C. D. Johns, L. VJ, M. S. Islam, Univ. of California/Davis

We investigate the Rayleigh instabilities of metal nanowires at elevated temperature to position metal-catalyzed semiconductor nanowires on a surface with predictable period, size and shape. A linear array of metal wires were fabricated on a Si surface using optical lithography and lift-off process subsequent to an e-beam evaporation of 10-20nm of gold

(Au). The metal wires were found to break up into arrays of identical droplets when the sample was annealed at 800oC in a furnace for an hour. Variations in the temperature, thickness and width of the Au wires were found to influence the breakdown of the wires. There exists a correlation between the physical growth parameters and the formation of a uniformly spaced linear array of metal droplets. The origin of the disintegration of these Au wires into metal particles can be attributed to the Rayleigh instabilities at high temperature. The uniformly spaced metal nanoparticles are developed into metal-catalyzed nanowires with uniform diameters and spacing offering exciting opportunities for positioning semiconductor nanowires 'in place' for future nano-electronics, photonics and energy conversion. This novel technique of forming regular arrays of metal nano-particles may offer exciting opportunities in plasmonics, bio-chemical sensing and ultra-high density information storage.

6370-25, Session 6

Growth and characterization of single crystal InAs nanowire arrays using a simple vapor growth method

S. M. Prokes, Naval Research Lab.; H. D. Park, Johns Hopkins Univ. and Naval Research Lab.; A. Gaillot, R. C. Cammarata, Johns Hopkins Univ.

Currently, there is significant interest in the growth of semiconductor nanowires. Since interesting and useful electrical, mechanical and optical properties have been reported in these systems, they may be attractive for a variety of applications, including FETs, TFTs, and sensors. However, many of the current results are based on single nanowires, which have been carefully manipulated to form a device. A better and more manufacturable option is the in-situ growth of nanowires arrays, either epitaxially from an existing substrate, or the formation of random nanowire array films, which can be easily integrated into a device configuration, with no complicated manipulation. The system which we chose is InAs, which has been reported to have an electron accumulation layer at its surface in the bulk. This is a significant advantage, since most semiconductors have a surface depletion layer that will result in a complete depletion of electrons in small-diameter nanowires. For these reasons, we expect that InAs will an excellent candidate for high performance nanowire TFTs.

In general, the growth of InAs nanowires is difficult, due to the very different vapor pressures of the constituents, and due to the rapid oxidation of In. However, we have developed a very simple and inexpensive growth process, which can grow high quality, single crystal InAs nanowire arrays. We will show results on the growth of InAs nanowire arrays,including random epitaxial arrays, ordered epitaxial arrays using nanosphere lithography, and random arrays on non-crystalline substrates, such as oxides and nitrides. We will also show that this growth process follows the VLS growth mechanism, and does not follow the vapor-solid-solid (VSS) mechanism, which has been suggested.

6370-64, Session 6

Sensing and catalysis on the nano-scale

M. Moskovits, X. H. Chen, Univ. of California/Santa Barbara; A. A. Kolmakov, Southern Illinois Univ./Carbondale; Y. Lilach, Pacific Northwest National Lab.; A. Morrill, Univ. of California/Santa Barbara

No abstract available

6370-27, Session 7

Integration of phase-change and silicon nanowires for nanoelectronics

Y. Cui, S. Meister, H. Peng, J. Zhu, Stanford Univ.

Integrating phase-change phenomena with current semiconductor technology represents new opportunities for nanoelectronics such as memory devices. Here we present our recent progress in making and characterizing phase-change nanowires, and heterostructured nanowires with components of silicon and phase-change materials. In addition, the possibility to fabricate large area dense arrays will be discussed.

6370-28, Session 7

Unique mechanism of semiconductor nanowire growth

N. P. Kobayashi, S. Wang, R. S. Williams, Hewlett-Packard Labs.

The development of a highly unique method of semiconductor nanowires will be presented.

6370-29, Session 7

New bio-inorganic photo-electronic devices based on photosynthetic proteins

N. Lebedev, Naval Research Lab.; A. Spano, Univ. of Virginia; S. A. Trammell, Naval Research Lab.; I. Griva, George Mason Univ.

Photosynthetic reaction center proteins (RCs) are among the most advanced light sensing materials developed by Nature. Their coupling with inorganic surfaces is attractive for the identification of the mechanisms of interprotein electron transfer (ET) and for the possible applications in the construction of protein-based innovative photoelectronic and photovoltaic devices. Here we describe a new type of hybrid bio-inorganic photoelectronic devices based on photosynthetic proteins and inorganic electrodes. Using genetically engineered bacterial RCs and specifically synthesized organic linkers, we were able to construct self-assembled and aligned protein complexes with various metals and semiconductors, including gold, indium tin oxide (ITO), nanoporous TiO2, highly ordered pyrrolytic graphite (HOPG) and carbon nanotube (CNT) arrays. Our results show that photosynthetic protein-inorganic complexes can operate as highly efficient photo- and chemo-sensors, optical switches, photorectifieres, or photovoltaic devices.

6370-30, Session 7

Controlling electrochemical growth of conducting polymer nanotube: ultrafast electrochromics

S. B. Lee, S. I. Cho, R. Xiao, R. Liu, Univ. of Maryland/College Park

Conducting polymers are indispensable materials for the development of organic electronic devices, such as electrochemical power sources and displays. One of very important issues in such electronic devices is poor charge transport rate due to slow diffusion of counter-ions in to the conducting polymer film during redox processes. Nanotube structure of conducting polymer is one of the ideal structures to enhance the device performance by improving charge transport rate as well as surface area because the counter-ions inside of the nanotube are ready to diffuse into the thin wall thickness of the nanotube without sacrificing electrical and optical properties. However, studies on the synthesis of conducting polymer nanotube are lacking in spite of the importance and high applicability because it is a huge challenging problem to understand the synthetic mechanism and control the dimension of the conducting polymer nanotube structures. In this presentation, we describe very detailed electrochemical synthetic mechanisms and structural characterizations of the nanotube structures with various conducting polymers in a porous film using the template synthesis method. Nanotubular structures such as length and wall thickness could be controlled by adjusting electropolymerization time, applied potential, monomer concentration, and electrode shape at the bottom of pore. The ultrafast electrochromics (color switching rate 10 - 30 ms) is demonstrated by poly(3,4-ethylenedioxythiophene) (PEDOT) nanotube arrays decreasing counter-ion diffusion time into the thin wall of nanotube. Sufficient color contrast value is achieved by controlling the length of nanotube. A highly flexible electrochromic device is also demonstrated using a porous polycarbonate film as the flexible substrate.

6370-31, Session 7

Ozone sensing utilizing nanostructured metal oxide thin films

G. Kiriakidis, Foundation for Research and Technology-Hellas (Greece)

The structural, optical and electrical properties of dc sputtered InOx and ZnOx thin films are reviewed in as far as their utilization for Ozon sensing is concerned These show resistivity changes of five to eight orders of magnitude at room temperature after exposure to UV light

and subsequent Ozone treatment. Such behaviour underlines the potential of utilizing these films as low temperature gas sensing elements.

The structural properties and characteristics of the top few layers that are actively involved in the oxidation and photoreduction processes are found to have a decisive role on their sensing behaviour.

Characterization of InOx coatings on silicon substrates by EPMA and SIMS has shown a homogeneous structure in depths up to 150nm with an average In/O atomic ratio of 0.68, thus slightly off stoichiometric (In2O2.94). However, near-surface region (0-20nm) depth profile analysis has revealed a noticeable deficit in oxygen presence in the top 5nm for films in the "conducting" state, i.e., after UV exposure. The In:O atomic ratio concentration (CIn[at%] / CO[at%]) at the surface as derived by SIMS-depth profiles ranged from 0.73 to 0.62 Analyses on the sensing response for alumina-based transducers of InOx films with thickness in the range of 20-200nm studied in the 50-300 °C temperature range have shown maximum sensitivity (S=Rgas/Rair) for the thinner samples (<50nm) operating at around 100 °C. The minimum detection levels at 40% RH were in the range of 10 and 50 ppb for O3 and NO2 respectively.

On-going experiments on Sound Acoustic Wave (SAW) devices based on dc sputtered InOx and ZnOx thin films fabricated on LiNbO3 substrates indicate the capability of achieving sensing levels in the sub-ppb range.

6370-32, Session 8

Nanoscale antimony pH sensor

J. G. Lu, Univ. of California/Irvine

Antimony (Sb) exhibits remarkable linear response to solution H+ concentration and has been built into commercial pH sensors. Unlike conventional glass-based pH electrode, Sb is a pure solid state material and thus an excellent candidate for fabricating integrated sensors for its compatibility with the CMOS technology. In addition, Sb sensor plays an important role in clinical operations. It was utilized to determine the intramyocardial pH during open-heart surgery, ambulatory esophageal pH, dental plaque pH, etc.. Moreover by coating suitable enzyme, Sb becomes a potentiometric enzyme electrode that can be used to determine the concentration of uric acid. Because of its versatile biomedical applications, Sb ionic sensor of nanoscale size will enhance the scale compatibility with biological species, and enable sensitive in-vivo intracellular ion concentration determination. In this talk, I will present the fabrication and characterization of Sb nanowire based pH sensors. Sb nanowire arrays are synthesized by electrodeposition method using porous anodic aluminum oxide (AAO) membrane as a template. HRTEM images show that the Sb nanowires are embedded in an AAO matrix, and the (010) crystal plane has lattice spacing about 0.3 nm. pH measurement is performed by measuring the potential difference between a reference electrode and the Sb nanowires. Standard solutions are prepared with 0.02M Tris buffer solution and adjust the pH value by adding proper amount of 3M NaOH and HCl. Experimental data demonstrate that the nanowires have highly linear and stable response with a pH sensitivity of around -50 mV/pH. These results render a promising potential of using Sb nanowire as a non-invasive probe for intracellular pH sensing.

6370-33, Session 8

Gas sensors from quasi-1D metal oxide nanostructures: fabrication, sensitization, performance

A. A. Kolmakov, Southern Illinois Univ. Carbondale

Quasi 1-D metal oxide single crystal chemiresistors are close to occupy their specific niche in the real world solid state sensorics. Potentially, the major advantage of this kind of sensors with respect to available granular thin film sensors will be their small size and stable, predictable and reproducible performance in a wide range of operating conditions. The performance of such a gas sensor and especially its sensitivity is determined by its materials-specific surface chemistry as well as the size and shape of its active element(s). The influence of the nanostrucutre's size and shape on its performance is most directly related to its surface-to-bulk

ratio and the comparability of the Debye screening length with the effective diameter of the conducting channel. To compete with sensitivity with the best available nanocrystalline thin film sensors, one has to use very fine nanowires with effective diameter of the order of 10 nm.

Fabricating nanostructures reproducibly and controllably in this is a size domain that is still challenging even using existing nanotechnologies. The second challenge is an extreme susceptibility of the nanostructure's transport properties to poorly controlled contaminations both on its surface and on neighboring gate oxide (during device fabrication) and heat management of the semiconductor chemiresistor during the operation.

The array of methods which allow one to fabricate, functionalize and characterize chemiresistors and yet eliminate the above challenges will be reported. Namely, to produce the nanostructures with reduced conducting channel, we grow nanowires with oscillating morphologies where mesoscopic segments each a few microns long are connected by segments consisting of channels of much smaller diameters. To evaluate the heat management in the chemiresistor device we have performed a comparative study of the nanostructures with different thermal coupling to the support.

We have developed and tested few experimental approaches to tune sensitivity and selectivity of these sensors as well as implemented new methods to monitor the surface processes on individual nanostructures. In particular, the influence of the bulk doping (with donors) and surface sensitization with catalyst particles Ni, Pd, along with radiation induced defects on the surface reactivity and selectivity were directly demonstrated.

We have tested a range of spectroscopy and imaging techniques to address local transport particularities taking place in the individual operating metal oxide nanostructure sensor. In particular, we were using Scanning Surface Potential Microscopy (SSPM) to investigate dc potential distributions in an operating device. We also have successfully implemented of synchrotron radiation based photoelectron emission spectro-microscopy PEEM) to explore submicron compositional and electronic (work function) inhomogeneouties in individual metal oxide nanowire wired as a chemiresistor.

6370-34, Session 8

Nanosensors based on lanthanide compounds

S. Petoud, A. M. Yingling, D. A. Chengelis, C. M. Chade, G. R. Filipczyk, D. S. Oxley, P. D. Badger, Univ. of Pittsburgh

Luminescent lanthanide compounds have superior photophysical properties, such as sharp emission bands whose wavelengths are not affected by experimental conditions, long luminescence lifetimes (micro to milliseconds), large energy gap between absorption and emission bands, emission in the visible and/or in the near-infrared domains. For all these reasons, lanthanides could potentially be used in a broad range of bio-analytical assays and imagery applications. Nevertheless, few lanthanide compounds are currently used in practical applications, mainly because of their insufficient luminescence intensity. The reason for this limitation is doubly faceted: 1) lanthanide cations need to be sensitized with an "antenna" molecule. This has been done traditionally with small organic chromophoric molecules that need to be bound directly to the lanthanide cation. 2) the lanthanide cations need to be protected from the environment to prevent the loss of luminescence through non-radiative deactivation processes.

Herein we will present our work based on a novel approach where the lanthanide cation is sensitized using nanomaterial antenna. Examples will include the use of CdSe semi-conductor nanocrystals for the sensitization of lanthanide cations in doped CdSe:Ln nanocrystals. Other types of nanomaterials will also be presented in this paper which will demonstrate the flexibility and advantages provided by the nanoscale approach. Examples of applications of these nanomaterials as sensors will be also presented in this paper.

6370-35, Session 8

Nanoparticles superstructures

N. A. Kotov, Univ. of Michigan

The latest research on the formation of dynamic and static assemblies fronm CdTe and other nanoparticles will be presented. Emphasis will be

made on the unique 3D superstructures with combination of properties characteristic only for organized nanoscale systems.

6370-36, Session 9

Creating optimized platforms for biosensor systems

R. Ragan, Univ. of California/Irvine

Noble metal nanocrystals have demonstrated the ability for detection of biological molecules and a strong near field coupling between closely spaced particles enables single molecule detection limits. Substantial progress has been made; however, major challenges still exist in fabricating large-area, high-density, and uniformly-sized ensembles of metallic nanocrystals. We will present two methods for achieving arrays of closely spaced monodisperse metallic nanoparticles using a high-throughput and low-cost fabrication technique. Using rare earth disilicide nanowires that self-assemble in unidirectional dense arrays as a template, we have fabricated parallel arrays of Pt nanocrystals with feature size of 3.6 nm +/- 1.8 nm, interparticle spacings of 3-10 nm, and over areas greater than 1 square micron. Scanning electron microscopy images taken after reactive ion etching demonstrate the ability to select nanowires or nanocrystals as a function of metal coverage. Since decades of research have focused on silicon based CMOS technology, the creation of metallic nanostructure arrays on the silicon platform holds significant promise to yield innovative devices with functionality beyond that of silicon integrated circuits while allowing for integration with existing technology. Our second technique for noble metal nanoparticle arrays involves chemical self-assembly of metal nanoparticles on diblock copolymer templates via a bifunctional molecular linker. We will demonstrate selective chemical attachment on one phase of the phase-separated diblock copolymer template. The templates are used for the controlled creation of plasmon 'hot spots' that yield a strong electromagnetic signal enhancement for use in biological sensors. The integration of a nanotechnology-based biosensor into the fabrication process for polymer microsystems will constitute a huge step forward in the knowledge of bio-nano-micro integrated systems on polymer and seems well-suited to the creation of multifunctional structures from a perspective of both performance and cost.

6370-37, Session 9

Surface modification of nanocrystalline ZnO for bio-sensing applications

D. M. Steeves, J. W. Soares, U.S. Army Research, Development and Engineering Command

Zinc Oxide (ZnO) is a wide bandgap semiconductor that has been the subject of much research due to its potential applications in the areas of photonics, electronics and sensors. For example, the ability of ZnO to act as a gas sensor has been demonstrated by utilizing changes in its electrical resistivity. We describe an alternative property that can be leveraged for biosensing applications - changes in the inherent optical properties of nanocrystalline-ZnO (nano-ZnO). Nano-ZnO offers several advantages to existing biosensing platforms, most notably a large surface area for greater bio-functionalization and an inherent photoluminescence (PL) signal consisting of two emission peaks. One peak is in the UV, due to near band edge emission and the other is in the visible (green) region, due to oxygen vacancies caused by crystalline defects. Real-time detection of surface binding events may be possible if changes to the PL spectrum can be induced. Here, nano-ZnO powders have been functionalized with a silane crosslinking agent containing an amine-reactive aldehyde group for subsequent biomolecule attachment. We demonstrate that surface functionalization provides an optical indicator that a surface event has occurred. Furthermore, we have attached biomolecules to the reactive aldehyde and characterized the optical properties to probe changes that occur upon introducing a surface biomolecule. The functionalization protocol, fluorescent probing to confirm the presence of modifiers and surface characterization results will be discussed.

6370-38, Session 9

Ordered DNA arrays prepared via soft lithography techniques

M. Rahman, B. Day, C. Meadows, M. L. Norton, Marshall Univ.

One of our research goals is making ordered nanoscale DNA arrays and creating a general purpose platform to be used in the reproducible assembly of molecular electronic circuits. Here, we describe a method in which DNA molecules are attached to functionalized gold square arrays prepared by the combination of two soft lithography techniques, microcontact printing (μCP) and micromolding in capillaries (MIMIC). First, line patterns of hexadecanethiol [CH3(CH2)15SH] resist on gold are made by μCP, followed by assembling biotin-HP, a gold surface binding linker species, on the exposed gold areas. In the MIMIC procedure, a UV irradiated, and therefore hydrophillic polydimethysiloxane (PDMS) stamp with a grating pattern is first placed on the surface, oriented perpendicular to the line pattern. This assembly forms a network of empty channels crossing the line pattern. Strepavidin-coated quantum dots (Qdots) in aqueous solution are then placed at the open ends of the channels, and this liquid spontaneously fills the channels by capillary action. Qdots attach to the Biotin-HP at the junction areas creating ~200x200 nm2 squares for DNA attachment. Finally, after removing the PDMS mold, DNA attachment is accomplished by submerging the sample into a solution containing biotinylated DNA. This technique allows production of arrays on areas as large as 5x5 mm2.

6370-40, Session 9

Resonant-enhanced localized surface plasmon resonance spectroscopy

A. J. Haes, The Univ. of Iowa and Northwestern Univ.; S. Zou, J. Zhao, G. C. Schatz, R. P. Van Duyne, Northwestern Univ.

The peak location of the localized surface plasmon resonance (LSPR) of noble metal nanoparticles is highly dependent upon the refractive index of the nanoparticles' surrounding environment. In this study, new phenomena are revealed by exploring the influence of interacting molecular resonances and nanoparticle resonances. The LSPR peak shift and line shape induced by a resonant molecule varies with wavelength. In most instances, the trends in this data qualitatively track with the Kramers-Kronig transformation of the molecular resonance spectrum; however, the magnitude of the response is severely underestimated. This was verified from both experimental data and theoretical calculations. An alternative mechanism for these observations is suggested. These results will have implications in molecular enhanced LSPR sensing and in the understanding of surface-enhanced spectroscopy.

6370-41, Session 10

Concentration gradient donor-acceptor profiles in polymer solar cells

J. R. Heflin, Virginia Polytechnic Institute and State Univ.

Efficient polymer-fullerene photovoltaic devices require close proximity of the two components to ensure photoexcited electron transfer from the semiconducting polymer to the fullerene acceptor. While charge transfer is optimized in "bulk heterojunctions" in which the two species are blended throughout the device, charge transport is increased with concentration of the donor (acceptor) at the anode (cathode). A concentration gradient of the two species provides a desirable compromise. We describe studies in which a bilayer system consisting of spin-cast semiconducting polymer [poly(3-octylthiophene) (P3OT) or poly(3-hexylthiophene) (P3OT)] and sublimed C60 or PCBM C60 derivative is heated in the vicinity of the polymer glass transition temperature in an inert environment, inducing an interdiffusion of the polymer and the fullerene layers. With this process, a controlled, bulk gradient heterojunction is created bringing the fullerene molecules within the exciton diffusion radius of the polymer throughout the film to achieve highly efficient charge separation. The interdiffused devices show a dramatic decrease in photoluminescence and concomitant order-of-magnitude increase in short circuit currents, demonstrating the improved interface. Detailed studies of the effects of the initial donor and acceptor layer thicknesses and the time-temperature profile of the heat treatment on device efficiency will be presented and compared to models developed to quantify these effects. Transmission electron microscopy and Auger spectroscopy investigations of the concentration gradient profiles and effects of aggregation will also be described.

6370-42, Session 10

Venturi-assisted nanospray protein ion generation by a micromachined ultrasonic electrospray array

F. M. Fernandez, C. Y. Hampton, M. Meacham, A. Fedorov, L. F. Degertekin, Georgia Institute of Technology

Electrospray ionization (ESI) has catalyzed the rapid evolution of the field of proteomics, enabling to convert large biomolecules in the liquid phase into low-internal energy gas-phase ions. As mass spectrometry evolves into a structural tool, and the requirements for high throughput steadily increase, so does the need for softer, more sensitive array-format ionization methods.

Conventional micro and nanoelectrospray ionization, require the use of high voltages (1~3KV) to produce liquid atomization, and suffer of limited dynamic range due to charge transport limitations at the Taylor cone. We here present an Array of Micromachined UltraSonic Electrosprays

(AMUSE) which eliminates most of the limitations of conventional ESI, has the potential to perform parallel, high throughput analysis, and can be batch microfabricated using a simple process.

The AMUSE device has three major components: 1) a piezoelectric transducer used to create resonant ultrasonic waves to propel the liquid, 2) a micromachined silicon wafer with pyramidally-shaped cavities capable of focusing the ultrasonic waves, and 3) a spacer to prevent contact between the silicon wafer and the piezoelectric transducer ensuring that the ultrasonic energy is transferred to the sample with a high efficiency. A high pressure gradient is generated at the apex of the pyramids on the silicon wafers forcing the continuous ejection of a droplet stream from the nozzle of each of the pyramids.

We now demonstrate the successful operation of an AMUSE device with 3-micron orifices coupled to a Venturi air amplifier to enhance ion transmission efficiency from droplet streams generated by multiple cavities.

AMUSE decouples the process of droplet formation from that of droplet charging making it possible to generate charged droplets from purely aqueous solutions and applied DC potential of less than 100V. AMUSE results for the analysis of reserpine, leucine enkephalin and cytochrome C samples prepared in a 99.9:0.1 water:acetic acid solvent will be presented demonstrating the feasibility of using this device for biomolecule ionization.

6370-43, Session 10

Nonlithographic nanostructure devices and circuits

B. Das, A. N. Banerjee, Univ. of Nevada/Las Vegas

We have developed an ultra-high vacuum technique for the fabrication of complex nanosystems incorporating nonlithographic nanoparticles, ohmic contact metals and isolation dielectrics. It is believed that such a multi-component structure is a necessary prerequisite for the realization of practical photonic and electronic devices based on nanoparticles. The technique is compatible with silicon integrated circuit technology, thus making it suitable for volume manufacturing. The technique is also versatile, and allows the deposition of nanoparticles of any metal, semiconductor or insulator with diameters as small as 2 nm with less than 5% size variation. In addition, the technique allows the creation of multi-layered structures of nanoparticles of different dimensions separated by metal or dielectric layers. This technique also allows the creation of patterned layers of nanoparticles. At the heart of this new fabrication technique is a nanoclsuer source that consists of a dc magnetron sputtering unit, which is used to sputter particles into an aggregation region where these particles form clusters and channeled through a quadruple mass filter (QMF) to allow a pre-selected size-distribution of the nanoparticles. In addition, the system contains a 4-pocket electron-beam unit as well as a dc pulsed sputtering unit that allow the depsoition of contact metals and isolation dielectrics. We have fabricated nanoparticles of a variety of materials including Cu, Si, GaAs, CdS and CdSe on a variety of substartes incldluign silicon, glass and plastic. In addition, we have demonstrated the versatility of the equipment by depositing different sized nanoparticles with pre-selected narrow size-distributions as well as multi-layered structures of such nanoparticles.

6370-44, Session 10

Transmission line circuit representation of surface plasmon waves

A. Tarlis, J. Sarma, F. Causa, Univ. of Bath (United Kingdom)

Although well known for several decades the continued vigorous interest in Surface Plasmon Waves (SPWs) is driven by the realisation that SPWs have the potential for many applications ranging from nanophotonic circuit elements to highly sensitive sensors. At its simplest the SPW is a Transverse Magnetic (TM) polarised optical (electromagnetic) wave that is confined transversely at the single interface between a metal and a dielectric while propagating along the longitudinal axis. However, SPWs in multi-layer regions are often needed to improve, enhance and/or optimise ‘device’ applications. Further, the losses in the metal severely limit propagation distance of SPWs. This paper first examines the various SPW modes in multilayer structures and presents the Transmission-Line (T-L) method as a very convenient and ‘physically transparent’ procedure for obtaining a detailed quantitative analysis of SPWs in multilayer guides inclusive of losses and the frequently used prism excitation. The paper will report on the use of the T-L analysis to assess, in comparison with experiments, the practical issue of Surface Plasmon Resonance for sensing application to delineate the requirements of beam and spectral widths and power output when using compact semiconductor optical sources. In addition, the presentation will discuss the essential characteristics of the modes in multi-layer media, in particular the very large propagation constants that would enable the realisation of sub-wavelength probing and photonic circuit elements, but the associated large attenuations are detrimental. Thus the important issue of introducing an optical gain medium as a means of significantly reducing, if not overcoming, the modal loss is investigated quantitatively using the T-L method of analysis.

6370-45, Session 10

Functional 1D nanostructures as photoconductor, molecular sensor, and wavelength-selective nanoswitch

L. Chen, National Taiwan Univ. (Taiwan); K. Chen, Academia Sinica (Taiwan)

High performance functional devices often require integrations of multi-component nanomaterials. Three examples will be illustrated here: (1) metal-semiconductor-metal (MSM) device based on GaN nanowires (NWs) array as a super-photoconductor, (2) Ag nanoparticles (NPs) self-assembled on the Si nanotips array as molecular sensors [1], and (3) Au NPs encapsulated inside silica NWs as a wavelength-selective nanoswitch [2]. For the first case, an on-chip approach that involves lithographic patterning of GaN wafer and direct growth of GaN NWs array to fabricate MSM device will be illustrated. Photoconductivity studies on these arrayed GaN NWs reveal ultra-high responsivity and gain, typically several orders of magnitude higher than those reported for their thin film counterparts. For the latter two cases, nanoscale engineering and strategies for either dispersing noble-metal NPs on the nanotips (NTs) array or encapsulating them inside dielectric NWs, in a self-assembly manner, to enhance the functionality of the composite nanosystems will be presented. For the NPs on NTs, we start with fabricating well-aligned Si NTs array, again, in an on-chip manner by a single-step electron cyclotron resonance plasma process. The Si NTs were then dispersed (via simple sputtering technique) with Ag NPs, which showed excellent surface enhancement in Raman scattering (SERS). Up to 8 orders enhancement has been achieved, suggesting the potential of using SERS for molecular sensing. Finally, a novel micro-reactor approach has been developed to fabricate Au NPs chain encapsulated by dielectric NWs, also named as nanopeapods for brevity. These nanopeapods exhibit pronounced surface plasmon resonance absorption. More remarkably, a two-terminal device based on an ensemble of Au-silica nanopeapods shows a strong wavelength-dependent and reversible photoresponse under light illumination, while no photoresponse is observed for the plain silica nanowires. This result manifests the potential of using Au nanopeapodded silica nanowires as wavelength-controlled nanoswitches and sensors.

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6370-46, Session 10

Image-based nanocrystallography: fringe fingerprinting in two and three dimensions and methodology to derive the morphology of nanocrystals

P. Moeck, B. Seipel, Portland State Univ.; P. B. Fraundorf, Univ. of Missouri/St. Louis

The crystallographic phase and morphology of many materials changes with the crystal size in the ten nanometer range. New needs in determining the crystallography (i.e. structure and morphology) of ensembles of nanocrystals, therefore, arise. An overview of recent developments (P. Fraundorf et al., J. Appl. Phys. 98 (2005) 114308-1, P. Moeck et al., Nonlinear Analysis 63 (2005) e1323) in the field of image-based nanocrystallography is given.

Since information on spatial frequencies is combined with inter-planar angles, a fringe fingerprint plot is more characteristic of a nano-crystallographic phase that its powder diffraction pattern. Concepts from classical crystallometry (P. Terpstra and L.W. Codd, Crystallometry, Academic Press, New York, 1961) can be applied to image-based nanocrystallography in three dimensions when a double-tilt rotation specimen goniometer is employed. The extra degree of freedom to tilt ensembles of nanocrystals, which such a goniometer provides, allows for the alignment of the effective tilt axis of any tilt protocol parallel to the eucentric axis. The alignment could be done in small angular increments so that a novel type of discrete atomic resolution electron tomography for an ensemble of crystalline nanoparticles could be performed. While these methods are practicable with the current generations of (non-aberration corrected) transmission electron microscopes (TEMs) and two-axis specimen goniometers, they will become much more viable in aberration-corrected TEMs.

6370-63, Session 10

Heterogeneous integration of semiconducting and carbide nanowires

L. Tsakalakos, GE Global Research

Inorganic nanowires have the potential to enable many novel electronic & sensing device applications due to: (1) their one-dimensional shape makes them particularly amenable to electronic device configurations; (2) there is a wealth of composition space available for nanowires giving the materials/device designer the ability to add multiple functions in a confined space. We have been developing several nanowire-based technologies in recent years and have been studying their fundamental properties. One aspect of our work is related to the direct synthesis of novel transition metal carbide nanowire materials on Si substrates, new methods of synthesizing SiC nanowires, as well as novel device structures carbide materials enable. Another aspect of our work to be discussed is the study of semiconducting nanowires. We have demonstrated optoelectronic properties of single homogeneously doped Si nanowires and Si nanowire p-n junction diodes. Efforts towards manufacturable horizontal and vertical integration of nanowire arrays on rigid and flexible substrates will also be covered.

6370-49, Poster Session

A study on very thin sheet microformability by using laser ultrafast microforming

H. Tao, JiangSu Univ. (China)

Laser forming as a forming technique has gained in significance in manufacturing over the past years. The applications of laser forming such as sintering, forming, cutting, welding, powder coating and hardening with laser beam are used widely in many industrial fields.On the other hand, Micromachines or Micro Electro Mechanical System (MEMS) are becoming increasingly important and their fabrications will be a key technology.

In the present paper, a novel technique about laser ultra-fast microforming is presented for the first time that shock stress of single laser loading is used to deform the very thin sheet.

The purpose of this paper is to establish a microforming process system by laser forming for micro devices.

We investigate the deformation behavior of the single crystal metal (Al, Cu) and metallic glass under high strain rate condition.At micro length scale, the amorphous material exhibits superior plastic deformability. The sheet thickness of single crystal metal and metallic glass is from 1μm to 10μm. We design and fabricate micro dies on a silicon chip by plasma etching to evaluate the transferability of a die shape to the material.Using a neodymium-glass laser with pulse energy 300~800mJ and pulse width 7ns ,an experimental study on laser microforming of very thin sheet is carried out . The effects of laser parameters, material mechanical properties and confining boundary, etc. on microforming process are analyzed.Finally, the possibility of laser ultra-fast microforming as a fabrication method for MEMS is discussed, and some key problems for industrial applications are pointed out

6370-50, Poster Session

Using scanning near-field optical microscope couple with femtosecond laser to lithograph

F. Yan, JiangSu Univ. (China)

Diffraction limit is one of the main bottlenecks in further development of the photolithography . But now the widely using the scanning near-field optical microscope (NSOM) can make us overcome the diffraction limit. Because femtosecond laser can minimize the heat- and shock-affected zone and have the higher peak power intensity, we developed a novel method which combined the NSOM and femtosecond laser to directly write patter on the photoresist .

In this study we use the frequency-doubled Ti:sapphire femosecond laser with wavelength of 400nm , pulse duration of 30 fs , pulse-repetition rate of 82 MHZ. Because the ultrafast pulses through NSOM fibers can cause self phase modulation and stimulated Raman scattering, we decide to use photonic crystal fibre to transmit and couple the femosecond laser into the NSOM (Aurora-3,Veeco) . The NSOM tip which is mounted on the Pre-Mounted Tuning Fork(Veeco,1641)is also made of photonic crystal fibre . The tip has an aperture of about 50nm at the end . The photoresist thin flim used in this study is SU-8. It is sensitive to light radiation from 350 nm to 400 nm . The film coated on high reflectivity substrate because the high reflectivity can reduce the exposure time .At the end of the study we got a 40nm wide line on the photoresist thin flim .

6370-51, Poster Session

Demonstration of integrated optical functions by multiscale composite microstructures

X. Deng, NanoOpto Corp.

We experimentally investigate viable manufacture methods for optical function integration through microstructures of composite materials (MCMs). Following up with our previous design works (Optics Lett.,31, 344, 2006; Proc. SPIE, Vol. 6003, 2005), microstructures spanning about 50nm to a few micrometers on large area (e.g., 100-mm diameter wafers) are used to demonstrate transmission only polarizers (TOPOL) and pure dielectrics diffractive optics. The proposed structures can be further integrated.

6370-52, Poster Session

Determination of residual deformation of polymeric nanostructures using microscopic Moiré interferometry

X. Zheng, Y. Zhao, X. Zhang, Boston Univ.

The residual deformation is a common problem in replica molding of thermal curable polymeric nanostructures. The deformation is mainly due to crosslinking at an elevated temperature. The stamp removal also contributes to the problem. Therefore, there is a need to quantitatively determine the change of critical dimensions between the stamp and the replicated polymeric structures. In this paper, we utilized microscopic moiré interferometry to determine nanometer-scale residual deformation of a replica molded PDMS substrate. The

periodical polymer nanostructures were fabricated by using combination of e-beam lithography, reactive ion etching, and replica molding. The moiré pattern was generated by interference between the periodical nanostructures and the visual gratings generated by two coherent beams. The moiré fringes were observed by an optical microscope with a long-working distance and recorded by a CCD video camera placed at the image plane. The strain vector map was derived by comparison of the moiré patterns derived from the stamp and the replicated polymer structures. The thermal strain with a uniform profile and the removal-related strain with a non-uniform profile were successfully separated. With a nanoscale resolution, this work may contribute to the improvement of replica molded polymer structures in nanofabrication technologies.

6370-53, Poster Session

Gallium nitride nanowires: polar surface controlled growth, ohmic contact patterning by focused ion beam induced direct Pt deposition and disorder effects, variable range hopping, and resonant electromechanical properties

C. Nam, D. Tham, P. Jaroenapibal, J. Kim, D. E. Luzzi, Univ. of Pennsylvania; S. Evoy, Univ. of Alberta (Canada); J. E. Fischer, Univ. of Pennsylvania

Gallium nitride (GaN) nanostructure grown by thermal reaction of gallium oxide and ammonia exhibits a variety of morphologies, from nanowires (NW) to polyhedral crystals, at different ammonia flow rates. The interplay between Ga/N ratio in the feed and different characteristic lengths of polar surfaces in morphologies explain these variation [C.Y. Nam, D. Tham and J.E. Fischer, Applied Physics Letters 85, 5676 (2004)].

Low resistance Pt ohmic contacts are patterned on 40–70 nm diameter n-type GaN NWs by Ga+ focused ion beam (FIB) induced direct Pt deposition [C.Y. Nam, J.Y. Kim, J.E. Fischer, Applied Physics Letters 86, 193112 (2005)]. Linear I-V behavior is unexpected since Pt usually forms Schottky barriers on n-GaN. I-V-T characteristics of the FIB direct-write Pt contacts evolve from low-resistance ohmic to rectifying with increasing diameter. Strongly nonmetallic T-dependence is found for all diameters. The contact conduction in the small diameter is understood by two-dimensional variable range hopping with a small characteristic energy, the disorder being associated with Ga+ ion beam induced sputtering and amorphization in the GaN under the Pt. For large diameters, back-to-back Schottky barriers explain the nonlinear I-V at all T. These are corroborated by cross-sectional transmission electron microscopy (TEM) [C.Y. Nam, D. Tham, J.E. Fischer, Nano Letters 5, 2029 (2005), D. Tham, C.Y. Nam, J.E. Fischer, Advanced Materials 18, 290 (2006)].

Young¡¯s modulus E and quality factor Q of GaN NW were measured using in-situ TEM electromechanical resonance analysis. For large diameters E ~300 GPa, close to predicted bulk value, smaller for small diameters. Q ~2800 for diameter d = 84 nm, greater than is obtained from micromachined Si resonators with comparable surface-to-volume ratio, implying significant advantages of GaN NW resonators for nanoelectromechanical system (NEMS) applications [*C.Y. Nam, *P. Jaroenapibal, D. Tham, D.E. Luzzi, S. Evoy, J.E. Fischer, Nano Letters 6, 153 (2006), *; equal contribution].

6370-55, Poster Session

The Wigner function in signal processing of nanostructures

M. Palmoor, D. George, T. Materdey, Univ. of Massachusetts

To measure nanocurrents non-destructively sensors will need to come within 100nm of the currents and signal processing will need to deal with SNR of 0.2 or less. We show how frequency information in signals with SNR=0.2 can be recovered using the Wigner function. Results from a study of the SNR required for simulating the recovery of nanocurrents from their magnetic fields will be presented.

6370-57, Poster Session

A silicon-based biosensor using subwavelength structures for sensitive molecular detection

G. J. Sonek, Merrimack College

Periodic media, in the form of optical gratings [1] and subwavelength structures (SWS) [2,3], have previously been employed as biosensors that use guided-mode evanescent fields and surface-normal resonant modes, respectively, to detect molecules and biomolecular interactions on their surfaces. Porous silicon microcavities [4] have also been shown to be highly effective biosensors, based on having high-Q cavities and porous regions that provide large surface areas to facilitate molecular binding. These structures share many elements in common with photonic crystal nanostructures, which can provide another means for the sensitive detection of molecular interactions and surface-deposited nanoparticles. They not only contain large porous regions that can be infiltrated, but also provide unprecedented modal and spectral sensitivity, especially when patterned into optical waveguides and nanocavity structures [5]. Deposition on the SWS surface, or infiltration of the nanopores that comprise the SWS or photonic crystal lattice, produces either a spectral shift in transmission or reflection (bandgap tuning), a change in optical transmission at a specific probe wavelength, or both. In an SWS device, this detection can be accomplished using out-of-plane light propagation [6] in a mode akin to that of grating and surface-normal microcavity devices. This paper reports on our work in the design and development of a silicon-based biosensor using SWS structures for use in molecular detection and biochemical assays. A two-dimensional periodic nanostructure array having a period of 600 nm and air pores of 300 nm has been modeled and fabricated. Results indicate that such a structure affords a platform and sensitivity suitable for molecular and nanoparticle detection.

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6370-58, Poster Session

Spectral selectivity of photonic crystal infrared photodetctors

L. Chen, W. Zhou, The Univ. of Texas at Arlington; G. J. Brown, Air Force Research Lab.

Infrared (IR) photodetectors with wide spectral coverage and controllable spectral resolution are highly desirable for absorption spectroscopy gas sensing and hyper-spectral imaging applications. Significant progresses have been made in quantum well and quantum dot based IR photodetectors (QWIPs, QDIPs). The incorporation of photonic crystals (PCs) can lead to engineered spectral resolution with multi-spectral coverage in IR photodetectors. Simultaneous enhancement and suppression of absorption at different spectral locations is feasible via lithographically controlled photonic bandgap (PBG) and defect mode cavity.

Theoretical investigation has been carried out on the spectrally selective absorption properties in one- and two-dimensional (1D, 2D) PC structures with and without defect. The work is based on transfer-matrix method (TMM) and three-dimensional (3D) finite-difference time-

domain (FDTD) technique. For defect-free 1D PC structures, enhanced absorption was observed at either lower or higher frequency bandedges, depending on the relative refractive index of absorptive layers. Wavelength selectivity as high as 40 was observed. For 2D symmetric air hole triangular lattice PC structures, enhanced absorption at defect level was obtained, with the enhancement factor largely dependent upon the spectral overlap between the absorption material and the defect mode cavity. Complete absorption suppression within photonic bandgap region was observed in defect-free cavities, and in single defect cavities when the absorption spectral band has no overlap with the photonic bandgap. Work is ongoing to understand the trade-offs between the spectral resolution and absorption enhancement; the relative spectral width, and the coupling strength of absorption medium with PC cavities.

The work is supported by AFOSR and AFRL under SPRING program.

6370-59, Poster Session

Template-synthesized multifunctional nanotubes for biomedical applications

S. B. Lee, S. J. Son, B. He, X. Bai, Univ. of Maryland/College Park

Although most of current research has focused on spherical nanoparticles because they are easier to make, it requires much effort to fit the complicated biomedical problems with spherical nanoparticles for controlling particle sizes, surface functionalization, and their environmental compatibility due to the structural limitation of spherical particles when multifunctionality is especially required on their surfaces. Template-synthesized tubular structure of nanoparticle has become highly attractive for the multifunctional nanoparticles due to their structural attributes, such as the distinctive inner and outer surfaces, over conventional spherical nanoparticles. Inner voids can be used for capturing, concentrating, and releasing species ranging in size from large proteins to small molecules because tube dimensions can be easily controlled by the template synthesis. Distinctive outer surfaces can be differentially functionalized with environment-friendly and/or probe molecules to a specific target. These differentially functionalized, or multifunctionalized nanotubes have shown enormous potential in biomedical application including therapeutic tools, drug delivery, bioseparations, and biocatalysis, and provided a model system to study wetting and diffusion problems in nanoscale containers. In this presentation, the synthesis and characterization of magnetic nanotubes are described. Proof-of-concept experiments were demonstrated for magnetic-field-assisted targeted biointeractions and controlling drug uptake/release of the nanotubes. The magnetic nanotube was also used very effectively for extraction and separation of trace amount of extremely hydrophobic toxic chemicals from aqueous solution using a magnetic field. In addition, we exploited shape-coded silica nanotubes (SNTs) which can be used for biosensing as a new dispersible nanoarray system using sol-gel template synthesis with alumina template prepared from multi-step anodization process. The shape-coded SNTs can be identified by their different shapes using conventional optical microscope, completely suspended and stable in solution. For the proof-of-concept experiments with these shape-coded SNTs, a sandwich immunoassay was performed.

6370-61, Poster Session

Nanostructure based sensors for environmental monitoring and control

B. Das, Univ. of Nevada/Las Vegas

We are currently developing a compact low mass/power trace gas contaminant detection system that will be a valuable tool for environmental detection and control. The system, where a specific contaminant is identified from its optical signature, consists of a light emitter and a light detector with the air sample passing in between. Contaminants are identified from the specific wavelengths of light absorbed, and the pattern and magnitude of the spectra at a number of wavelengths are used to identify and quantify the presence of the different contaminants. The system is somewhat similar to the 'electronic nose', however, provides more sensitivity and specificity due to the optical detection technique used. The highlight of the system is the optical detection unit, which is implemented using semiconductor nanostructures since they can detect light selectively in narrow spectral bands with very high sensitivity and efficiency. Such narrow band detectors are not possible using bulk semiconductors due to their broad absorption spectra. In addition, by varying the size of the nanostructures, the band gap can be tuned to absorb a particular photon energy range, thus providing the specificity and contiguity needed for multiple contaminant detection. The semiconductor nanostructures are embedded in a layer of alumina and are contacted by two electrodes; the signal between the two contacts provides the magnitude of the absorption spectra at a specific wavelength. A particular advantage of the above system is that since the detectors are implemented on silicon substrates, it provides the potential for monolithic integration with silicon electronics.

6370-62, Poster Session

Nanostructured multispectral sensors

B. Das, Univ. of Nevada/Las Vegas

Multispectral sensors with narrow spectral sensitivities in the UV-Visible-Infrared ranges are of strong interest for space based reconnaissance and many civilian applications.. Multispectral sensors require spectral sensitivities ranging from blue to long-wave length infrared with the ability to correct for atmospheric effects. For such systems, it is necessary to have sensors with very narrow and contiguous spectral bands. Since the currently available sensors are sensitive to wide band of wavelengths, spectral sensitivity is typically achieved through the use of optical filters or a combination of a holographic grating and a large array of sensors. This significantly increases system complexity, cost and weight. We are currently developing a nanostructure based multispectral sensor that are expected to provide significant advantages including improved detector signal-to-noise ratio, potential for room temperature operation, elimination of the need for external gratings or angular incidence, significantly reduced dark current, and potential integration with silicon electronics. The compact multi-spectral sensors are being implemented using semiconductor quantum wires and quantum dots since they can detect light selectively in narrow spectral bands with very high sensitivity and efficiency. In addition, by varying the size of the quantum wire or quantum dot, the band gap can be tuned to absorb a particular photon energy range, thus providing the specificity and contiguity needed for multi-spectral detection. The semiconductor quantum wires and quantum dots are being implemented using a nonlithographic template based fabrication technique developed at UNLV. The foundation of the fabrication technique is an image reversal process that creates oxide nanopillars that are then used as masks to create the quantum wires and quantum dots.

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Part of Proceedings of SPIE Vol. 6371 Photonic Sensing Technologies

6371-01, Session 1

Tunable fiber Bragg grating ring lasers using macro fiber composite actuators for real-time health monitoring of aerospace vehicles

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Tunable fiber lasers are very promising because of their mode-hop free tunability, their narrow linewidth, and their ability to be rapidly tuned. A small, lightweight, rapidly tunable fiber laser is ideal for a grating measurement technique that is based on the principle of optical frequency domain reflectometry (OFDR) and enables the interrogation of hundreds of low reflectivity Bragg gratings. One drawback of these measurement systems is the 1 - 3 Hz measurement speed, which is limited by commercially available tunable lasers. The development of high-speed tunable Erbium-doped fiber lasers can alleviate this drawback. Fiber Bragg grating (FBG) lasers can be tuned simply by applying a strain to the grating using a mechanical compressor, a piezoelectric actuator, a thin resistive coating, or an acoustooptic superlattice modulator. The research reported herein includes the fabrication of a tunable fiber Bragg grating ring laser. A Macro-Fiber Composite (MFC) actuator invented at NASA Langley Research Center (LaRC) was selected to tune the laser. MFC actuators use a piezoelectric sheet cut into uniaxially aligned rectangular piezo-fibers surrounded by a polymer matrix and incorporate interdigitated electrodes to deliver electric fields along the length of the piezo-fibers. This configuration enables MFC actuators to produce displacements larger than the original uncut piezoelectric sheet. The wavelength tuning of the FBG ring laser resulting from stretching the FBG using MFC actuators is presented. The results from different ring configurations, Erbium-doped fiber concentrations and lengths, and pump powers are discussed.

6371-02, Session 1

Damage detection in bridges through fiber optic structural health monitoring

J. D. Doornink, B. M. Phares, T. J. Wipf, D. L. Wood, Iowa State Univ.

Advanced structural health monitoring (SHM) has become an important emerging field in which non-intrusive damage detection techniques are integrated into a structure to continuously monitor the entire bridge or individual components. While SHM is a very broad field that encompasses numerous monitoring technologies for a wide variety of structures, one contributing factor to the development of the entire field of SHM is recent and continual advancement in sensing technologies. As these technologies evolve, however, it is imperative that they be tested, scrutinized, and verified before they are implemented into SHM systems.

A unique fiber optic SHM system for fracture-critical steel bridges has been developed at the Iowa State University Bridge Engineering Center and has been installed on one of Iowa's fracture-critical bridges. This system utilizes 40 surface-mountable fiber bragg grating (FBG) strain sensors to monitor the structural performance of the bridge and to detect sudden or gradual damage in the primary structural members. Prior to system deployment, laboratory testing was conducted to investigate the influence of different adhesives and fiber reinforced polymer (FRP) packaging sizes on fiber optic sensor (FOS) performance. After installation of the system, field testing was performed to verify the performance of the installed FOS and SHM system.

In addition to laboratory and field testing on FOS adhesives and packaging, this project also showcases advanced methods of managing and reliably analyzing large, continuous data files. The paper will present an overview of the SHM system components, results of the laboratory and field testing of the FOS, and samples of the reduced and analyzed data.

6371-03, Session 1

Optimization of Brillouin optical correlation domain analysis based on intensity modulation to enlarge the measurable strain limit

K. Song, Z. He, K. Hotate, The Univ. of Tokyo (Japan)

A correlation-based Brillouin distributed sensor, called Brillouin optical correlation domain analysis (BOCDA), can provide unique advantages of high spatial resolution (~ 1 cm) and high speed (~ 57 Hz) measurements with the random accessibility of measuring position. The signal from the BOCDA system is the sum of all the local Brillouin gain spectra (BGS) along the fiber due to the CW interaction between the pump and the probe waves. While the local BGS at the sensing position is sharp and Lorentzian-shaped, those at all the other positions are spread out and accumulated to compose a background noise as the substructure of the signal. This noise tends to stack higher with longer measurement range, which restricts the maximum measurable strain and the measurement range of the BOCDA system by leading to the failure of sensing over certain limit.

In this paper, we newly introduce an intensity modulation to the BOCDA system to control and suppress the substructure appearing as the background noise of the measurement. We analyze the effects of several kinds of modulation waveforms using simulation, and propose an optimal one based on the result. The optimum configuration is experimentally demonstrated, where the increase of the measurable strain limit is clearly observed as a result of proper suppression of the background noise. The improvement of the SNR is measured to be more than 40%. The effect of the enhancement is confirmed by the successful distributed measurement of a short and heavily-strained section that is not detectable in former BOCDA configuration.

6371-04, Session 1

Analysis on the influence of intrinsic thermal stress on Brillouin gain spectra in optical fibers

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Optical fiber's Brillouin gain spectrum (BGS), including Brillouin frequency shift, Brillouin gain coefficient and gain linewidth, is determined by the optical and longitudinal acoustic modes originally decided by the waveguide characteristics of the fiber. The linear dependence of Brillouin frequency shift on environmental disturbance, such as temperature and strain, has been investigated as a distributed fiber-optic sensing technique for monitoring the condition of structures and materials.

In this work, we investigated the influence of the intrinsic thermal stress in optical fibers on their Brillouin gain spectra. By applying our newly-proposed two-dimensional finite element modal analysis to a single-mode optical fiber (SMF) and a PANDA polarization-maintaining fiber (PMF), we evaluated both the optical and the acoustic effective velocities and the corresponding field displacements and obtained the BGS of the fibers. Experimentally, we measured the BGS of the fibers and observed that there are considerable differences between their profiles of BGS. The measured results of BGS are in good agreement with the calculated ones.

We found that the acoustic modes in PMF are strongly influenced by the two-dimensional intrinsic thermal stress. The velocities of the acoustic modes in PMF are so close that its profile of BGS is a singular-peak although it has 4 components in total as like in the case of SMF. Furthermore, we learned that the intrinsic thermal stress in PMF leads to decrease the effective refractive index which results in a decrease of Brillouin frequency shift. However, the intrinsic thermal stress induces an increase of the effective acoustic velocity resulting in a net increase of Brillouin frequency shift, which is shown by both our calculated and measured results. The physical reason is that the dependence extent of acoustic velocity on thermal stress is about 4 times larger than that of refractive index on thermal stress. This property is very useful for designing an optical fiber either for the purpose of fiber-optic sensing or for suppression of Brillouin scattering in fiber communication.

6371-05, Session 1

Novel Brillouin fiber sensing system using extremely narrow linewidth fiber lasers

S. Jiang, NP Photonics, Inc.

A novel Brillouin fiber sensing technique that uses an actively stabilized single-frequency Brillouin fiber laser as a local oscillator has been demonstrated, which offers highly stable long-distance distributed fiber sensing for both temperature and strain.

6371-06, Session 2

Real-time control of micro-reactors by Raman spectroscopy

C. S. Shende, P. Maksymiuk, F. E. Inscore, S. R. Farquharson, Real-Time Analyzers, Inc.

For more than half a century, the chemical manufacturing industry has produced commodity chemicals by scaling-up 1-liter laboratory syntheses to million-gallon per year productions. In the past few years a new approach to chemical manufacturing is emerging, numbering-up. This new approach is based on two resent developments, parallel synthesis employed in combinatorial chemistry, and small-scale reactors that utilize the high surface to volume ratio at the nano- and micro-scales to improve chemical reactivity and selectivity. Many researches have shown that micro-reactors offer a number of advantages over traditional large scale reactors, principally increased control of reaction pathways and hence product choice and yield. This is particularly true in the Pharmaceutical Industry where only small scale synthesis is required until clinical trials are complete, at which time full scale production needs to be accomplished in the shortest possible period. One of the most often used reaction steps during the synthesis of pharmaceuticals is protecting carboxylic acid groups by esterification. We have been developing Raman spectroscopy as a novel analytical tool to monitor and control chemistry in such small-scale reactors. Here we will present Raman spectra of the esterification of benzoic acid performed in a 5-mL continuous loop reactor.

6371-07, Session 2

Temperature-insensitive open top ridge waveguide refractometer by using core and cladding Bragg resonances

X. Dai, S. J. Mihailov, R. B. Walker, C. L. Callender, C. Blanchetiere, Communications Research Ctr. Canada (Canada)

In this paper, a novel temperature-insensitive open top ridge waveguide refractometer is proposed that utilizes the core and cladding Bragg resonances from a single grating. To enhance the refractometer's sensitivity and improve its polarization dependent behavior, a UV-induced polarization-independent Bragg grating is inscribed into a top-clad-free ridge waveguide. The device possesses higher sensitivity, better polarization stability, and a more simple fabrication process than previously proposed waveguide sensors. To overcome the instability of the Bragg wavelength shift with temperature (~ 11pm/ °C in silica waveguides), the Bragg resonances associated with the retroreflective core mode and lossy transmitted cladding modes from the grating induced in the top-clad-free ridge waveguide are monitored simultaneously. The sensitivities to external refractive index and temperature of the core and cladding modes are measured, respectively. In the experiments, it is found that the temperature dependence of the cladding mode Bragg resonance is similar to that of the core mode Bragg resonance. However unlike similar devices in optical fiber, the Bragg resonance of the core mode is more sensitive to the refractive index change of the liquid on top of the waveguide, than the cladding mode resonances. Using the cladding mode resonance as a temperature reference, the relative shift of the core mode resonance can be used to measure the refractive index change of the liquid on the top only. The temperature cross-sensitivity of the refractive index sensor is investigated. The application of the sensor in monitoring chemical changes in solution is presented. This technology can offer some advantages such as temperature instability, compact structure, and easy fabrication. The further results will be discussed in the paper.

6371-09, Session 2

Fiber Bragg grating chemical sensor

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Fiber optic-based chemical sensors were created by coating fiber Bragg gratings (FBG) with the glassy polymer cellulose acetate (CA). CA is a polymeric matrix capable of localizing or concentrating chemical constituents within its structure. Some typical properties of CA include good rigidity (high modulus) and high transparency. With CA acting as a sensor element, immersion of the gratings in various chemical solutions causes the polymer to expand and mechanically strain the glass fiber. This elongation of the fiber sections containing the grating causes a corresponding change in the periodicity of the grating that subsequently results in a change in the Bragg-reflected wavelengths. A high-resolution tunable fiber ring laser interrogator was used to obtain room-temperature reflectance spectrograms from two fiber gratings at two different design wavelengths - 1540nm and 1550nm. The graphical representation from this device enables the display of spectral shape, and not merely shifts in FBG central wavelength, thereby allowing for more comprehensive analysis of how different physical conditions cause the reflectance profile to move and alter overall form. Shifts in the FBG central wavelength and changes in spectral shape were observed in both sensors upon immersion in a diverse selection of chemical reagents, including DI water, isopropanol, gasoline, hydrochloric acid, ammonium hydroxide, ethanol, potassium hydroxide, and dimethylformamide. Fiber Bragg gratings provide several advantages over chemical assay devices in that they are real-time, reagentless, repeatable, reusable, and multifunctional. In addition they can be used remotely at great distances, due to the low-loss fiber optic, and have other desirable characteristics, including being lightweight, small, inexpensive and immune to vibration, EMI and explosive atmospheres.

6371-10, Session 2

Chemically robust platform for optical solid state conducting polymer sensor

A. L. Holt, S. A. Carter, Univ. of California/Santa Cruz; J. P. Bearinger, Lawrence Livermore National Lab.

Conducting polymers are unique materials for use in the development of chemical and biological sensors because of their ability to function as both the sensing element and the signal transducer. Utilizing both optical and electrical signals, these materials are being explored as sensors in solution as well as in thin-film form via spin-casting, drop-casting, electrochemical polymerization and layer-by-layer deposition methods. In order to produce a more chemically robust thin film, for use as a "solid-state" optical sensor, we succeeded in grafting various poly (3-alkyl-thiophene)s to substrates such as glass, quartz, and silicon. This was accomplished by first grafting a thiophene monomer to the surface by silanization of the oxide layer with an isocyanate functionalized silane, followed by reaction with an amine functionalized thiophene monomer. The polymer films were then chemically grown via surface oxidative polymerization. XPS studies indicated that each chemical step was accurately understood. Film thicknesses range from 20 to 100 nm and depending on the substrate surface, exhibited varying degrees of surface roughness, an aspect that is important when anticipating the sensitivity of the sensor device. Reaction times and solvents were varied in order to optimize the desired film properties. The polythiophene growth, unaltered by sonication and tape peeling tests, was uniform across the substrate and could be directed by selectively silanizing the area of interest. The photoluminescence intensity of the grafted films was highly sensitive to the surrounding environment. Trace amounts of iron chloride in water was quantified using changes in the photoluminescence intensity.

6371-20, Session 2

Analysis of environmental factors affecting the performance of packaged FBG strain sensors

S. Ferguson, Micron Optics, Inc.; A. Méndez, MCH Engineering LLC; T. W. Graver, Micron Optics, Inc

Optical fiber Bragg grating sensors have seen an increased acceptance as well as a widespread use for structural sensing and monitoring in

civil engineering, aerospace, marine, oil & gas, composites and smart structure applications. However, one of the areas in need of further development and commercial maturity is that of sensor packaging and installation technique.

In this paper, we report the findings of an environmental and mechanical testing program conducted on a pool of diverse—commercially available—packaged FBG strain, temperature and elongation sensors. The results indicate a broad variability of the devices' reliability, long-term durability and accuracy. The most detrimental environmental factor identified was moisture.Recommendations for sensor packaging improvements are also provided.

6371-11, Session 3

Advanced optoelectronic devices for optical fuzing technology

J. J. Liu, Army Research Lab.; C. M. von der Lippe, U.S. Army Research, Development and Engineering Command

Technological advancements in optoelectronic and photonics devices and systems in recent years have provided impetus to advance the Army's new applications in precision weapon systems such as the Optical Fuzing (OF) technology. OF is a promising alternative approach to standoff fuzing traditionally using radio-frequency (RF) or RADAR sensing techniques especially in situations where a highly directional sensor is required. The compactness and directness of micro-semiconductor laser offers a distinctive advantage for actively sensing targets in cluttered environments. The ability to focus on narrow targets allows OF to be used in direct fire munitions. This technology can provide precision fuzing for both short and long standoff engagements with extremely accurate resolution.

We developed an OF system based on high-power high-frequency vertical-cavity surface-emitting laser (VCSEL) transmitters and high-performance metal-semiconductor-metal (MSM) photodetectors. Mounted on the tip of a projectile, the laser transmits a highly collimated beam with the frequency modulated at fRF. Photoreceivers composed of MSM photodetectors with transimpedance amplifiers are installed on the sides of the projectile and bias-modulated at the same operation frequency as the laser transmitter. As the photoreceivers pick up the reflected signal from the target, the on-board signal processor generates a target distance related signal with a distinguished frequency fIF. This frequency-modulated continuous-wave (FM-CW) operation provides good resolution in both range and frequency over the waveform domain. Such a system forms a robust and compact optoelectronic proximity sensor which is currently being demonstrated for OF in munitions applications. Many civilian applications can also be realized in automotive, robotics, and aerospace industries.

6371-12, Session 3

Digital balanced detection for fast optical computerized tomography

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Analogue Balanced Photo-detection has found extensive usage in high-sensitivity small signal applications e.g. coherent heterodyne detection. It is particularly effective for laser intensity noise removal. Nevertheless, the high cost of the commercially available analogue systems makes them unsuitable for multi-channel applications, such as fast tomography. In this paper a flexible, scalable, inexpensive and compact solution for multi channel digital balanced detection is presented.

The proposed system has two components: an electronic front-end, comprising a Differential Photodiode Amplifier for minimizing the external interference noise, and a Digital Balanced Noise remover. The latter component initially calculates a balancing factor (BF) from the average power ratio of the signal and reference photocurrents, measured with the object removed from the signal path. Three digital balancing algorithms (BDAx) are considered for subsequent processing. In BDA1, BF is directly used in real-time ratiometric calculations. In BDA2, the BF is adjusted in real time by monitoring the window-averaged power of the reference photocurrent. It is then used to balance the two photocurrents and calculate their difference. In BDA3, BF is continuously calculated in real-time from the window-averaged signal and reference power ratio. This BF is used for calculating their differences. The data from multiple channels are processed in parallel by pipelined hardware, configured as a state machine. Thus, in single-source, multi-channel detection systems only one measurement of the reference beam is necessary.

Test results on the system implemented on low-cost FPGAs are also presented.

6371-13, Session 3

Analysis of fiber-based coherent detection employing optical preamplifier and time-domain filter

Y. Chen, Fibertek, Inc.; W. E. Torruellas, Fibertek, Inc; R. L. Burnham, H. R. Verdun, Fibertek, Inc.; B. Mark, George Mason Univ.

Sensitivity improvement employing a fiber preamplifier has been successfully demonstrated in direct detection but not in coherent detection systems. In coherent systems, the amplified spontaneous emission (ASE) of an amplifier causes the severe sensitivity degradation. We present a new architecture for a coherent detection system employing an optical preamplifier and a time-domain filter (TDF) to overcome the ASE impairments.

The architecture employs a TDF to eliminate the in-band ASE components between pulses and a spectrum filter to cut off the out-band ASE. By suppressing the ASE in both the time and frequency domains detection sensitivity can be significantly improved. We describe a theoretical model for the coherent detection systems and use the model to explain how the detection architecture can effectively suppress the ASE related noises.

We present experimental results to validate the proposed coherent detection architecture. An InGaAs optical detector with 10GHz bandwidth, 10nA dark current, and 0.83 responsivity is used in the experiment. A 20mW PM DFB laser diode is externally modulated by two MZM modulators. The spectrum filter is made of a circulator and a 50GHz PM FBG filter. The third MZM is synchronized with the pulse generator to work as the TDF. Compared with direct detection, coherent detection shows a 20dB sensitivity improvement in the experiment. For a fiber preamplified coherent detection system, the detection performance is improved further by introducing a TBF. The detection sensitivity is determined by several parameters, including modulation rate, gate width of TDF, gain, and population inversion factor of the preamplifier.

6371-14, Session 3

Photonic sensor opportunities for distributed and wireless systems in security applications

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Photonic sensors have a broad range of opportunities for security applications that includes perimeter security, cargo container security, power lines, pipelines and smart structures such as bridges and tunnels. Typically, fiber optic sensors are excellent for monitoring strain, temperature, pressure and seismic activity. However, expanding fiber optic concepts to include free-space photonic sensors and biophotonic sensors has created the ability to detect toxic gases and bio-toxins. The integration of various photonic sensing concepts can achieve the multi-functional sensing requirements of evolving security needs. The presentation will focus on the technology, opportunities and barriers for wide spread use.

6371-15, Session 3

Compact high-resolution wavelength detectors for read-out of optical sensors

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An extremely compact wavelength detector is presented which is capable of resolving wavelength changes down to about 1 pm. A photosensor array or position detector element is coated with a linear variable bandpass filter. The filter converts the wavelength information of the incident light into a spatial intensity distribution. The centroid of the spatial distribution is determined by a differential read-out of two adjacent elements of the photosensor array or the position detector. The centroid of the distribution shifts as the wavelength distribution of

the incident light changes. The device can be used as the read-out for any optical sensor that produces a wavelength shift in response to a stimulus. In particular, changes in the reflection properties of one and two-dimensional photonic crystals can been detected.

The strength of this interrogation method will be demonstrated for the case of Fiber Bragg grating (FBG) sensors, which are frequently used in a wide range of applications. An FBG is formed by a periodic modulation of the refractive index along a finite length of the core of the fiber. This pattern reflects a certain narrow wavelength spectrum determined by the period of refractive index profile. An external stimulus (e.g., temperature or strain) changes the periodicity of the grating and, therefore, alters the reflected wavelength spectrum. The resulting wavelength shift is a direct measure of the stimulus.

The two- and three-dimensional analogs to FBG sensors are photonic crystal sensors. In these crystals a periodic modulation of the refractive index is realized in more than one direction. The crystals may be filled with or attached to a species under test. Alterations of the species can be detected by monitoring the optical reflection and transmission properties. Our interrogation unit is perfectly suited for the read out of photon crystal sensors as we have developed concepts which allows to provide simultaneously spectral and spatial resolution.

6371-08, Session 4

Luminescence spectrometer employs a nanosecond gated photomultiplier to detect emission from lanthanide chelates excited by a pulsed-UV LED

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Signal detection can present a major challenge for fluorescence based detection modalities when target is encountered together with intrinsically fluorescent (autofluorescent) components. Luminophores with long emission lifetimes (eg lanthanide chelates) afford a means to discriminate signal from short-lived autofluorescence through the use of Time-Gated Luminescence (TGL). We have recently synthesized a number of novel europium chelates and required an instrument to accurately compare luminescence lifetime, spectral output and emission intensity. The photophysical response of the chelates was captured using a lab-built time-gated luminescence spectrometer employing pulsed UV (360 nm) excitation from a high-power (~200 mW) LED. Chelate luminescence was collected and directed onto a diffraction grating, the output of which was quantified using a R2658 photomultiplier tube gated electronically into conduction shortly after the excitation pulse had ceased. The photomultiplier dynodes were configured in a novel switching arrangement using high-voltage field effect transistor (FET) devices driven by an optically isolated signal. Using this arrangement, the photomultiplier was gated off until LED excitation had fully extinguished whereon the tube was switched to full-gain within less than a microsecond. In the prototype instrument, the diffraction grating was manually adjusted to divert the strongly emitting europium line (5D0 * 7F2) to the detection electronics, however the system was controlled using an embedded microcontroller and the potential exists for automated scanning across a broad spectral range within a couple of seconds.

We intend to use the instrument to determine the quantum yields of our various novel chelates using the luminescence resonant energy transfer (LRET) technique pioneered by Xiao et al. (2001) and report the photophysics of BHHCT (Yuan et al. 1998), an intensely luminescent europium chelate.

6371-16, Session 4

Modeling and measurement of accuracy/distortion in an operationally-passive FBG demodulation technique

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A system for interrogating fiber optic Bragg grating arrays at kiloHertz sampling rates with sub-microstrain resolution was presented recently. The system makes use of a tunable fiber Fabry-Perot filter for demultiplexing and a path-imbalanced Mach-Zehnder interferometer for wavelength conversion. The operationally-passive demodulation technique for the interferometer makes use of probing the 3x3 coupler at theinterferometer output for its coupling parameters to execute the technique. In this work, we discuss the effects of how errors in determining these parameters translate into measurement error and harmonic distortion. We compare measured effects in the laboratory with predictive models to give error sensitivity metrics. We also consider two modes of sampling errors for such frequency-modulated systems and propose a generalized sampling criterion for minimizing harmonic distortion and measurement error.

6371-17, Session 4

A fiber grating based distributed light source

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Line scan cameras are used for rapidly monitoring a moving web or sheet of material. Lighting for line scan inspection must illuminate a long narrow rectangle, which is imaged onto the linear array of pixels in a line scan camera. This distributed light source should provide a uniform power density at the desired wavelengths. Tungsten halogen lamps and LED arrays can meet these objectives, but not in a highly directional beam with minimal thermal issues. We have developed a new distributed light source that is based on diffracting light from a highly blazed grating written in the core of a single mode fiber. The grating is blazed such that out-coupling is 90 degrees to the fiber axis. The fiber is bonded to a cylindrical optic that collimates the azimuthal power distribution. Connecting a single laser diode to the fiber generates 1 milliwatt per square centimeter over a 10 cm by 0.5 cm rectangular region. Longer gratings and/or multiple segments can be connected to illuminate longer regions. The distributed power density, spatial uniformity, degree of collimation, and the spectral bandwidth of these illuminated rectangles are reported. This highly directed distributed source will enhance the utility of line scan cameras in multiple applications.

6371-19, Session 4

Long-period gratings functionalized with ionic self-assembled multilayers for biosensor applications

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Long-period gratings (LPGs) in optical fibers are attractive as chemical and biological refractive index sensors and other index-modulating optical fiber devices because of their sensitivity to the ambient conditions. The existence of the LPG in the fiber causes a strong attenuation at a particular wavelength, referred to as the resonant wavelength. The sensitivity is normally attributed to the index of the bulk medium surrounding the fiber, and sub-wavelength features are not expected to modulate the resonance of LPGs. We have demonstrated dramatic resonant-wavelength-shifts in an LPG that is coated with only nm-thick films of ionic self-assembled multilayers (ISAMs). Record shifts in the resonant wavelength, of 40 nm, were observed for film thicknesses of only 25 nm. The ISAM fabrication method is a layer-by-layer (LBL) deposition technique that provides a highly controllable means to build precise, nm-thick films on the surfaces of fibers by simply immersing in aqueous solutions of oppositely-charged polyelectrolytes for two minutes. Simulations employing weakly-guiding scalar mode theory and LPG theory demonstrate that the strong coupling results from the combined effective refractive index of the high-index nanoscale film and the bulk exterior medium. We have demonstrated the effectiveness of an ISAM film on an LPG as a biosensor using the biotin-streptavidin model system.

6371-21, Poster Session

Design of temperature insensitive refractometer by waveguide and Bragg grating structure optimization

X. Dai, R. B. Walker, S. J. Mihailov, C. L. Callender, C. Blanchetiere, Communications Research Ctr. Canada (Canada)

Experimentally, it is shown that for cladding and core mode Bragg resonances of gratings inscribed in top-clad-free ridge waveguides, the sensitivities of the resonances differ for variations in the refractive index change of the surrounding medium. To increase the relative evanescent sensitivity of the core mode to the cladding mode, a

theoretical model is developed which optimizes the waveguide and Bragg grating structures. The methods to increase the evanescent sensitivity of a waveguide Bragg grating refractometer are investigated. For an open-top ridge waveguide Bragg grating refractometer, the evanescent sensitivity is enhanced by using small core size waveguides, and by making the effective index of the waveguide close to the refractive index of the analyte. It is also shown that the evanescent sensitivity is increased by inducing a tilted Bragg grating within the ridge waveguide since the efficiency of the light coupled into the core and the bottom layer by the tilted Bragg grating is varied with the change of the tilt angle of the Bragg grating. In this paper, the relationships between the waveguide core size, the thickness of the cladding, the refractive index distribution of the waveguide, the tilt angles of the Bragg grating and the relative evanescent sensitivity of the core mode to the cladding mode are established. By optimizing the geometric structure of waveguide, and giving an appropriate tilted Bragg grating, a highly sensitive and temperature independent refractometer is proposed.

6371-22, Poster Session

Planar waveguide photonic crystals for sensing applications: a general proposal

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At optical frequencies, periodic dielectric materials offer a great deal of control over the propagation of electromagnetic waves. In this work, we demonstrate the possibilities of planar waveguide photonic crystals to be used in general sensing proposes. The electromagnetic performance of photonic crystals obtained by connecting in cascade planar optical waveguides with high index contrast was analysed. In our case, the periodicity of the lattice is obtained in the substrate, instead of in the guiding region, as in conventional waveguide photonic crystals. The theoretical model involves a new generalized scattering matrix concept, together with the generalized telegraphist equations formulism and the modal matching technique.

The implementation of the pattern waveguide photonic crystals was carried out by connecting abruptly planar optical waveguides. To get the periodic lattice, we use the substrate refractive index as lattice periodic parameter, and the waveguide lengths as lattice constant. Photonic band gaps and photonic windows were obtained. In all cases the power conservation was excellent.

If a local defect is introduced in the PBG structure, an on state can be introduced in the gap. The local defect modifies the optical path, so that the PBG is broken, and the on state appears in the PBG interval. Besides, the on state wavelength can be tuned if the the optical path of the defect is modified: changing the physical length or/and the refraction index of the defect. In this way, planar waveguide photonic crystals could be used for sensing aplications when a specimen modifies refraction index lattice site.

6371-23, Poster Session

Analysis of the transient response of erbium fiber lasers and application for sensors

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Many types of optical fibre sensor are based on either sensitive measurement of optical attenuation or on spectral measurements involving absorption at specific wavelengths or a shift in wavelength as a result of the measurand. Examples include strain and temperature sensors based on fibre Bragg gratings, and chemical analysis based on spectroscopy. Sensor measurements are usually performed under steady-state or quasi-steady-state conditions. Here we investigate a technique for optical sensors based on performing measurements during the transient period of operation of fibre lasers. The principle involves the use of an intra-cavity sensor element (or intra-cavity cell) which modifies the attenuation or spectral properties of the cavity. Analysis of the cavity output during the build-up period of laser operation, ideally in both time and spectral domains, yields information on changes caused by the measurand. A detailed theoretical study of the dynamics of erbium fibre ring lasers has been carried out, with simulation of the full transient period. Time domain analysis involves measurement of parameters such as build-up time, spiking levels and characteristics of the relaxation oscillations, all of which are dependent on the cavity parameters. Spectral domain analysis involves monitoring the detailed optical spectrum during the build-up period. Due to the multiple circulations of light within the cavity during this period, monitoring the spectral evolution may provide high-sensitivity spectroscopic data on absorption lines of gases within an intra-cavity cell. A key challenge, however, is the experimental capture of mode evolution which requires high resolution spectra in the 1500-1600nm region to be collected during the build-up period.

6371-25, Poster Session

Low-cost high-sensitivity fiber optic accelerometer with wide operation range

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For low accelerations in low frequencies of vibrations sensitivity is a key point. To improve the sensitivity in the accelerometer proposed by F.R.Barbosa et al in SPIE 2005 (“A Novel Optical Accelerometer with Wide Operation Range”), we propose to introduce microlenses onto the fiber edges. We achieved prototypes that reduced drastically the need of signal amplification in the reception. These new sensor is much more sensible than its antecessor, using the same principle of operation that is based on the variation of the optical signal power coupled between single mode fibers fixed in the optical sensor head.

6371-26, Poster Session

Methane detection with 1.65-μm LED

S. Yang, D. Song, S. Li, T. Koscica, D. Y. Li, H. Cui, Stevens Institute of Technology

Because methane is an inflammable and explosive gas, it is indispensable to monitor methane. To achieve high detection sensitivity, a strong absorption line should be used. Methane has strong υ3 and υ4 vibrational bands at 3.3μm and 7.7μm respectively. However, it is difficult for diode lasers of longer wavelength to operate at room temperature. The stronger bands of methane in the region below 2μm are the υ2+2υ3 band whose center is 1,331μm and 2υ3 band whose center is located 1.665μum. Although the υ2+2υ3 band is weaker than 2υ3 band, many researcher chose the υ2+2υ3 band, because the commercially available optical source operating at room temperature has been confined to the spectrum range 1.55μm and 1.33μm which are of particular interest in optical communication. However, recently a 1.65μm LED has been developed that can be used to detect methane. In this paper, we demonstrate several methods for sensing methane by using this new 1.65μm LED, because the 1.65μm band is stronger than the 1.33μm band by several times. We compare the different methods and present the key factors to improve the detection sensitivity.

6371-27, Poster Session

Characterization of micromaterials using laser speckles

R. Kothbauer, S. J. Rupitsch, Johannes Kepler Univ. Linz (Austria); P. Zimprich, Univ. Wien (Austria); B. G. Zagar, Johannes Kepler Univ. Linz (Austria)

For an optimal design of sensors and actors in micro/nano-technology, the accurate knowledge of the mechanical and thermal properties of the used components is necessary. Thermal mismatch between used components and physical effects according to size are having big impact on the design.

Non-contact measurements using Laser Speckles Technology provides a method for obtaining mechanical and thermal properties of extreme small samples of metals, ceramics and plastics. This method provides data for FEM-Simulations which is closer to reality than material properties taken from tables gained from macro-samples, since the property transfer to micro-samples is disputed.

The construction of the method basically consists of a light source emitting a collimated monochromatic laser beam illuminating an orthogonal orientated specimen (object plane), and two line cameras (observation plane), which are arranged symmetrically to the incident laser beam.

The cameras are recording the granular laser speckles, which, accordingly processed, provide accurate information about the state of strain.

The mechanical state of the samples in the object plane is calculated using the pictures taken by the cameras, and the theoretical results of research work done by Ichirou Yamaguchi.

The presentation takes a closer look at the measuring principle and is introducing some typical applications like determining thermal parameters and the coefficient of elasticity of specific samples.

6371-28, Poster Session

A new method for demodulation of fiber Bragg grating

J. Ning, H. Cui, Y. Zhang, Stevens Institute of Technology

In this paper, a general review was given for several existing fiber Bragg grating (FBG) demodulation. Difficulties encountered using conventional demodulation techniques render FBG sensors not particularly useful for high precision, large dynamic range applications, not to mention that such sensors are usually not easy to use and have low performance/cost ratios. This paper suggests a new method based on the follow reasoning. Similar to fingerprints, the shape of the reflection spectra of FBG's may appear different even made by same phase mask. The wavelength will shift following the change of temperature or strain, but the shape of the FBG "fingerprint" will be essentially unchanged. We propose to digitally record the reflection spectrum of an FBG fingerprint before it is interrogated at the sensor. A field program gate array (FPGA) may be used for the digital signal processing required by the new demodulation method. The sensor's sampling data and each digital fingerprint of the FBG will be analyzed using the method of spectrum correlation. The correlation coefficient is used to distinguish different FBG's and their wavelength shifts. Details of the mathematical model and experiment results using the new method will be presented.

6371-29, Poster Session

Detection of seismic signal using fiber Bragg grating sensors

Y. Zhang, S. Li, R. A. Pastore, Jr., Z. Yin, H. cui, Stevens Institute of Technology

An unattended seismic sensor based on optical fiber Bragg grating (FBG) sensing technology is presented in this paper. One of the applications is its deployment in the battlefield remote monitoring system to track and geo-locate the presence of personnel, wheeled vehicles, and tracked vehicles. The customized FBG sensor prototype is demonstrated which consists of two FBG sensor/demodulation grating pair attached on a spring-mass mechanical system. The sensor performance is evaluated in laboratory and the field tests were carried out in the shooting range using the conventional military Rembass-II S/A sensor (remotely monitored battlefield sensor system IIseismic acoustic sensor) as the benchmark. Personnel and a series of vehicles were used as targets. The experimental data of the field test show that the FBG sensor averaged a 30.20 % greater detection range than the Rembass-II S/A sensor. It is hoped that the FBG sensor system will be a promising tool for real time monitoring system in the battlefield applications.

6371-30, Poster Session

Fast-tuning narrow-linewidth all polarization-maintaining fiber ring laser

Z. Meng, Y. Hu, Z. Hu, S. Xiong, C. Cao, National Univ. of Defense Technology (China)

Narrow-linewidth, linearly-polarized fibre ring lasers have attracted much research interests because of their potential applications in optical communications and optical sensors. Several methods have been investigated to suppress mode hopping and obtain stable single-frequency lasing. Previous work has demonstrated that a narrow-band reflection filter can be established in unpumped erbium-doped fibre (EDF), which acts as a saturable absorber in a ring cavity. The importance of using PM rather than SM unpumped EDF for enhancing stability has also been experimentally demonstrated. However, in practical hostile environments, the fluctuation of state-of-polarization in other SM fibres and devices in the laser cavity also induces the lasing mode hopping. This paper presents an all polarization-maintaining fibre ring laser with fast tunability, which is required to operate in some applications, such as phase generated carrier (PGC) technique.

The structure of the laser is a travelling-wave ring cavity, which includes an EDF amplifier, wavelength-division multiplexing (WDM) coupler, a circulator, a piezoelectric ring wrapped with PM fibre, a FBG, an unpumped EDF and a coupler. All of the polarization-maintaining fibre and devices can suppress the polarization instability effects on the mode hopping. With a 100mW pump power, the output power of the stable single-frequency laser is up to 5mW at 1535nm. The extinction ratio of the linearly-polarized output is 25dB, the SNR is larger than 67dB, the RIN is below -110dB/Hz and the linewidth is less than 1.0kHz. The fast tuning rates of the lasing optical frequency achieves ~50kHz with no noticeable power fluctuations, and the maximum tuning range is about 10MHz. This fibre laser has been used in an interferometric fibre sensor and the experimental results show the equivalent phase noise is approximately -100dB/Hz with 20m optical path difference between two arms.

6371-32, Poster Session

Benefits of wireless networks integrated with distributed fiber optic sensing systems

P. Lefebvre, R. Caporuscio, LxSiX Photonics Inc. (Canada)

Wireless sensor networks often referred to as Mote networks provide many distinct advantages for both military and homeland security sensing applications. Advantages include easy deployment over a large area, mesh configurations for rerouting information under fault conditions and potentially low cost. Limitations are in the sensor functionality. Mote systems use MEMS sensor technology. The system can detect intrusion and potentially seismic activity. However, the sensing needs are greatly expanding due to a multitude of potential threats such as toxic chemicals, bio-toxins and radiation. Incorporating either single point or distributed fiber optic sensing systems into a Mote architecture can expand the sensing function to include bio-chemical detection as well as providing highly accurate seismic data to generate an intrusion signature or an expanded intrusion alarm capability. Furthermore, a mote architecture coupled with a distributed fiber optic sensing can potentially extend the reach and benefits to extreme and harsh environments.

6371-33, Poster Session

High resolution underwater fiber optic threat detection system

A. Berger, S. Hermesh, E. Durets, L. U. Kempen, Intelligent Optical Systems, Inc.

Current underwater protection systems are complex expensive devices consisting of multiple electronic sensing elements. The high price of these devices makes them feasible only for localized implementations, while the protection of large stretches of coastline requires a different approach. We present a novel multi-channel sonar design that augments current active sonar transducers with a passive fiber-optic multi-channel acoustic emission sensing array, resulting in increased resolution. The system provides continuous monitoring of the reflections of acoustic wave emitted by a single projector, yielding information about the size and shape of approaching objects. A novel fiber hydrophone enclosure is utilized to dramatically enhance the sensor response to the sonar frequency, while suppressing out-of-band sound waves and noise.

The ability of a fiber hydrophone to respond to acoustic emissions is based on the well established fiber Bragg grating sensing techniques. In this approach the energy of an acoustic wave is converted into modulation of the in-fiber optical transducer's optical properties. The obtained results demonstrate significant response of the designed fiber optic hydrophone to the incident acoustic wave over the frequency domain from 1-80 kHz. Our approach allows selective tuning of the sensor to a particular acoustic frequency as well as extension of the spectral response to 300-400kHz.

Sunday-Tuesday 1-3 October 2006

Part of Proceedings of SPIE Vol. 6372 Advanced Photon Counting Techniques

6372-01, Session 1

Multidimensional time-correlated single photon counting

W. Becker, A. Bergmann, Becker & Hickl GmbH (Germany)

Time-correlated single photon counting (TCSPC) is based on the detection of single photons of a periodic light signal, measurement of the detection time of the photons, and the build-up of the photon distribution versus the time in the signal period. TCSPC achieves a near ideal counting efficiency and transit-time-spread-limited time resolution for a given detector. The drawback of traditional TCSPC is the low count rate, long acquisition time, and the fact that the technique is one-dimensional, i.e. limited to the recording of the pulse shape of light signals. We present an advanced TCSPC technique featuring multi-dimensional photon acquisition and a count rate close to the capability of currently available detectors. The technique is able to acquire photon distributions versus wavelength, spatial coordinates, and the time on the ps scale, and to record fast changes in the fluorescence lifetime and fluorescence intensity of a sample. Biomedical applications of advanced TCSPC techniques are time-domain optical tomography, recording of transient phenomena in biological systems, spectrally resolved fluorescence lifetime imaging, FRET experiments in living cells, and the investigation of dye-protein complexes by fluorescence correlation spectroscopy. We demonstrate the potential of the technique for a number of selected applications.

6372-02, Session 1

Differentiation of ocular fundus fluorophores by fluorescence lifetime imaging using multiple excitation and emission wavelengths

M. Hammer, D. Schweitzer, S. Schenke, Friedrich-Schiller-Univ. Jena (Germany); W. Becker, A. Bergmann, Becker & Hickl GmbH (Germany)

Ocular fundus autofluorescence imaging has been introduced into clinical diagnostics recently. It is in use for the observation of the age pigment lipofuscin, a precursor of age - related macular degeneration (AMD). But other fluorophores may be of interest too: The redox pair FAD - FADH2 provides information on the retinal energy metabolism, advanced glycation end products (AGE) indicate protein glycation associated with pathologic processes in diabetes as well as AMD, and alterations in the fluorescence of collagen and elastin in connective tissue give us the opportunity to observe fibrosis by fluorescence imaging. This, however, needs techniques able to differentiate particular fluorophores despite limited permissible ocular exposure as well as excitation wavelength (limited by the transmission of the human ocular lens to \>400 nm). We present an ophthalmic laser scanning system (SLO), equipped with picosecond laser diodes (FWHM 100 ps, 446 nm or 468 nm respectively) and time correlated single photon counting (TCSPC) in two emission bands (500 - 560 nm and 560 - 700 nm). The decays were fitted by a triple-exponential model. Fluorescence spectra were measured by a spectrograph attached to the SLO.

Upon excitation at 446 nm, the fluorescence of AGE, FAD, and lipofuscin were found to peak at 503 nm, 525 nm, and 600 nm respectively. Accordingly, the statistical distribution of the fluorescence decay times was found to be different by the use of different excitation wavelengths and emission bands. The use of multiple excitation and emission wavelengths in conjunction with fluorescence lifetime imaging allows us to discriminate between intrinsic fluorophores of the ocular fundus. Taken together with our knowledge on the anatomical structure of the fundus, these findings suggest an association of the short, middle and long fluorescence decay time to the retinal pigment epithelium, the retina, and connective tissue respectively. Interestingly, the shortest decay time, attributed to the RPE, was greatly increased in atrophic lesions of AMD - patients. This is in good agreement with the clinical finding of RPE defects in AMD.

6372-03, Session 1

Time-resolved photon counting allows for new temporal and spatial insights into nanoworld

A. A. Gaiduk, R. Kühnemuth, M. Antonik, Heinrich-Heine-Univ. Dusseldorf (Germany); W. Becker, Becker & Hickl GmbH (Germany); S. Felekyan, V. Kudryavtsev, Heinrich-Heine-Univ. Dusseldorf (Germany); M. Koenig, Stanford Univ.; F. Oesterhelt, Heinrich-Heine-Univ. Dusseldorf (Germany); C. Sandhagen, Opsolution Spectroscopic Systems GmbH (Germany); C. A. M. Seidel, Heinrich-Heine-Univ. Dusseldorf (Germany)

We present an advanced time-correlated single photon counting (TCSPC) technique that simultaneously provides traditional autocorrelation fluorescence correlation (FCS) or cross correlation (FCCS) and fluorescence lifetime data [1]. In combination with scanning techniques and atomic-force microscopy new powerful tools for studies in chemistry, physics and biology are designed.

:Multiparameter Fluorescence Detection (MFD) [2] is the time-resolved observation of all five intrinsic properties of a chromophore that can be probed in a fluorescence experiment, i.e. spectral properties of absorption and fluorescence, fluorescence quantum yield, fluorescence lifetime, and anisotropy. Selective analysis of molecular subensembles and even direct studies on single molecule dynamics become accessible [3].

:Newly developed electronics allow for detection and registration of single photon events over time periods of hours with picoseconds accuracy. Subsequent software-correlation yields correlation curves covering more than 12 orders of magnitude in time. At the same time, the original data, containing all information accessible by single photon counting techniques, can be analyzed conventionally according to common single molecule fluorescence techniques.

:Confocal imaging combined with present TCSPC techniques [4,5] is capable of intensity, lifetime, anisotropy, correlation times and spectral properties pictures reconstruction of biological complexes and single molecules adsorbed on a surface.

:Mechanical manipulation of molecules and simultaneous fluorescence detection with high temporal resolution [6] opens new level of chemical structure studies and dynamics investigation.

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6372-04, Session 1

Multiwavelength fluorescence lifetime imaging by TCSPC

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We present a fluorescence lifetime imaging technique with simultaneous spectral and temporal resolution. The technique is fully compatible both with confocal and multi-photon laser scanning microscopes. The data acquisition is based on a multi-dimensional time-correlated single-photon counting technique. Each photon is characterised by its coordinates in the scanning area, its wavelength, and its time in the excitation pulse period. The recording process builds up a four-dimensional photon distribution over these parameters. The method delivers picosecond time resolution, near-ideal counting efficiency, and an accuracy sufficient for resolving double-exponential decay functions. We demonstrate the performance of the technique for FRET experiments and for autofluorescence imaging of tissue.

6372-05, Session 2

In vivo diffuse optical imaging and spectroscopy based on TCSPC

H. Wabnitz, D. Grosenick, Physikalisch-Technische Bundesanstalt (Germany); M. Moeller, Physikalisch-Technische Bundesanstalt (Germany) and Hochschule für Technik und Wirtschaft des Saarlandes (Germany); A. Liebert, Physik-Tech Bundesanstalt (Poland); J. Steinbrink, Charité-Univ. Medizin Berlin (Germany); R. Macdonald, Physikalisch-Technische Bundesanstalt (Germany)

Non-invasive in vivo optical imaging and spectroscopy of large tissue volumes like breast and brain rely on diffuse propagation of near-infrared light that is dominated by strong scattering. Since only a small fraction of the photons injected into the tissue reaches the detector, highly efficient detection is required. Therefore single photon counting is the detection method of choice. Time-correlated single photon counting (TCSPC) together with picosecond pulsed laser sources enables us to determine the time of flight within the tissue of each photon detected. The resulting time-of-flight distributions can be exploited to estimate tissue optical properties such as reduced scattering and absorption coefficients. Concentrations of tissue chromophores, e.g., oxy- and deoxyhemoglobin, are obtained from measurements at various wavelengths. Moreover, recording of time-resolved diffuse reflectance makes depth localization of absorption changes possible, in particular in measurements on the human head. Likewise, fluorescence originating from fluorophores in deep tissue structures can be detected and analyzed at high temporal resolution. We will give a summary of our experimental experience with TCSPC in the fields of time-domain optical brain imaging and optical mammography and describe the corresponding instruments developed by our group. We will discuss methods to optimize the accuracy of results derived from measured time-of-flight distributions, in particular proper recording of the instrumental response function, correction for differential nonlinearity and correction for dead-time related effects. The performance of the instruments and the associated data analysis will be demonstrated by results of in vivo measurements.

6372-06, Session 2

Time-resolved fluorescence diffuse optical tomography using ultrafast time-correlated single photon counting

Y. Bérubé-Lauzière, V. Robichaud, Univ. de Sherbrooke (Canada)

Means to localize fluorescent inclusions in thick turbid media in 3D non-invasively by optical imaging techniques are currently intensely researched. This is the subject of fluorescence diffuse optical tomography (FDOT). The interest in optical methods lies in the wide variety of functionalized fluorescent dyes that have been developed for microscopic imaging of specific and medically relevant bio-molecular processes and pathologies (e.g. cancer) in thin slices of biological tissues. Exploiting these dyes for imaging through larger tissue volumes paves the way to optical molecular imaging (i.e. imaging bio-molecular processes in-vivo). This is of great interest for the medical and pharmaceutical communities, such as for breast cancer detection, small animal imaging for drug discovery, etc....We show how we achieve fluorescent emission localization in 3D via time-resolved (TR) fluorescence measurements using ultra-fast multi-channel time-correlated single photon counting (TCSPC). Our technique is based on the arrival times of the first fluorescent photons reaching detectors arranged in a multi-view ring configuration around the medium being imaged along with a precise modelling and characterization of photon travel times through our system's optics. Of importance is that we perform the measurements in a non-contact manner with the medium, thereby implementing non-contact FDOT. In contrast to other approaches exploiting TR fluorescence for FDOT, ours provides full 3D reconstruction (not limited to a plane) based on a novel ray intersection algorithm. We describe how the high temporal resolution, high SNR, and multi-channel capabilities allowed by the TCSPC electronics we use are crucial and fully exploited in our application.

6372-07, Session 2

Application of low-intensity non-scanning fluorescence lifetime imaging microscopy for monitoring excited states dynamics in individual chloroplasts and living cells of photosynthetic organisms

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Picosecond Fluorescence lifetime imaging microscopy (FLIM) provides a most valuable tool to analyze the primary processes of photosynthesis in individual cells and chloroplasts of living cells. In order to obtain correct lifetimes of the excited states the peak intensity of the exciting laser pulses as well as the average intensity has to be sufficiently low to avoid distortions of the kinetics by processes like singlet-singlet annihilation, closing of the reaction centres of Photosystem II or photoinhibition. In the present study this requirement is achieved by non-scanning wide-field FLIM based on time- and space-correlated single-photon counting using a novel microchannel plate photomultiplier with quadrant anode(QA-MCP) which allows parallel acquisition of time resolved images under minimal-invasive low-excitation conditions. The potential of the technique is demonstrated by presenting results obtained from measurements of the fluorescence dynamics in individual chloroplasts of moss leafs and living cells of the chlorophyll d containing cyanobacterium Acaryochloris marina.

6372-08, Session 2

Time-correlated single photon counting as the principle technique in a plate reader for assay development and high-throughput screening

D. U. Näther, Edinburgh Instruments Ltd. (United Kingdom)

A new and unique single modality plate reader is presented that has the principle design features of a confocal microscope and utilises the technique of Time Correlated Single Photon Counting for data acquisition.

The advantages of the Fluorescence Lifetime Measurements in the nanosecond time scale in general, and of the technique of Time Correlated Single Photon Counting in particular, will be discussed based on theoretical investigations as well as on real data.

First working assays will be presented that clearly demonstrate the distinct advantage of the new instrument for biochemical assays.

6372-09, Session 3

Monitoring mechanotransduction in cells by time-correlated single photon counting

T. Tabouillot, R. R. Gullapalli, P. J. Butler, The Pennsylvania State Univ.

Endothelial cells (ECs) are known to convert mechanical stimuli into chemical signaling pathways which regulate their functions and properties. It is hypothesized that perturbation of cellular structures and molecular-scale signaling are each accompanied by changes in molecular dynamics. Thus, we use time-correlated single photon counting (TCSPC) to determine mechanically-induced changes in the dynamics of molecules in live cells from fluorescence lifetimes and autocorrelation analysis (fluorescence correlation spectroscopy). To improve localization of mechanotransduction events, we have integrated our system into a multimodal microscope which includes total internal reflection fluorescence (TIRF), differential interference contrast (DIC), and epifluorescence combined with deconvolution. A unique aspect of our system is the ability to obtain lifetime and correlation data from a single measurement using the TCSPC method; an important feature since the local environment of a cell rapidly changes. In this paper we detail the construction of our system and how all the modules interact. We present control experiments for molecular dynamics in solution, on model membranes, and in cells. TCSPC is a useful method to obtain high temporal and spatial resolution information on localized mechanical phenomena in living endothelial cells. Such insight into mechanotransduction phenomenon may uncover the origins of mechanically-related diseases such as atherosclerosis.

6372-10, Session 3

Fluorescence lifetime microscopy with a time- and space-resolved single-photon counting detector

X. Michalet, Univ. of California/Los Angeles; O. H. W. Siegmund, J. V. Vallerga, P. N. Jelinsky, Univ. of California/Berkeley; J. E. Millaud, Lawrence Livermore National Lab.; S. Weiss, Univ. of California/Los Angeles

We have recently developed a wide-field photon-counting detector (the H33D detector) having high-temporal and high-spatial resolutions and capable of recording up to 500,000 photons per sec. Its temporal performance has been previously characterized using solutions of fluorescent materials with different lifetimes, and its spatial resolution using sub-diffraction objects (beads and quantum dots). Here we show its application to fluorescence lifetime imaging of live cells and compare its performance to a commercial confocal TCSPC solution. With the expected improvements in photocathode sensitivity and increase in detector throughput of the future H33D generation, this technology appears as a promising alternative to current lifetime imaging solutions. We also briefly describe other applications of this detector in astronomical polarimetry and lidar, to emphasize the versatility of this detector architecture.

6372-11, Session 3

Correction of dead-time related distortions for TCSPC measurements at very high count rates

H. Wabnitz, Physikalisch-Technische Bundesanstalt (Germany); M. Moeller, Physikalisch-Technische Bundesanstalt (Germany) and Hochschule für Technik und Wirtschaft des Saarlandes (Germany); R. Macdonald, Physikalisch-Technische Bundesanstalt (Germany); W. Becker, Becker & Hickl GmbH (Germany)

Today's TCSPC technology is capable of recording time-of-flight distributions of photons as well as fluorescence decays at high count rates of up to several MHz. Temporal photon distributions can thus be acquired with good signal-to-noise ratio within a few tens of milliseconds, which is particularly important when recording images or time series. However, if the count rate is on the order of the reciprocal dead time, a noticeable fraction of single photon events is lost during dead time periods. Consequences are both decreased sensitivity and distortions in the time-of-flight histograms. The latter is known as pile-up effect. In contrast to the classic pile-up effect, no remedy has been reported yet for the inter-pulse pile-up effect that occurs when the dead time ends non-randomly within one of the signal periods following the detection of a photon. We present a method to quantitatively correct measured distributions for these effects. The algorithm requires knowledge of the dead time as a function of the start-stop interval which can be obtained by appropriate calibration measurements. The correction algorithm eliminates the influence of all dead-time related distortions, i.e. counting losses, classic pile-up and inter-pulse pile-up effects. We demonstrate the effectiveness of the correction on real measurements. In addition, we describe a method to predict the distortions of a given signal based on the known dead times and the actual count rate of the measurement.

6372-12, Session 3

Photon counting by large-area detection with multianode photomultiplier tube in high-throughput multiphoton microscopy

D. Kim, P. T. C. So, Massachusetts Institute of Technology

As a photodetector, photomultipler tube (PMT) is an excellent tool in measuring the intensity of fluorescent images, although its performance is restricted by fluorophore saturation which occurs when the fluorescence intensity reaches near maximum due to population inversion of the electron state of molecules. In photon counting mode, PMT has high enough bandwidth to detect each incoming photon and provides photon discriminator with single photon counting capability. However, intensity measurement by photon counting has narrow dynamic range due to discrimination problem between simultaneously incoming photons. This is because when several photons are generated at once by multiphoton excitation, they are identified as one single photon in the photon discriminator. Therefore, high throughput imaging is restricted to either using low concentration of fluorescent agents or decreasing laser irradiance, resulting in poor signal to noise ratio or reduced image contrast.

In this paper, we propose a new technique of counting photons simultaneously generated in a sample. Multianode PMT (MAPMT) is used as a detector, with its each channel working as a single PMT. Large area detection is used instead of simple temporal detection in order to maximize uniform spatial distribution of photons to fit in the active area of MAPMT. Each photon discriminator counts the number of photons assigned to its corresponding channel in MAPMT. The proposed technique is compared with conventional photon counting, and is validated to be useful in several multiphoton applications which require time-resolved photon counting. This work is supported by Singapore-MIT Alliance II.

6372-13, Session 3

New light sources for time-correlated single photon counting in commercially available spectrometers

D. U. Näther, Edinburgh Instruments Ltd. (United Kingdom)

The method of Time Correlated Single Photon Counting requires high repetitive light sources (\>100kHz) with pulse widths of ideally less than approximately 20ps. While these light sources have been available for some time now in the form of Ti:Sapphire lasers, picosecond pulsed diode lasers (<90ps) and light emitting diodes (<700ps), they all have the drawback of either no spectral tuneablity, or tunablility in a very narrow spectral range (10nm-100nm).

While this is often sufficient for specific laboratory setups for measurements of fluorescence lifetimes, commercial Fluorescence Lifetime Spectrometers have suffered for a long time from the lack of the availability of simple, compact and relatively inexpensive broad spectral band light sources that can be employed for Time Correlated Single Photon Counting.

A new light source as an integral part of a commercial Fluorescence Lifetime Spectrometer will be discussed that allows tuneabilty over a wide spectral band of more than 500nm.

6372-14, Session 4

A view on progress of silicon single-photon avalanche diodes and quenching circuits

S. D. Cova, M. Ghioni, F. Zappa, I. Rech, A. Gulinatti, Politecnico di Milano (Italy)

Silicon Single-Photon Avalanche-Diodes (SPAD) are nowadays considered a solid-state alternative to Photomultiplier Tubes (PMT) in photon counting (PC) and time-correlated photon-counting (TCPC) over the visible spectral range up to 1 micron wavelength. SPADs implemented in planar epitaxial CMOS compatible technology offer the typical advantages of microelectronic devices (small size, ruggedness, low voltage and low power, etc.). Furthermore, they have inherently higher photon detection efficiency, since they do not rely on electron emission in vacuum from a photocathode as PMT, but instead on the internal photoelectric effect. However, PMTs offer much wider sensitive area, which greatly simplifies the design of optical systems; they provide position-sensitive photon detection and imaging capability; they attain remarkable performance at high counting rate and offer picosecond timing resolution with Micro-Channel Plate (MCP) models. In order to make SPADs more competitive in a broader range of PC and TCPC applications it is necessary to face both semiconductor technology issues and circuit design issues, which will be here dealt with. Technology issues will be discussed in the context of two possible approaches: employing a standard industrial high-voltage compatible CMOS technology or developing a dedicated CMOS-compatible technology. Circuit design issues will be discussed taking into account problems arising from conflicting requirements set by various required features, such as fast and efficient avalanche-quenching, high resolution photon timing and gated detector operation.

6372-15, Session 4

Verifying a two-photon calibration method for photon-counting detectors to high accuracy

S. V. Polyakov, National Institute of Standards and Technology; M. J. Ware, Brigham Young Univ.; J. C. Bienfang, A. L. Migdall, National Institute of Standards and Technology

We present a high accuracy verification of a photon-counting detector

efficiency calibration technique using correlated photon pairs created through parametric down-conversion. In this scheme, the detection of a one photon triggers a measurement sequence aimed at the detection of its twin by a detector under test (DUT) that is the detector to be calibrated. The two-photon method yields a time-resolved histogram of DUT detection events consisting of correlated photon signals and background signals due to detection events of the DUT that are not correlated with the trigger. This background has a complex structure, owing to dead time and afterpulsing effects typical of avalanche photodiode (APD) detectors. We present a method for separating the correlated signal from the background signal that accurately handles these effects in both CW and pulsed mode two-photon setups. Also discussed is a formation of an afterpulse feature and the underlying timing effects. Understanding of these is essential to adequately describe delays of up to 10 nanoseconds in the electronic registration of approximately 1% of correlated events. As the goal of our work is to verify the two photon calibration method to an uncertainty of 0.1%, understanding of each of these effects is essential.

6372-16, Session 4

Recent developments in pixellated Geiger mode APDs

J. D. Swain, S. Reucroft, Y. Musienko, Northeastern Univ.

We report on recent development in pixellated Geiger mode APD's, highlighting device characteristics and applications where single and few photon sensitivity is required.

6372-17, Session 4

Geiger-mode InGaAsP/InP APDs optimized for single photon counting at 1.06 μm

K. W. Forsyth, N. Clay, Sensors Unlimited, Inc.

InGaAsP/InP APDs optimized for Geiger-mode single photon counting at 1.06 um have been fabricated based on a novel design intended to reduce the dark count rate without sacrificing high photon detection probability. The ratio of detection probability to dark count rate of these devices is more than an order of magnitude higher than that of Geiger-mode APDs fabricated using a conventional design.

The new APD design incorporates a quaternary InGaAsP absorption layer having a bandgap of approximately 1.2 eV, as well as a shaped PN junction intended to eliminate edge breakdown and the resulting excess tunneling currents while maintaining the reliability and array fabrication advantages of a planar device structure. This design has the further advantage of requiring only a single diffusion step rather than two as required by conventional planar InGaAs/InP APDs.

The after-pulsing performance of these devices is also novel, showing very little degradation with reduced device temperature. This after-pulsing behavior allows for lower temperature operation without sacrificing maximum count rate, and also offers new clues to the physical origin of after-pulsing in all photon-counting APDs fabricated in the InGaAsP materials system.

6372-18, Session 5

Millimeter precision laser ranging using solid state photon counting

I. Prochazka, Czech Technical Univ. in Prague (Czech Republic)

We are reporting our results in research and development in the field of avalanche semiconductor single photon detectors and their application in high precision laser ranging during the last 20 years. Our objectives where: avalanche detector structure, sensitive area diameters exceeding 50 microns, active quenching and gating electronic circuit, high timing resolution and rugged design. Avalanche photodiodes specifically designed for photon counting devices have been developed on the basis of various semiconductor materials: Si, Ge, SiGe, GaP, GaAs and InGaAs. All the semiconductor detectors operate at a room temperature or at thermoelectrically achievable temperatures except of the germanium based detector, which requires liquid nitrogen cooling. Electronic circuits for these detectors biasing, quenching and control have been developed and optimised for different applications. Circuits permitting operation of solid state photon counters in both single and multiple photon signal regimes have been developed and applied. Additionally, these circuits provide the estimate of the photon number involved in the detection process. The timing resolution of the order of units to several tens of picoseconds enables millimeter precision laser ranging. Different photon counting detectors for applications in ground-ground, ground-air, air-ground and ground to space high precision laser ranging have been developed and operated in the field on 11 different wavelengths in the range of 355-1548 nanometres. The range resolution and accuracy of the satellite laser ranging system achieved is so high, that it enables to resolve atmosphere induced optical signal propagation delay fluctuations on the sub-millimetre level. The recent results will be presented.

6372-19, Session 5

Ultra compact CMOS single photon detector

A. Rochas, A. Pauchard, L. Monat, O. Guinnard, A. Matteo, G. Ribordy, id Quantique SA (Switzerland)

In the past several years, the detection of single photons at visible wavelengths has received a growing interest from academic researchers and industrial companies in various fields. Compact single photon detectors with outstanding timing features are needed in lifetime spectrofluorometers, confocal microscopes and portable devices. Biological measurements in microarrays would greatly benefit from a detector array.

A new solid-state single photon detector suited for the visible spectral range will be presented. It is based on an avalanche photodiode (APD) biased above the breakdown voltage in the so-called Geiger mode. The sensor is fabricated using a CMOS process, a technology widely used in the microelectronics industry. Using this technology, a fast active quenching circuit can be integrated on the same chip in order to operate the APD in single photon counting mode. The fabricated sensor consists of a 0.8x0.8mm silicon chip mounted on a thermo-electric cooler and packaged in a standard TO5 header, bringing the degree of miniaturization to a level never reached. In addition to compactness and low fabrication cost, the sensor exhibits best-in-class timing resolution of 50ps. The detector is thus essential for applications such as multicomponent fluorescence decay experiments, sub-nanosecond fluorescence decays and ultra-short luminescences. For experiments based on time-of-flight, the 50ps timing resolution guarantees an excellent measurement accuracy. Because the sensor has a thin active region, the photon detection probability peaks in the blue/green at almost 35% and is limited to a few percents in the red and near-infrared regions. The cleanliness of the fabrication process leads to a very low intrinsic noise level. When cooled down to 0°C, 50um diameter diodes achieve a typical dark count rate lower than 100Hz. In the same conditions, the afterpulsing is maintained to a low level, below 2%. The fast active quenching circuit leads to a dead time of 50ns allowing a measurement frequency of up to 20MHz. The detector does not suffer from memory effects found in photomultiplier tubes and is not damaged by ambient light. It requires two low power levels 5V and -25V to operate in the single photon counting mode.

Finally, the small detector size makes it possible to assemble several closely-spaced TO-headers on a printed circuit board to build arrays of photon counters. Among other potential applications, single molecule detection would benefit from a parallel analysis of individual spots in microarrays or in microfluidic channels.

6372-20, Session 5

Low dark count rate 4H-SiC Geiger mode avalanche photodiodes operated under gated quenching at 325 nm

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The detection of light at ultraviolet (UV) wavelengths is important for many military, medical and environmental applications. Applications such as biological agent detection and non-line-of-sight communications require the detection of scattered UV light. Currently, photomultiplier tubes operated as single photon counters are used to detect these low light levels, but they have many unfavorable characteristics for such applications. SiC based avalanche photodiodes (APDs) operated in Geiger mode could potentially meet the needs of these applications. Our first results, using SiC Geiger

mode avalanche photodiodes (GAPDs), showed prohibitively high dark counts, due to a large tunneling current component in the multiplied dark current. Here we show the results of two p-i-n structures with 260μm and 480μm i-regions, which reduced the primary dark current by two orders of magnitude, operated under gated quenching conditions at 325nm. The lower dark current resulted in a dark count rate of 28kHz at 3.6% single photon detection efficiency (SPDE) in a 100μm diameter device. This is a three order reduction in the dark count rate over our previous results using a p-n junction GAPD.

6372-21, Session 5

In orbit performance of Si avalanche photodiode single-photon counting modules in the Geoscience Laser Altimeter System on ICESat

X. Sun, NASA Goddard Space Flight Ctr.; P. L. Jester, Stinger Ghaffarian Technologies, Inc.; S. P. Palm, J. B. Abshire, J. D. Spinhirne, M. A. Krainak, NASA Goddard Space Flight Ctr.

Si avalanche photodiode (APD) single photon counting modules (SPCMs) are used in the Geoscience Laser Altimeter System (GLAS) on Ice, Cloud, and land Elevation Satellite (ICESat), currently in orbit measuring Earth surface elevation and atmosphere backscattering. These SPCMs are used to measure cloud and aerosol backscatterings to the GLAS laser light at 532-nm wavelength with 60-70% quantum efficiencies and up to 15 millions/s maximum count rates. The performance of the SPCMs has been closely monitored since ICESat launch on January 12, 2003. There has been no measurable change in the quantum efficiency, as indicated by the average photon count rates in response to the background light from the sunlit earth. The linearity and the afterpulsing seen from the cloud and surface backscatterings profiles have been the same as those during ground testing. The detector dark count rates monitored while the spacecraft was in the dark side of the globe have increased almost linearly at about 60 counts/s per day due to space radiation damage. The radiation damage appeared to be independent of the device temperature and power states. There was also an abrupt increase in radiation damage during the solar storm in 28-30 October 2003. The observed radiation damege is a factor of two to three lower than the expected and sufficiently low to provide useful atmosphere backscattering measurements through the end of the ICESat mission. To date, these SPCMs have been in orbit for more than three years. The accumulated operating time to date has reached 290 days (7000 hours). These SPCMs have provided unprecedented receiver sensitivity and dynamic range in ICESat atmosphere backscattering measurements.

6372-22, Session 5

Gated operation of InGaAs SPADs with active-quenching and fast timing circuits

A. Tosi, A. Gallivanoni, F. Zappa, S. D. Cova, Politecnico di Milano (Italy)

InGaAs and Germanium devices employed as Single-Photon Avalanche-Diodes (SPAD) for the infrared spectral range must be cooled to low temperature for reducing the dark-counting rate due to thermal generation and are plagued by strong avalanche carrier trapping. Released trapped carriers re-trigger the avalanche and generate correlated afterpulses. This effect can be counteracted by reducing the avalanche pulse charge and by covering the trapped carrier release transient with a hold-off time after quenching. Reducing the temperature, however, remarkably increases the release time. Free-running operation thus becomes unpractical and gated operation is employed, with an idle time enforced for covering the release of the trapped charge after each gate where a pulse occurs. The avalanche charge should be minimized in order to minimize this idle time. Simple gated passive circuits are suitable for short gate intervals (a few nanoseconds), but become inefficient for longer gate times.

Gated operation of a SPAD under the control of an active quenching circuit has been investigated and accurate timing of infrared photons has been pursued. An integrated active quenching circuit (iAQC) suitable for gated mode was designed for operating down to cryogenic temperature with the SPAD. The iAQC senses the avalanche and swiftly quenches it, without waiting the end of the gate interval. Operation with longer gate times (100ns and more) is achieved with remarkably reduced afterpulsing with respect to passive gated circuits. Fast circuits have been expressly designed for processing the avalanche pulse, cancelling spurious spikes due to gate transients and accurately extracting the photon timing information, with less than 50ps jitter.

6372-23, Session 5

Planar silicon SPADs with 200-μm diameter and 35-ps photon timing resolution

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Time-correlated single photon counting (TCSPC) is exploited in emerging scientific applications in life sciences, such as single molecule detection, DNA sequencing, fluorescent lifetime imaging. Detectors with wide active area (diameter \> 100 μm) are desirable for attaining good photon collection efficiency without requiring complex and time-consuming optical alignment and focusing procedures. Fiber pigtailing of the detector, often employed for having a more flexible optical system, is also obtained more simply and with greater coupling efficiency for wide-area detectors. TCSPC, however, demands to detectors also high photon-timing resolution besides low noise and high quantum efficiency. Particularly stringent requirements are set for single-molecule fluorescence analysis, where components with lifetimes of tens of picoseconds are often met. Small photon timing jitter and wide area are considered conflicting requirements for the detector.

We developed an improved planar silicon technology for overcoming the problem and providing a solid-state alternative to MCP-PMTs in demanding TCSPC applications. We have fabricated Single Photon Avalanche Diodes (SPADs) with 200 μm active area diameter and fairly low dark counting rate (DCR). At moderately low temperature (-20 C with Peltier cooler) the typical DCR is 1500 c/s and it is not difficult to select devices with less than 1000 c/s. The photon detection efficiency peaks at 48% around 530 nm and stays above 30% over all the visible range. A photon timing resolution of 35 ps FWHM (full width at half maximum) is obtained at room temperature by using our patented pulse pick-up for processing the avalanche current.

6372-24, Session 5

A single-photon avalanche diode array fabricated in 0.35 μm CMOS and based on an event-driven readout for TCSPC experiments

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The design and characterization of an imaging sensor based on single photon avalanche diodes is presented. The sensor was fully integrated in a 0.35um CMOS technology. The core of the imager is an array of 4x112 pixels that independently and simultaneously detect the arrival time of photons with picosecond accuracy. A novel event-driven readout scheme was designed to allow parallel column-wise and non-sequential, on-demand row-wise operation. Both time-correlated and time-uncorrelated measurements are supported in the sensor. The readout scheme is scalable and requires only 11 transistors per pixel. At 25um, the pixel pitch achieved by this design is the smallest ever reported. A number of standard performance measurements for the imager are presented in the paper. An average dark count rate of 6Hz is reported at room temperature, with 98.9% of the pixels at less than 10Hz, while the dead time is 40ns and the crosstalk less than 0.05%. A timing resolution better than 80ps over the entire integrated array makes this technique ideal for a fully integrated high resolution streak camera, thus enabling fast TCSPC experiments. Applications requiring low noise, picosecond timing accuracies, and measurement parallelism are prime candidates for this technology. Examples of such applications include bioimaging at cellular and molecular level based on fluorescence lifetime imaging and/or, fluorescence correlation spectroscopy, as well as fast optical imaging, optical rangefinders, LIDAR, and low light level imagers.

6372-25, Session 5

High-efficiency single-photon detectors

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Single-photon detectors with high efficiencies and low error probabilities are indispensable for optical quantum computing and large scale quantum information protocols. Visible light photon counters (VLPCs)

and solid-state photomultipliers (SSPMs) are an attractive choice because of their high quantum efficiency, and low pulse-height dispersion, leading to multi-photon counting capability. The VLPCs have an inferred internal quantum efficiency of 94% ± 5% (at 694 nm) [Appl. Phys. Lett, 74, 902 (1999)] and SSPMs 96% ± 3% (at 660 nm) [Applications of Photonic Technology, Plenum Press, New York, 471 (1995)]. However, the actual measured values for both the detectors were in fact limited to less than 88%, attributed to in-coupling losses. There are two main issues associated with the in-coupling optical fibers: shielding from room-temperature (RT) thermal photons and absorption and reflection losses. We attempt to overcome these by using narrower and anti-reflection coated fibers. To reduce transmission losses to <1%, we designed a novel cryogenic setup that allows the use of shorter fibers. We thus expect a net in-coupling efficiency (at 710 nm) of \>97%. We reduced the reflection losses from the devices themselves, from ~23% to <0.5% by in-house custom coatings, and this technique can be applied to optimize for high-efficiency detection at any wavelength within the sensitivity range of the detectors. Finally, we discuss low-noise electronics techniques to achieve the high signal-to-noise ratios required for reliable signal detection and photon-number resolving capabilities. With these improvements, we anticipate actual detection efficiencies in excess of 90%.

6372-26, Session 5

Time-correlated single photon counting with superconducting single-photon detectors

M. J. Stevens, R. H. Hadfield, R. E. Schwall, S. W. Nam, R. P. Mirin, National Institute of Standards and Technology

Time-correlated single photon counting (TCSPC) is a highly sensitive technique that is widely used for time-resolved emission studies. Typical detectors for TCSPC are avalanche photodiodes (APDs) or photomultiplier tubes (PMTs). For visible wavelengths, the fastest silicon APDs and microchannel plate PMTs offer temporal instrument response functions (IRFs) at or approaching 20 ps full-width-at-half-maximum (FWHM); however, the narrow central peaks in these IRFs are typically followed by long exponential tails. Moreover, the scarcity of good detectors sensitive to wavelengths beyond ~1000 nm presents a serious limitation to TCSPC.

Recent advances in superconducting single photon detectors (SSPDs) based on nanopatterned niobium nitride wires demonstrate their ability to overcome some of the shortcomings of conventional detectors. SSPDs boast timing jitter as low as 18 ps FWHM, low dark count rates, and sensitivity well into the infrared. Here, we discuss the use of an SSPD in a TCSPC scheme. We show that the IRF of this device has a Gaussian profile with 68 ± 3 ps FWHM, offering a dramatic advantage over conventional detectors. With the low dark count rate on this detector (<100 Hz), we can make time resolved photoluminescence measurements with nearly five decades of dynamic range. Furthermore, we use the SSPD for measurements beyond 1200 nm, well outside the range of conventional silicon detectors. Finally, we demonstrate use of the SSPD to fully characterize the emission of a quantum dot single photon source, measuring the spontaneous emission lifetime and the second-order intensity correlation function.

6372-27, Session 5

Fast single photon detection using superconducting Nb nanowires

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We have fabricated and tested single infrared photon detectors based on a current-biased superconducting Nb nanowire. The detectors are fabricated from high quality, hot-deposited Nb thin films on a sapphire substrate. We present a phenomenological model accounting for our experimentally observed response dynamics, and describe a readout scheme for single and few photon counting. We will compare our Nb detectors to recent results for NbN-nanowire detectors. Nb offers several advantages compared to NbN, including lower resistance and kinetic inductance. This should yield a very fast recovery time for a useable size detector with high detection efficiency, as well as enable photon counting directly from the response pulse magnitude. Nb is also a simpler material than NbN. Such detectors have applications in imaging of IR photoemission in CMOS logic circuits as well as in optical spectroscopy studies of single molecule florescence.

6372-28, Session 6

Fast and practical single photon detection at telecom wavelengths

R. T. Thew, H. Zbinden, N. Gisin, Univ. de Genève (Switzerland)

Single photon counters are one of the most critical enabling technologies in the emerging fields of quantum information processing and communication (QIPC), as well as having potential applications in any field where photonics plays a role. Indeed, single photon detection at telecom wavelengths is fundamentally important for long distance quantum communication protocols and for future and emerging telecom technologies. Telecom wavelength detection has generally been at a disadvantage compared with Si detectors which work for wavelengths below 1μm. However, in recent work we have attempted to overcome this by incorporating sum-frequency generation (SFG) to convert single photons from the telecom bandwidth into the domain of Si detectors. We have used several different approaches to realise this using both bulk and waveguide nonlinear elements. Further to this, we have also taken advantage of new “low jitter” Si detectors. This has seen allowable count rates improved by several orders of magnitude and timing precision reduced by an order of magnitude to 40ps, compared to standard InGaAs/InP detectors.

We discuss our latest results and some of the advantages associated with performing both QIPC and emerging tasks in quantum metrology with these hybrid detectors. We have previously shown the use of these type of detectors in a GHz rate QKD experiment. Here we discuss improvements in the efficiency noise characteristics of these detectors. We then show their utilisation in a more recent QKD protocol that is currently being developed. In terms of quantum metrology we will show the improvement this scheme provides in precision for single photon OTDR.

6372-29, Session 6

Do we count indivisible photons or discrete quantum events experienced by detectors?

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As low light detection technologies are advancing, novel experiments like single molecule spectroscopy, quantum computation (or quantum encryption) are proliferating. Quantum mechanical detectors can produce only discrete “clicks” at different rates based on the propagating field energy through them, irrespective of whether the photons are divisible or indivisible packets of energy. Highly successful quantum formalism is not capable of providing the microscopic picture of the processes undergoing during QM interactions; that is left to human imaginations allowing for sustained controversies and mis-interpretations. The purpose of this paper is to promote new innovative applications at very low light level through better understanding of what a photon is. We have demonstrated [Opt.Ex.11, p944, 2003; SPIE 5531, p450, 2004; SPIE 5866, p26, 2005] that we ignore the obvious fact that EM fields do not interact (interfere) with each other. Otherwise the visual world would have been full of speckles and the WDM technologies would have never worked. The effects of superposition of EM fields become manifest when the right detector molecule, allowed by QM rules, is able to respond to all the superposed fields on it and sum the induced effects. Panarella [SPIE 5866, p.218, 2005] has demonstrated that a minimum of four photon equivalent energy is required to detect discernable diffraction pattern. We propose to show that photons are space and time finite classical wave packets that propagate following Huygens-Fresnel principle. Quantum detectors respond to (are stimulated by) the simultaneously present multiple superposed wave packets and absorbs the necessary amount of energy , as long as all the wave packets have the same allowed frequency . QM formalism does not restrict simultaneous energy absorption from multiple sources. Our model of recognizing detectors’ role in displaying the superposition effects brings causality and reality within the framework of current QM formalism.

6372-30, Session 6

Ultrafast infrared superconducting single-photon detector system

R. H. Hadfield, M. J. Stevens, R. E. Schwall, R. P. Mirin, S. W. Nam, National Institute of Standards and Technology; J. L. Habif, BBN Technologies

Superconducting single photon detectors (SSPDs) based on niobium nitride nanowires offer single photon counting with low dark counts and excellent timing resolution well into the infrared. We have integrated fiber-coupled SSPDs in a 4-channel cryogen free detector system. The system detection efficiency (measured from the fiber input to the cryostat) is 1 % at 1550 nm at a base temperature of 2.9 K. Our current focus is on applications in quantum information: we have demonstrated the feasibility of using this type of detector system to improve the range and secure bit rate of quantum cryptography systems at fiber telecommunications wavelengths (1310 nm, 1550 nm). We have demonstrated Quantum Key Distribution (QKD) with the BB84 protocol at 3.3 MHz over 40 km of fiber in the lab and employed system in an operational metropolitan fiber-based QKD system (the DARPA Quantum Network in Cambridge, MA). We have also used this detector system to characterize quantum dot-based single photon sources and quantum wells in the infrared. The exquisite timing resolution (60 ps FWHM jitter) and infrared sensitivity of this type of detector opens up a wealth of applications in imaging and ranging.

6372-31, Session 6

Application of a new time-correlated single-photon counting instrument in a fiber-based quantum cryptography system

I. P. S. Choi, H. N. J. Fernando, P. D. Townsend, Tyndall National Institute (Ireland); M. Wahl, PicoQuant GmbH (Germany)

Time-Correlated Single Photon Counting (TCSPC) is a powerful method for sensitive time-resolved optical measurements. Its primary goal was historically the measurement of fluorescence lifetime. This application is still important today and therefore has a strong influence on instrument design. However, modifications and improvements over the early designs allow the recovery of much more information from the captured photons and allow entirely new applications. One such important new application is quantum cryptography (QC), a technique that exploits fundamental physical laws in order to achieve the secure transfer of cryptographic keys. Here we present a TCSPC instrument that captures single photon events on multiple synchronized channels with picosecond resolution over virtually unlimited time spans and with extremely short dead-times, and describe its use within an optical fiber-based QC system. The QC system operates at a wavelength of 1550nm and employs an interferometric approach in which phase-shift encoded optical pulses from a strongly attenuated semiconductor laser are used to represent bits at the quantum level. The QC channel, together with additional conventional data channels, is carried over a single transmission fiber using a coarse wavelength division-multiplexing (CWDM) scheme with a 20nm channel separation. The keys transferred across the QC channel can be used to encrypt the conventional channels, which in the experiments are provided by gigabit Ethernet streams generated by low-cost, un-cooled CWDM transceivers. These conventional channels in turn carry timing and protocol information required for the implementation of the QC channel as well as additional data traffic.

6372-32, Session 6

High-speed photon counting techniques for broadband quantum key distribution

D. J. Rogers, National Institute of Standards and Technology and Univ. of Maryland; J. C. Bienfang, A. Mink, B. J. Hershman, A. Nakassis, X. Tang, L. Ma, D. H. Su, C. J. Williams, C. W. Clark, National Institute of Standards and Technology

Quantum Cryptography has demonstrated the potential for ultra-secure communications. However, with quantum-channel transmission rates in the MHz range, typical link losses and signal-to-noise ratios have resulted in key-production rates that are impractical for continuous one-time-pad encryption of high-bandwidth communications. We have developed high-speed data handling electronics that support quantum-channel transmission rates up to 1.25 GHz. This system has demonstrated error-corrected and privacy-amplified key rates above 1 Mbps over a free-space link. While the transmission rate is ultimately limited by timing jitter in the single-photon avalanche photodiodes (SPADs), we find the timing resolution of silicon SPADs sufficient to operate efficiently with temporal gates as short as 100 ps. We have developed systems to implement such high-resolution gating in our system, and anticipate the attendant reduction in noise to produce significantly higher secret-key bitrates.

6372-33, Session 6

High-rate photon-counting optical communication with a superconducting nanowire single-photon detector

E. A. Dauler, Massachusetts Institute of Technology; B. S. Robinson, A. J. Kerman, R. J. Barron, D. O. Caplan, M. L. Stevens, J. J. Carney, S. A. Hamilton, MIT Lincoln Lab.; J. K. W. Yang, K. K. Berggren, Massachusetts Institute of Technology

We demonstrate photon counting optical communication using a superconducting nanowire single-photon detector (SNSPD) at gigabit-per-second data rates. The use of a high-speed NbN SNSPD, in contrast to a previous demonstration that used a photon counting InGaAs avalanche photodiode, resulted in a more than 1000-fold increase in the demonstrated data rate. Photon counting optical communication is well-suited to long distance free-space communication links, such as interplanetary links, where the data rate is primarily constrained by the amount of received power and the receiver sensitivity. A pulse position modulation format, where a single optical pulse carries several bits of information based on its position within many slots in time, was used along with a forward-error-correcting code to achieve error-free performance. The impact of recent improvements in the device performance on the communication data rate and sensitivity will be discussed, demonstrating the suitability of the SNSPD for photon counting optical communications. This work is sponsored by the United States Air Force under Air Force Contract# FA8721-05-C-0002.

Opinions, interpretations, recommendations and conclusions are those of the authors and are not necessarily endorsed by the United States Government.

6372-34, Session 6

Optical entanglement for quantum communication

A. V. Sergienko, M. A. Jaspan, B. E. A. Saleh, M. C. Teich, Boston Univ.

We review the role of single-photon detectors in quantum optics and quantum information processing with entangled-photon states. We show that such properties of single-photon detectors as timing resolution (jitter), number-photon resolution, size of photosensitive area, and quantum efficiency can be extremely important in quantum cryptography applications.

Polarization entanglement is one of the most frequently used types of entanglement in quantum information processing and in precise optical measurement. The required two-photon pair correlated in polarization is usually produced form a non-linear crystal selected for a type-II phase matching or from two perpendicularly oriented type-I phase-matching crystals positioned next to each other.

We combined an advantage of generating photon pairs in Periodically Poled Lithium Niobate (PPLN) with the possibility of using two perpendicularly oriented type-I phase-matching crystals when they are spatially separated. We have demonstrated that such a design represents very flexible and efficient system for engineering entangled states with desired frequency, polarization, and spatial properties. We demonstrated that the spatial profile of SPDC could be tailored appropriately to achieve the desired spatial and temporal overlap of photon pairs born from separate crystals inside a telecommunication fiber. This guarantees necessary indistinguishability and high-contrast quantum interference that is sufficient for performing a quantum key distribution at the telecommunication wavelength 1550 nm.

6372-35, Poster Session

Timing stability of TCSPC experiments

W. Becker, A. Bergmann, Becker & Hickl GmbH (Germany)

Advanced time-correlated single-photon counting (TCSPC) devices are

able to record several 10E6 photons per second and deliver an instrument response function down to 25 ps FWHM. Under these conditions the accuracy of the recorded waveforms is limited by systematic timing errors rather than by the photon statistics. The experiments described below determined the variation of the instrument response function (IRF) with the count rate and the timing drift for a commonly used TCSPC module and a number of commonly used detectors. For count rates from 3*10E4 to 4*10E6 s-1 a shift of the first moment of the IRF smaller than 2 ps was obtained. The drift over 16 minutes was within +/-0.7 ps.

6372-36, Poster Session

Development of a high-speed combined spectral and lifetime detector for fluorescence microscopy of living specimens

M. Z. Nazir, K. W. Eliceiri, J. G. White, Univ. of Wisconsin/Madison

A fluorescence signal contains more information than just intensity; other properties such as spectra and lifetime can reveal additional information about the fluorophore and interactions with its microenvironment. Typically, spectra and lifetime are collected separately, but a combined detector would have advantages in many situations, such as FLIM FRET measurements, where two fluorophores may be spectrally separated and lifetime measurements made on each. Current single channel photon counting techniques are generally not fast enough to collect lifetime data on multiple spectral channels for studies of in vivo dynamics. We are currently developing a time-correlated 16-channel photon counting detector for fluorescence lifetime imaging which will have burst counting rates of nearly two orders of magnitude faster than currently available single channel systems. Each spectral channel has a dedicated microwave amplifier, a constant fraction discriminator and a timing channel. The photon arrival times with respect to the excitation source are measured using TDC chips with psec resolutions. A single TDC chip can provide eight timing channels each with 5.6nsec pulse pair resolution giving a peak measurement rate of 178MHz on any channel. This substantially reduces the number of photons lost to the dead time of the device and the exposure time of the sample. The time information along with the spatial coordinates of the pixel generating the photons are stored in FIFOs defined on an FPGA device. The FIFOs act as elastic buffers from where the data is transferred to the host PC via high speed USB2.0 interface.

6372-37, Poster Session

Highly sensitive single-photon detection system for multi-lane DNA sequencer

D. Gavrilov, B. Gorbovitski, G. Gudkov, A. Stepukhovich, M. Tcherevishnik, G. Tyshko, A. Tsupryk, V. B. Gorfinkel, Stony Brook Univ.

A method for improvement of the performance of a multichannel fluorescence detection system for multi-lane DNA sequencer based on single photon counting is presented. The discussed detection system is using side excitation of a flat capillary array. Fluorescence is collected by a lens at 90 degree angle and projected on the input window of a linear array PMT.

Sensitivity of the system may be increased by widening the collection angle of the fluorescence detector, i.e. installing the collection lens of a larger numerical aperture. This may result in blurring of the projected image of the capillary array on the PMT surface and, as a consequence, optical cross-talk between the detection channels. The optical cross-talk is adding to the internal electronic cross-talk of the PMT. High quality estimation of fluorescence in each detection channel requires cancellation of the cross-talk.

We proposed a method for calibration of the fluorescence detector for cross-talk and subsequent elimination of the cross-talk from the measurement data. The method is demonstrated by data obtained on our experimental 32-lane DNA sequencer. We demonstrated 4-fold improvement in the fluorescence detection sensitivity by increasing the fluorescence collection angle from 45 to 90 degrees.

6372-38, Poster Session

32-channel single-photon counting module for ultrasensitive detection of DNA sequences

V. H. Dhulla, G. Gudkov, D. Gavrilov, O. Kosobokova, A. Tsupryk, A. Stepoukhovitch, B. Gorbovitski, Stony Brook Univ.

We present a 32-channel single photon counting module for ultra-sensitive detection of fluorescently labeled DNA in DNA sequencing systems. Unavailability of large area APD based single photon counting arrays and our desire to enhance fluorescence collection efficiency drove us to use individual APDs with active area of 0.2 sqr mm(C30902S-DTC, Perkin Elmer Optoelectronics(PKI), Canada). Each channel of the detector has fiber input (400um core diameter) coupled to the APD using GRIN lens. Each detector channel comprises of a temperature controller and a quenching circuit of our design. System characterization showed that the quantum efficiency of our detector is the same as that of SPCM module from PKI, linear photon detection range is 1M count/s and dark count rate is in the range of 300-1,000 count/s. Noise analysis showed that the only source of the system's noise was a stochastic character of the photon flux and that the electronic circuits employed did not add any noise to the recorded signal. The detector comprises of a single board computer PC-104 that enables data visualization, recording, processing, and transfer. The use of the detector in a DNA sequencing system enabled highly accurate (99%) sequence detection using DNA sequencing reagents produced by Applied Biosystems Inc. (CA) with less than 1,000 DNA fragments per peak.

6372-39, Poster Session

Controllable photon source

D. Oszetzky, A. Nagy, A. Czitrovszky, Magyar Tudományos Akadémia Szilárdtestfizikai és Optikai (Hungary)

We have developed our pervious experimental setup using correlated photon pairs (to the calibration of photo detectors) to realize a controllable photon source. For the generation of such photon pairs we use the non-linear process of parametric down conversion. When a photon of the pump beam is incident to a nonlinear crystal with phase matching condition, a pair of photons (signal and idler) is created at the same time with certain probability. We detect the photons in the signal beam with a single photon counting module (SPCM), while delaying those in the idler beam. Recently we have developed a fast electronic unit to control an optical shutter (a Pockells-cell) placed to the optical output of the idler beam. When we detect a signal photon with the controlling electronic unit we are also able to open or close the fast optical shutter. Thus we can control which idler photons can propagate through the Pockells-cell. So with this photon source we are able to program the number of photons in a certain time window. This controllable photon source that is able to generate a known number of photons with specified wavelength, direction, and polarization could be useful for applications in high-accuracy optical characterisation of photometric devices at the ultra-low intensities. This light source can also serve as a standard in testing of optical image intensifiers, night vision devices, and in the accurate measurement of spectral distribution of transmission and absorption in optical materials.

6372-40, Poster Session

An ultra-fast Geiger-mode single photon avalanche diode in 0.18 μm CMOS technology

H. Finkelstein, M. J. Hsu, S. C. Esener, Univ. of California/San Diego

Silicon single-photon avalanche diodes have been used in diverse applications, from LIDAR to single molecule imaging. When operated in Geiger-mode, these devices must withstand electric fields in excess of 1 MV/cm (the breakdown field of silicon), instantaneous current densities above 0.3 mA/mm2, and operate at voltages far higher than those of standard CMOS devices. As a result, SPADs have traditionally been manufactured using custom processes, with the required timing and processing circuitry being bonded off-chip. More recently, a CMOS SPAD has been manufactured on a 0.8 mm high-voltage commercial process but with poor fill factor. The manufacture of SPADs in commercial processes is highly desirable because of the low defect densities of these processes, the ability to reduce the diodes'

capacitance by on-chip integration of the timing circuitry, and by economies of scale.

We demonstrate a new single-photon avalanche diode device, which utilizes the silicon-dioxide shallow-trench isolation (STI) structure common to all deep-submicron technologies, simultaneously as a junction planarization mechanism and as a guard-ring. This makes it possible to achieve an order-of-magnitude improvement in fill factor and in pixel area, and results in improved SPAD performance. We present numerical simulations and experimental results from a test chip incorporating passively and actively quenched devices, which was manufactured in an IBM 0.18 mm technology. Due to the efficient structures, sub-10ns dead times are achievable without requiring active-quenching, creating the opportunity to integrate large arrays of these ultra-fast SPADs for use in biological imaging systems.

Monday-Wednesday 2-4 October 2006

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6373-01, Session 1

Signature science in the terahertz

F. C. De Lucia, The Ohio State Univ.

Applications in the region of the electromagnetic spectrum between 0.1 and 10 THz have been proposed for many decades. Some of these have come to fruition and technologies to support them have been developed that approach the limits set by nature. Typically, these applications are supported by a sophisticated understanding of their sometimes complex spectral signatures. However, there are a number of other applications, which have been widely discussed in recent years, that have yet to come to fruition. Some of these are very important in that they are 'public' applications that have the potential to have direct impact beyond the scientific and technical communities. While strictly speaking most of these are not new, the attention that they have gathered is. This talk will focus on what we know about the signatures of these applications and how these signatures interact both with their environment and choice of system approaches.

6373-02, Session 1

THz dynamics of the metal-insulator transition in vanadium dioxide

P. U. Jepsen, Danmarks Tekniske Univ. (Denmark); B. M. Fischer, Univ. of Adelaide (Australia); A. Thoman, H. Helm, Albert-Ludwigs-Univ. Freiburg (Germany); R. Lopez, R. F. Haglund, Jr., Vanderbilt Univ.

Bulk vanadium dioxide undergoes a phase transition from semiconductor to metal at a temperature near 341 Kelvin. We have investigated the dynamics of this phase transition in vanadium dioxide thin films with THz time-domain spectroscopy in the frequency band below the phonon bands of vanadium dioxide. We show unambiguously that the phase transition occurs via gradual growth of metallic domains in the film, and that the dielectric properties of the film in the vicinity of the transition temperature must be described by effective-medium theory. The simultaneous measurement of both amplitude and phase, unique to THz time-domain spectroscopy, allows us to show that Maxwell-Garnett effective-medium theory is superior to the Bruggeman effective-medium theory frequently used to describe percolation in this material. Our results have important implications for the interpretation of transmission- and reflection spectra recorded on a wide range of composite materials and mixtures.

6373-03, Session 1

Ab-initio prediction of terahertz vibrational modes in crystalline systems

P. U. Jepsen, Danmarks Tekniske Univ. (Denmark); S. J. Clark, Univ. of Durham (United Kingdom)

In the recent years there has been strong efforts to develop THz technology for stand-off detection of explosives and other dangerous or illicit chemicals. The background of this activity is the rich and unique absorption spectrum displayed by such chemicals. Even though the THz spectrum is by now known for a wide range of chemicals, the understanding of such spectra is still limited, and accurate prediction of THz absorption spectra has so far been virtually impossible for most realistic materials. Here we present an ab-initio density-functional perturbative method capable of accurate prediction of the THz vibrational spectrum of molecules in the crystalline phase, and assignment of absorption bands to specific modes consisting of intramolecular motion strongly coupled to phonon modes of the crystal.

6373-04, Session 1

Terahetz spectroscopy of molten sulfur using a tunable THz source

M. Mross, T. Lowell, Vermont Photonics, Inc.; G. C. Vezzoli, New Hampshire Community Technical College

We will study the liquid-liquid allotropic transitions in molten sulfur using terahertz (THz) spectroscopy. Liquid sulfur is selected as an initial choice of materials because its structure and properties are well established from previous in-situ studies by one of the current investigators (and by other researchers) using a variety of physical and chemical methodologies, and because as an elemental inorganic polymeric material, it can be used effectively as an analogue and a precursor material to studying advanced life-sciences organic polymeric molecules, to include amino acids, polypeptides, DNA, and rhodopsin. It is known that sulfur melts to an equilibrium mixture of octameric (S8) rings and polymer chains, with a small concentration of hexameric rings (S6). As temperature is increased, thermal energy initiates ring scission and the resulting diradically-terminated short chains undergo covalent bonding to induce polymerization at 159-166 °C. Further increase in temperature causes an increase in chain length and an increase in chain species concentration until a temperature of 188 C is reached at which the long chains (~106 atoms in length) undergo chain scission, and although the chains start to break up, the polymer concentration of the mixed phases still increases. We will experimentally map THz laser absorption, transmission, and scattering effects with these known transitions in liquid sulfur.

6373-06, Session 2

Fabrication and characterization of GaN/AlGaN multilayer structure for teraherz quantum cascade laser

S. C. Wang, National Chiao Tung Univ. (Taiwan); R. A. Soref, Air Force Research Lab.; G. Sun, Univ. of Massachusetts

The GaN-based QCL has many advantages compared to the GaAs-based QCL. These include larger LO-phonon energy (ELO~90 meV), very fast carrier dynamics, far infrared emission wavelengths (\> 40 mm), and room-temperature operation capability. The recent analysis of the GaN-based THz QCL with GaN//AlGaN quantum well active layer structure also predicted low-threshold operation potential. However due to the lack of suitable GaN substrate the growth of GaN material has been mostly on the lattice-mismatched foreign substrate such as sapphire. As a result the fabrication of high quality GaN/AlGaN active layer structure for GaN QCL is relatively difficult. In particular the good surface morphology of the grown structure and the precise control of Al composition and layer thickness are critical for the realization of GaN-based THz QCL. In this talk we present the growth and characterization of the AlxGa1-xN epilayer structures with Al composition ranging from 0 < x < 1 and a multi-period AlxGaN1-x/GaN active-layer structure. These structures were grown on sapphire substrate using a commercial MOCVD system. The grown AlxGa1-xN samples showed good surface morphology with controllable Al composition. The multi-period AlxGa1-xN/GaN structure sample also showed crack-free and smooth surface morphology as examined by optical microscopy and atomic force microscopy (AFM) The x-ray diffraction (XRD) and transmission electron microscopy (TEM) measurement showed the multi-period AlxGaN1-x/GaN structure has sharp interface between layer structures. The analysis of XRD and TEM data also showed a well-controlled layer thickness and Al composition that are applicable for fabrication of GaN QCL active layer structure. Detailed results will be discussed in this talk.

6373-07, Session 2

A 200-GHz low phase noise photonic local oscillator module

R. S. Kimberk, T. R. Hunter, E. Tong, R. Blundell, Harvard-Smithsonian Ctr. for Astrophysics

A low phase noise photonic Local Oscillator module has been tested in the 200 GHz frequency range. This module is based on an optical comb generator. The comb generator relies on a microwave oscillator which is used to phase modulate the output of a 1550 nm diode laser. The optical comb then passes through a Mach-Zehnder interferometer to produce an amplitude-modulated optical output. One of the interferometer's two outputs is directed to a photomixer, which is used to phase-lock the microwave oscillator to a reference oscillator. The other output feeds a purpose-built photomixer, optimized for 200 GHz operation. The entire module operates fully under computer control. It can deliver sufficient power (~2μW) to operate an SIS mixer at 230 GHz. Furthermore, the LO module generates a very clean output with good

phase characteristics: at the IF output of the phase-lock loop, an Adjacent Channel Power (ACP) ratio of about -30dBc has been measured using a signal channel width of 16 kHz, and a noise pedestal bandwidth of 250 kHz. By comparison, a typical LO chain based on a phase-locked Gunn oscillator would have ACP ratio in the range of -30 to -35 dBc. Field tests are underway to deploy this LO module for use in a submillimeter interferometer.

6373-08, Session 2

The properties of terahertz sources based on dopant transitions in semiconductors

J. Kolodzey, P. Lv, S. Kim, Univ. of Delaware

During the past few years, terahertz emission has been investigated from radiative intracenter transitions in doped semiconductors. Both acceptor and donor transitions have been observed to produce THz signals in host materials including silicon, germanium, gallium arsenide, and silicon carbide. For instance, gallium acceptors in Si emit at 7 to 13 THz, and nitrogen donors in SiC emit at 9 THz. The initial dopant based devices were optically pumped from a 10.6 μm CO2 laser, but subsequently, devices were designed to operate by electrical pumping. For our electrically pumped THz sources, the output powers reached above 0.1 milliwatt, and the pulse-mode operating temperature reached 150 K. In this talk, we describe the characteristics and limitations of dopant-based emitters, including their frequency range, emitted power, efficiency, and operating temperature. The feasibility of producing terahertz lasers using this mechanism will be analyzed.

This work was supported by AFOSR, DARPA, NSF and ONR.

6373-09, Session 2

Continuous-wave submillimeter-wave gyrotrons

S. Han, Massachusetts Institute of Technology

Electromagnetic wave sources at submillimeter wavelengths have important applications in research in physics, chemistry, biology, materials science and medicine. Recently, dynamic nuclear polarization enhanced nuclear magnetic resonance (DNP/NMR) has emerged as a powerful technique to obtain significant enhancements in spin spectra from biological samples. For DNP in modern NMR systems, a high power CW source in the submillimeter wavelength range is necessary. Gyrotrons can deliver tens of watts of CW power at submillimeter wavelengths and are well suited for use in DNP/NMR spectrometers. Using a smooth wall interaction structure, whose transverse dimensions are many wavelengths of the operating frequency, gyrotrons have the ability to generate very high power when compared to slow wave microwave tubes such as TWTs or solid state devices. To date, 140 GHz and 250 GHz gyrotrons are being employed in DNP experiments at 200 MHz and 380 MHz spectrometers at MIT. A 460 GHz gyrotron, capable of 8 W of CW output power, will soon be installed in a 700 MHz NMR spectrometer. In this presentation, the present status of compact CW gyrotrons developed for DNP/NMR spectroscopy at MIT will be reviewed. These gyrotrons typically operate at relatively low beam voltage of 12 kV and produce CW power at tens of watts at very high frequency with good power stability. High power radiation with good spectral and spatial resolution from these tubes should provide NMR spectrometers with high signal enhancement. Other promising applications to utilize these powerful CW submillimeter-wave sources, such as imaging and cancer therapy, will also be discussed.

6373-10, Session 2

Electrical domains and submillimeter signal generation in AlGaN/GaN superlattices

V. I. Litvinov, I. Gordion, WaveBand Corp.; A. Manasson, Univ. of Maryland/College Park

The feasibility of a terahertz-signal source made of an AlGaN/GaN superlattice is discussed. Based on miniband parameters that follow from the polarization-distorted band profile, we represented a superlattice as an effective Gunn medium. This allows modeling Gunn oscillations with the help of the commercial Atlas-Silvaco simulator. Negative differential conductivity, electrical domain formation, current oscillations, and power efficiency of a perspective source are described. We relate the superlattice geometry and conduction band profile to the oscillation frequency and power efficiency of the device. We also determine the optimal Al content, the superlattice period, and the parameters of the external circuit that favor sub-millimeter wave generation.

6373-11, Session 2

Spectral properties of very deep zero-order metallic gratings with subwavelength slits at THz frequency region

Z. Tian, Q. Xing, D. Liang, N. Zhang, S. Li, J. Gu, L. Chai, Q. Wang, Tianjin Univ. (China)

To study the reflection and transmission properties of the gratings, a novel system based on terahertz time domain spectroscopy was established. With this system, we have simultaneously measured both the reflection and transmission spectra of the deep zero-order grating with subwavelength slits. In the experiments we found that the enhanced transmission spectra of the grating are complementary to the reflection spectra, which strongly depend on the geometry of the sample, the incidence angle of THz beam and the orientation of the grating slits with respect to the p-polarized THz radiation. The experimental results agree with the theoretical analysis based on the surface plasmon polaritons (SPPs) and waveguide theory.

6373-12, Session 3

Subwavelength plastic fiber for terahertz wave guiding

C. Sun, L. Chen, H. Chen, J. Lu, National Taiwan Univ. (Taiwan)

We report a simple subwavelength-diameter plastic wire, similar to an optical fiber, for guiding terahertz wave with a low attenuation constant. With a large wavelength-to-fiber-core ratio, the fractional power delivered inside the lossy core is reduced, thus lowering the effective fiber attenuation constant. In our experiment, we adopt a polyethylene fiber with a 200 micron diameter for guiding terahertz wave in the frequency range of 0.3 THz in which the attenuation constant is reduced to the order of or less than 0.01 cm-1. Direct free-space coupling efficiency as high as 20% can be achieved by using an off-axis parabolic mirror. The application of the plastic THz fibers will also be discussed in this conference.

6373-14, Session 3

Terahertz sources, sensors, and components: performance and capabilities

G. Chattopadhyay, J. S. Ward, I. Mehdi, P. H. Siegel, Jet Propulsion Lab.

The next generation of space missions with terahertz receivers will require not only detectors with quantum-limited sensitivity and high-power broadband solid-state sources, but also novel low-loss and low-mass waveguide components as well as receiver architectures that are complex yet practical to fabricate and assemble. Solid-state waveguide circuits have now become very much a necessity at terahertz frequencies for their low loss and are in use up to at least 2.5 THz. However, at frequencies beyond a few hundred gigahertz, the feature sizes of all but the simplest waveguide circuits are too small and the required tolerances are too demanding to be fabricated using conventional machining. Moreover, the time-tested techniques at low frequencies of building up complex receiver circuitry by bolting together discrete flanged waveguide components is inadequate at terahertz frequencies due to the losses they incur and the reflections they produce. Therefore, to deal with these issues new thinking in integrated system architecture and component design, development, and fabrication is required to develop the next generation of sensitive receiver systems at terahertz frequencies.

In this review paper, we will discuss the most challenging issues in the development of future receivers for space applications and state of the art sensors and sources at frequencies up to at least 3 THz, a region of the electromagnetic spectrum of great interest in the scientific community. We will also present techniques for fabricating integrated waveguide components at terahertz frequencies by using deep reactive ion etching (DRIE) based silicon micromachining. Silicon micromachining can achieve small feature sizes with large depths and excellent tolerances, making it the most attractive technology for

fabricating waveguide components which require sharp vertical walls that range in depth from 10 μm to ≥ 1 mm. New receiver architectures which are compatible with silicon micromachining techniques and are being developed at JPL for the next generation receivers will also be presented.

The research described herein was carried out at the Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA, under contract with National Aeronautics and Space Administration.

6373-15, Session 3

Toward the modulation of negative index materials by photoconductive coupling

V. J. Logeeswaran, M. S. Islam, Univ. of California/Davis; E. Ponizovskaya, A. Bratkovsky, W. Wu, S. Wang, R. S. Williams, Hewlett Packard Labs.

We investigate the possibilities of modulating the behaviour of negative index materials using a photoconductive coupling through the substrate. Preliminary HFSS simulations undertaken show the feasibility of the approach by the shift in the resonance frequency of the Split-Ring Resonator (SRR). The coupling not only shifts the resonance frequency but decreases the amplitude of transmission by increasing the dielectric losses. The Ultra-fast modulation using the Schottky effects between the SRR resonator metal and the substrate are also being investigated.

6373-16, Session 3

Tailoring quaternary buffer/channel/barrier metamorphic HEMTs for THz operation

R. T. Webster, Air Force Research Lab.; M. Anwar, Univ. of Connecticut

The tailored growth of the buffer, channel, and barrier material in High Electron Mobility Transistors (HEMTs) may allow the realization of devices with unity gain current cut-off frequencies over 200 GHz and maximum frequency of oscillation close to 1 THz. We will demonstrate the theoretical THz performance potential of Sb-based HEMTs with quaternary buffers, channels, and barriers. Calculations for AlGaAsSb/ InGaAsSb/ AlGaAsSb structures will include self-consistent Schrödinger-Poisson solutions for energy bands, band alignment computations, and transport parameters obtained from Monte Carlo simulations for a range of alloy mole fractions. The theoretical calculations will be validated by experimental data obtained from Sb-based Metamorphic HEMTs having quaternary buffers and barriers with ternary channels. This work supported in part by AFOSR.

6373-17, Session 4

Terahertz interferometric imaging of a concealed object

A. M. Sinyukov, A. Bandyopadhyay, A. Sengupta, R. B. Barat, D. E. Gary, Z. Michalopoulou, J. F. Federici, New Jersey Institute of Technology

Terahertz radiation can propagate through nonmetallic, non-polar materials allowing a positive detection of weapons and dangerous agents concealed behind barriers, such as clothing, book bags etc. In addition, many materials of interest for security applications (for example C-4, HMX, RDX, TNT) have characteristic transmission/ reflection spectra in the THz range. Therefore, these materials should appear as different “colors” to the THz detector as compared to non-hazardous items. Among other methods for stand-off THz detection, interferometric imaging is attractive for security screening applications due to a potentially rapid and confident detection of lethal agents with a limited number of THz detectors as well as a compact and inexpensive imaging system based on semiconductor lasers.

We present experimental results of terahertz interferometric imaging of a real object. Continuous waves at 0.25-0.3 THz are used to detect a metal object behind a book bag barrier. The barrier is ~2 mm thick and non-transparent to visible light. Also, this metal object moved behind a barrier has been detected. Only one detector placed at several positions is used to imitate the performance of a detector array. The distance between the target and the detector is ~1 m. Experimental results in both 1D and 2D imaging have been obtained. These results are in a good agreement with theoretical predictions. This is a step to develop a THz interferometric imaging system for stand-off detection of concealed weapons, explosives and dangerous chemical/biological agents.

6373-18, Session 4

Imaging and spectroscopy at terahertz frequencies using hot electron bolometer technology

E. Gerecht, D. Gu, National Institute of Standards and Technology; K. S. Yngvesson, F. Rodriguez, Univ. of Massachusetts/Amherst

Imaging and spectroscopy at terahertz frequencies (defined roughly as 300 GHz - 3 THz) have great potential for both healthcare and homeland security applications. Terahertz frequencies correspond to energy level transitions of important molecules in biology and astrophysics. Terahertz radiation (T-rays) can penetrate clothing and, to some extent, can also penetrate biological materials, and because of their shorter wavelengths they offer higher spatial resolution than microwaves or millimeter waves.

I will describe the development of a novel two-dimensional scanning, passive, terahertz imaging system based on a hot electron bolometer (HEB) detector element. HEB mixers are near quantum-noise limited heterodyne detectors operating over the entire terahertz spectrum. HEB devices absorb terahertz radiation up to the visible range due to the very short momentum scattering times. The terahertz imaging system consists of the front-end heterodyne detector integrated with the state-of-the-art MMIC LNA on the same mixer block. The terahertz local oscillator (LO) signal is provided by a commercial harmonic multiplier source.

6373-19, Session 4

Scene simulation of terahertz images

M. R. Fetterman, W. Kiser, Jr., The Pennsylvania State Univ.

We simulate the images from a terahertz imaging system, using a non-sequential ray-tracing program. These simulated images will be useful for terahertz imaging system design. Also, since few terahertz imaging systems have been experimentally demonstrated, the theoretical images will give insight into the potential benefits of terahertz imaging.

We constructed scenes of a man with a concealed weapon, and of a plexiglas sailboat in the ocean. We assigned material properties to each element in the scene. These material properties included scattering, transmission, and absorptive material coefficients, taken from the literature. Then, we used a non-sequential ray-tracing program to propagate light through the scenes. Our model gives effective antenna temperatures and is accurate from a radiometric point of view. We modeled the detector as a focal plane array, including the effects of noise and the diffraction resulting from a finite aperture size.

We simulated the scenes with different illumination sources. For the case of the man with the concealed weapon, in one scenario, the dominant source of radiation was the man’s heat. In the second scenario, the man was incoherently illuminated by uniform lighting, and by a spot light. We also modeled coherent illumination sources. We will discuss the assumptions made in the simulations and compare our results to available experimental results.

6373-20, Session 4

Si-based tunnel junction devices for sub-terahertz communication and imaging

P. R. Berger, The Ohio State Univ.; P. E. Thompson, Naval Research Lab.

Quantum functional circuits based on negative differential resistance (NDR) devices, such as tunnel diodes, have superior performance to those based on conventional circuits in terms of higher speed operation and lower power consumption. Many quantum functional circuits for high-speed mixed-signal, low-power consumption memory, and ultra-fast logic applications have already been demonstrated using III-V-based NDR devices. However, such technology is not readily compatible with the mainstream platforms of CMOS and heterojunction bipolar transistor (HBT) technologies. Recently, we demonstrated the successful monolithic integration of Si-based resonant interband tunnel diodes (RITD) with CMOS and SiGe HBTs, which makes them more attractive than III-V based tunnel diodes for large scale system level integration.

Here, we report on Si-based RITDs with high resistive cutoff frequencies (fr0), ultra-high peak current densities (PCD), and a world record speed index for any Si-based tunnel diode. The resistive cutoff frequency is significantly higher than previous reports of Si-based tunnel diodes and enables mixed-signal and RF circuit applications for the first time, such as analog-to-digital converters, voltage-controlled oscillators, and ultra-fast logic circuits. A more detailed discussion of the issues associated with high fr0 performance for Si-based tunnel diodes will be discussed. Also, some discussion of Si-based diodes for passive millimeter wave imaging systems will also be introduced.

6373-21, Session 5

Quantum cascade lasers from quantum design to a high performance technology for mid-infrared and THz photonics

F. Capasso, Harvard Univ.

The unipolar nature of these devices combined with the capabilities of electronic and photonic bandstructure engineering leads to unprecedented design flexibility and functionality compared to other lasers. Topics to be discusses also include: nonlinear optical QCLs based on the integration within the active region of a nonlinear optical element with giant nonlinear susceptibilities with high conversion efficiency, coherent instabilities and self-modelocking in Terahertz QCLs, ultrabrodband devices, photonic crystal QCLs and optofluidic lasers. The talk will conclude with applications to chemical sensing and trace gas analysis along with the ongoing commercialization of this technology.

6373-22, Session 5

THz-photomixer based on vertical quasi-ballistic transport

G. H. Döhler, S. Preu, F. Renner, M. Eckardt, A. Schwanhäusser, S. Malzer, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany); M. P. Hanson, A. C. Gossard, J. Chan, E. R. Brown, Univ. of California/Santa Barbara; L. J. Wang, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany); G. Loata, T. Löffler, H. G. Roskos, Johann Wolfgang Goethe-Univ. (Germany)

The standard photoconductive photomixers based on low-temperature-grown- (LT-)GaAs or GaAs with ErAs islands take advantage of the short recombination lifetime of photo-generated carriers in these materials [1]. These short recombination lifetimes (ca. 150 fs) determine the roll-off frequency of about 1 THz and limit the photoconductive gain to values < 10-2. This implies very low conversion efficiency. In pin-photomixers all the photo-generated carriers can fully contribute to the photocurrent. However, they still suffer from RC- and transit time roll-offs, even for the most advanced version, the “uni-traveling-carrier” (UTC) mixers [2]. We have recently developed a new concept for THz-photomixers [3], which overcomes these (intrinsic) drawbacks. In this contribution we present the concept and recent experimental results.

Our photomixers consist of a periodic sequence of nano-pin-diodes (forming a “nipnip-hetero-superlattice” with a bandgap grading in the pin diodes). Electron-hole generation in the pin diodes takes place in the region of lowest bandgap close to the p-layers. Thus, the photo-current is mostly due to the (light) electrons. In order to optimize both the THz-photo-current and the THz-photo-voltage, the length of the intrinsic layer is chosen such, that the i-layer thickness corresponds to the maximum distance over which an electron can propagate quasi-ballistically within a time of flight corresponding to about 1⁄2 THz-period. By appropriate choice of the number of superlattice periods the capacitance of the mixer can be adjusted independently to avoid RC roll-off.

For the realization and optimized performance of the photomixer it is crucial that the electrons and holes generated in the nano pin-diodes and accumulating in the n- and p-layers, respectively, screen the built-in electric field such that the potential drop in the pin-diodes oscillates around the value at which intervalley scattering sets in. This implies extremely high recombination current densities of about 10 to 100 kA/cm2 at a photo-induced “internal forward bias” of about 1 V in the “recombination-pn-diodes” (whereas the external bias is zero or close to zero!). We achieve these high current densities by introducing (quasi-metallic) ErAs- or LT-GaAs recombination layers into these diodes. Our experimental results confirm that under optimized operating conditions the transport in our mixers, in fact, becomes ballistic.

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6373-23, Session 5

Photonic terahertz-wave generation using uni-traveling-carrier photodiodes

H. Ito, Nippon Telegraph and Telephone Corp. (Japan)

(Invited paper) The generation of continuous THz-waves using photonics technology is promising since it offers extremely wide bandwidth, the capability of long-distance signal transmission through low-loss fibers, and a very simple configuration. Especially, the use of a long-wavelength (1.55 um) light is important because we can use various optical components developed for optical communications systems. The uni-traveling-carrier photodiode (UTC-PD) is a promising solution for such requirements. In this paper, our recent results on THz-wave generation using UTC-PDs is described.

The UTC-PD has a unique mode of operation where only electrons are the active carriers. This is the key to achieving high speed and high saturation output powers simultaneously. To date, a record 3-dB bandwidth of 310 GHz and a record output power of over 20 mW at 100 GHz for PDs operating at 1.55 um have been achieved.

There are two approaches to generate sub-millimeter-waves using a UTC-PD. One is to use a waveguide-output module, and the other is to use a quasi-optic configuration. For the former, we have demonstrated an overmoded operation of F-band waveguide-output UTC-PD modules at frequencies of up to over 0.8 THz. For the quasi-optic approach, we have fabricated a log-periodic-antenna integrated UTC-PD and fabricated a quasi-optic module using a Si lens. Using this module, signal output of up to 1.5 THz (record frequency) has been achieved. The maximum output power is 2.6 uW at 1.04 THz. To further increase the output power, we fabricated a twin-dipole resonant-antenna integrated UTC-PD and obtained a record output power of 10.9 uW at 1.04 THz.

6373-24, Session 6

Coherent CW THz transceivers

E. Mueller, Coherent, Inc.

As the field of THz Photonics has been rapidly been advancing a great deal of work has been performed in THz imaging utilizing short-pulse broad-band THz transceivers. More recently groups have begun to do similar imaging work with cw THz sources. While much of that work has utilized incoherent detectors, some activities have started to use fully-coherent transceivers to realize more than 10 orders of magnitude of improvement in available dynamic range. This presentation will provide an overview of THz technologies with an emphasis on fully-coherent cw transceivers. Background motivation for cw imaging will be presented along with cw THz images in both amplitude and phase-contrast space.

6373-25, Session 6

Extraordinary terahertz transmission of subwavelength plasmonic structures

W. Zhang, A. K. Azad, Oklahoma State Univ.

To localize and manipulate electromagnetic waves below wavelength scale has been the challenging work in science and technology. It represents a revolutionary new direction in photonics and will lead to the development of ultracompact integrated photonic components. Recent discovery of extraordinary transmission of light in periodic subwavelength hole arrays is attributed to the resonant excitation of surface plasmon polaritons (SPPs) at the metal-dielectric interface. We present experimental studies of extraordinary terahertz (THz) transmission through subwavelength plasmonic structures patterned on both metals and semiconductors. Transmission efficiency higher than unity is achieved when normalized to the area occupied by the holes. The incident THz radiation is coupled into the holes in the form of SPPs which are squeezed through the holes and then converted back into THz wave on the far side of the film. The effects of hole

shape, dielectric function of metals and surrounding media, polarization dependence, and array thickness on the enhanced THz transmission are demonstrated by use of THz time-domain spectroscopy. In addition, extraordinary THz transmission is realized with metallic arrays having thickness of only one-third of the skin depth. THz surface plasmon resonance has potential applications in THz imaging, biosensing, interconnects, and the development of next generation photoconductive antennas for THz generation and detection.

6373-26, Session 6

Surface plasmon modes for metal-clad optical and terahertz waveguides

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The emerging terahertz (THz) technology opened up a new frontier of fundamental research and many novel applications, such as imaging and spectroscopy. The THz frequency region is a large portion of the electromagnetic spectrum located in between the traditional microwave and the optical frequencies, offering significant technological potential but remaining practically unexplored. Recent progress in the sources and receivers of THz waves has generated much interest in the guidance of these waves, either as an integral part of a device, such as a laser, or to interconnect various components.

Amongst the various THz waveguides, so far the metal-coated or metal-clad dielectric guide supporting surface plasmon modes are showing the greatest promise. The relative permittivity of a metal is complex and predominantly negative and the TM-polarized surface plasmon mode (SPM) can be supported only at these metal dielectric interfaces, where the magnetic field is tangential to the interface. To date, most of the research into these structures has had a strong experimental basis [1]. Although, the modal solutions of the simple slab waveguides can be obtained by solving a complex transcendental equation, however for the solution of the SPMs supported by a practical waveguide with two-dimensional confinement, a rigorous full-vectorial numerical method would be necessary.

Optical modes in a high-index contrast metal-clad guide with a two-dimensional confinement are also hybrid in nature, with all six components of the E and H fields being present. To characterize accurately such waveguides, a full-vectorial approach is necessary and such a H-field based full vectorial approach has recently been extended to study the polarization dependence of such waveguides. The modal solution approach based on the powerful finite-element method (FEM) [2] is more flexible, can represent any arbitrary cross-section more accurately and has been widely used to find the modal solutions of a wide range of optical waveguides.

The fundamental and higher order surface plasmon modes in two- and three-dimensional optical waveguides will be presented in this paper. The modal solutions of the metal-clad THz waveguides supporting SPMs will also be presented. The propagation constants, attenuation characteristics, full-vectorial modal field profiles, the spot-size, and the formation of the supermodes by coupling SPMs at the interfaces will also be demonstrated.

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6373-27, Session 6

Research progress of terahertz wave technology in food safety

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Food safety concern has become more and more significant in recent years. Terahertz (THz) wave technology, as a new aera of research, has shown its wide prospects in imaging, diagnosis, detection, and monitoring, etc. The two main applications in which THz fields are involved are THz spectroscopy (TDS) and THz imaging. In this paper, a brief review is given to summarize the progress of THz techqiues in the field of food safety and the problems existed, and is focused on the applications in the determination of food contamination.

6373-39, Poster Session

Effect of microwave radiation on the stability of terahertz hot-electron bolometer mixers

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Currently, the integration time of terahertz receivers based on hot-electron bolometer (HEB) mixers is limited to less than 5 seconds. Unfortunately, integrating beyond this limit is ineffective in part because of fluctuations in the local oscillator (LO) coupling, which in turn causes the drift of the operating current of the mixer. In order to compensate for the drift of the operating point we propose the injection of additional microwave radiation, together with terahertz radiation, with the aim of improving the performance of the receiver. As our experiments have demonstrated, the substitution of microwave radiation for terahertz radiation up to ~ 15 % relative to the optimum LO power level has not resulted in significant deterioration of the noise temperature and the gain of the HEB mixer. So, the realisation of the proposed method holds great potential of enhancing the capabilities of a receiving system with an HEB mixer in it.

6373-28, Session 7

Microwave generation by Josephson vortex motion in stacked high-T_c intrinsic junctions

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A stack of Bi$_2$Sr$_2$CaCu$_2$O$_{8+x}$ (Bi-2212) containing N intrinsic Josephson junctions (IJJs) exhibits N eigen collective transverse plasma (CTP) modes, which can be excited by the moving Josephson vortex lattice (JVL) that forms in a high magnetic field. If the frequency of the temporal oscillation of the phase difference across a junction due to moving JVL matches with that of a transverse plasma mode, a resonant plasma oscillation is excited with microwave emission at the boundary of stacked IJJs. We report the observation of the CTP modes induced by the JVL motion and the excitation of corresponding electromagnetic waves in a stack of IJJs in Bi-2212. The existence of the CTP modes was confirmed by observing the multiple branches in the tunneling current-voltage curves of stacked junctions in the Josephson vortex-flow region. In addition, for a proper bias, the emission of the electromagnetic waves by the collective vortex resonance motion in a stack of IJJs (the oscillator stack) was examined using another stack of IJJs (the detector stack), which was placed within a fraction of μm from the oscillator stack. The microwave emission from the oscillator stack and the resulting irradiation onto the detector stack was evidenced by the suppression of the tunneling critical current revealed in the quasiparticle branches and the increase of Josephson vortex-flow voltages in the detector stack. Our numerical calculation for the effect of microwave irradiation on the detector stack was also consistent with our observed results.

6373-29, Session 7

Ultrafast kinetic inductance samplers

C. J. Stevens, Univ. of Oxford (United Kingdom)

We report developments of kinetic inductance samplers in high temperature superconducting microbridge structures. These devices allow direct sampling of ultrafast voltage signals in superconducting devices without the requiement for additional materials such as photoconductors. The time resolution and frequency performance are investigated and a simple model based on hot electron relaxation used to determine optimum performance.

6373-30, Session 7

A 1.5-THz hot electron bolometer receiver for ground-based terahertz astronomy in northern Chile

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A 1.5 THz superconducting receiver has been in operation since Dec. 2004 at the RLT telescope in Northern Chile. This receiver incorporates a Hot Electron Bolometer mixer chip based on an NbTiN thin film, mounted in a precision-machined waveguide mixer block with corrugated horn assembly. With a noise temperature of around 1500 K, this receiver is sensitive enough for use in our pioneering work in the

field of ground-based Terahertz astronomy. This receiver employs a number of innovative techniques, including near-field vector beam mapping, and the use of a tunerless planar diode based Local Oscillator unit capable of generating ~10 micro-watts at 1.5 THz. In this paper, we will report on the design, set-up and operation of this state-of-the-art instrument.

6373-31, Session 7

THz signal generation/propagation in an integrated traveling-wave superconductive/photoconductive heterodyne photodetector

A. H. Majedi, Univ. of Waterloo (Canada)

An integrated traveling-wave superconductive transmission line with photoconductive substrate is introduced as an optoelectronic waveguide. This device combines the ultrafast photoconductivity effect in some semiconductors with ultrafast and braodband photoresponse in some High-Temperature Superconductors (HTSs) to perform THz optoelectronic functions such as signal generation and propagation. HTS thin films on both sides of the photoconductive substrate can form an optical multilayer waveguide in which the HTS thin films can be used to transmit high-frequency electrical signals. If the herodyne optical signal is fed to the waveguide, the coexistence of photoconductive response in semiconductor substrate and HTS thin films photoresponse can produce beat electrical signal which can be transmitted via HTS transmission line. The copropagation of optical wave and THz signal makes this device as a fully-integrated traveling-wave which does not suffer from bandwidth limitation in conventional lumped photodetectors.

In this paper, we introduce a systematic analysis and design of optical waveguide along with THz transmission lines to maximize the THz signal power. An optical propagation analysis in lossy waveguides can be used to extract the optical propagation constants and the cuttoff wavelengths for different propagation modes in an HTS/photoconductive multilayer structure. Subsequently, the frequency-domain modified transmission line is developed for calculating the photo-induced THz signal in the structure.

The proposed device can be a new platform for integrated optoelectronic devices with specific applications in THz signal generators, mixers and switches.

6373-32, Session 7

THz radiation from intrinsic Josephson junctions of Bi-2212 single crystals

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Microwaves can be generated by using of Josephson junctions[1]. The mechanism is based on the ac Josephson effect, and the modes excited are tuned by the geometrical resonance in the Josephson junction of the length L as f_n=nc*/2L, where f is the frequency, c* is the velocity of the microwave in the junction and n=1, 2, 3,... This can be seen by the I-V characteristics of the junction as Fiske steps. Recently, beautiful Fiske steps have been observed in the intrinsic Josephson junction such as high Tc superconductor Bi-2212. However, the observed microwave power is unexpectedly tiny as low as 10^-12 W, which corresponds to the order of single junction. This means that the phases between stacked layers are not coherently working. Furthermore, the frequency is limited up to 300 GHz at L=1 micron because of slow Swihart velocity.

Recently, the dynamical effect of Josephson vortex flow is expected to generate THz waves[2]. According to this the anisotropic radiation power is observed by the bolometer detector as expected. However, the power of THz radiation directly measured is much low, indicating poor efficiency of radiation out of the junction due perhaps to the impedance mismatch. We argue results obtained by experiments so far to improve and to remove these difficulties.

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6373-33, Session 8

Terahertz comb radio frequency generation in nonlinear optical devices

E. J. Donkor, Univ. of Connecticut

We describe a method for generating terahertz signals using two semiconductor laser diodes and a semiconductor optical amplifier. The two laser diodes are driven such that one of them operates below its lasing threshold whereas the other operates above the lasing threshold. The lasing diode signal serves as the carrier. The sub-threshold laser produces spontaneous emissions over a wide band and serves to generate sidebands. The output signals of these lasers are multiplexed together and fed to a semiconductor optical amplifier incorporated in a fiber loop circuit in which the two laser diode outputs beat together. As a result a comb of radio frequencies are generated inside the loop circuit. The number of comb frequencies and the spacing between adjacent combs depends on the loop circuit parameters. We shall describe the key design parameters and present experimental results for a 2THz comb frequencies span with frequency separation of 200GHz.

6373-34, Session 8

Terahertz quantum cascade lasers

E. H. Linfield, A. G. Davies, Univ. of Leeds (United Kingdom)

We will review recent developments in terahertz frequency quantum cascade lasers, and discuss the state-of-the-art in the international community. In particular, we will outline developments over the last two years in the design, growth and fabrication of quantum cascade lasers on the European Framework VI programme, 'TeraNova', together with the design and construction of a terahertz frequency cascade-laser-based 3D imaging system on a Research Councils UK Basic Technology programme.

We will also discuss in detail our own work in this field at the University of Leeds, including the optimisation of the cascade laser structure itself, and the use of cascade lasers for terahertz spectroscopy and imaging applications. As examples, we will discuss how the molecular beam epitaxial growth is optimized for high performance quantum cascade laser operation, and how post-growth patterning of the laser structure can be used to select specific output frequencies for spectroscopic applications.

6373-35, Session 8

Development of double negative metamaterials in the THz regime

A. Akyurtlu, N. Wongkasem, K. A. Marx, Univ. of Massachusetts/Lowell

Materials that support strong, tunable magnetic and electric properties in the terahertz (THz) frequency range have wide range of applications in security screening, medical imaging, and remote sensing. To assemble the metamaterials (MTM) at a THz or higher frequency by scaling down the dimensions, the main challenge is in the difficulty of the fabrication process. Consequently, we propose and demonstrate a model of spilt-ring resonator(SRR)/wire composite MTM which can create a double-negative (DNG) passband approximately two and a half times higher than those of the conventional SRR/wire structures, by using the same dimensions. In this case, the magnetic field is parallel to the plane of the SRR so that the propagation direction is normal to the plane and the electric field is parallel to the gap-side of the SRR. Increasing the size of the structure will significantly improve the fabrication procedure when we deal with devices at high frequencies. The new SRR/wire structure can produce a broad passband - nearly two and a half times larger than those of the primary models. In this presentation, we demonstrate the theoretical design and experimental validations of DNG metamaterials in the THz regime. Furthermore, a novel structure which demonstrates not only DNG properties but also chirality will be presented. Unlike other fields in electromagnetics which try to eliminate the cross-polarization, the form of handedness sensitive rotation of the polarization state and elliptization of visible light diffracted from the chiral structures appeals to the optoelectronic technologies such as photonic bandgap crystals and microsculptured films.

6373-36, Session 8

Mask repair using layout based pattern copy for the 65-nm node and beyond

V. A. Boegli, NaWoTec GmbH (Germany)

Recent advances in mask repair technology have slowed the projected cost explosion in mask production. As we progress towards the 45nm node, electron-beam induced deposition and etching has proven to be the most likely candidate capable of meeting the stringent repair specifications. This technology employs a method frequently called “pattern copy”, which derives the repair structure by comparing a high-resolution image of the defective area with the same image of a non-defective area. The repair shape is generated as the difference of these two images, and adjusted for processing purposes.

Traditionally, the pattern copy reference image is taken from the mask under repair. For this method to work, a suitable area containing a non-defective feature, identical to the defective feature, has to be identified on the mask and imaged. In general, this works well, however there are several drawbacks. For one, all the inaccuracies of the reference feature, like line edge roughness (LER), CD error, and imaging artifacts will be transferred to the repaired spot. Secondly, a slight variation from the target size of the scan field is not noticed and leads to additional CD error after repair. Furthermore, logic designs make it hard to find identical reference areas, especially for larger defects.

To overcome these drawbacks, we have developed layout based pattern copy (“die-to-database”). In this case, the reference is generated using information taken from the original mask design file. This is the file which was used to write the mask in the first place, and it contains the exact reference information we need to perform a pattern copy step. We create an image of the features inside the applicable field of view, and render this image according to a specified set of criteria, with the aim to make it look exactly like the image taken from the mask. The rendering step is necessary to emulate and compensate the basic characteristics of mask writer, manufacturing process, and image formation in our e-beam tool. The pattern copy process then continues as usual, only with the “ideal” reference image instead of the “real” reference image from the mask. As a result, we achieve a reduction in the CD error of repaired features, with the side benefit of greatly improved work flow, since the reference is automatically generated and aligned to the defect.

In this paper we compare mask repair using conventional pattern copy (reference taken from the mask) to layout based pattern copy, and demonstrate the overall improvement in repair quality. This is manifested in reduced CD variation of repaired features, and verified by CD-SEM as well as AIMS(tm) measurements. We also highlight the improvements in work flow, and show the potential of further automation in the repair process.

Sunday-Tuesday 1-3 October 2006

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6374A-01, Session 1

Laser motor

H. Okamura, International Christian Univ. (Japan)

Introduction

There have been many reports of manipulating objects by light. Properties of light such as heat deposit, ablation, and radiation pressure are used for these applications. These applications can be regarded as conversion of light energy into mechanical energy, however, if you consider the energy conversion efficiency, it is usually very small.

As an example, optical tweezers can trap a small dielectric material at the focus of a laser beam, and by shifting the focal point one can manipulate the object (ref. 1&2). Manipulation of atoms is also realized and is used for laser cooling (ref. 3&4). These techniques cannot be used to manipulate macroscopic objects because the force is extremely small.

The reason why optical tweezers cannot produce large force is that it utilizes the momentum of light. It is a well-known fact that light has energy and momentum. The energy of light and momentum are given by E = h?, and p = h/? = E/c, respectively. Since c is a very large number, p becomes much smaller than E. In the case of optical tweezers, the momentum of light is utilized and not its energy. Light retains most of its energy after interaction with matter. One might as well say it is the entropy of light that creates forces in this case. Therefore, if one wants to manipulate a macroscopic object one has to convert the energy of light into mechanical energy.

The energy of light is actually large enough to manipulate macroscopic objects. Commercial laser oscillators of more than 10W of output power are easily obtainable. This is a power capable of accelerating a 1kg object to 5m/s in one second. If in some way an efficient conversion of light energy into mechanical energy is realized various new applications will become feasible. NASA's laser plane will be a good example to illustrate the possibilities (ref. 5). This is a model airplane that is propelled by a laser beam. The light energy is converted to electrical energy by a solar panel. It does not need to carry any fuel and can fly for unlimited time as long as the laser beam is tracking the airplane.

In the case of NASA's application energy is converted to electrical energy and drives a motor. If one can do the same thing without first converting to the electrical energy it would not only offer potentially higher energy conversion efficiency but also offers much lighter motor, which would lead to applications such as micro robots. The question is, is it possible to convert light energy efficiently to mechanical energy? In this report we would like to propose a new scheme for a potentially efficient light-driven actuators, which convert light energy into mechanical energy directly.

Method

As is evident from the above discussions, if one wants to manipulate macroscopic objects by light, it has to use the energy of light, not its momentum. This seems to be suggesting that a second object which is in physical contact with the first object is needed other than the object that is being moved, and the second object absorbs light and induces a relative motion between the two objects.

One possible scheme for realizing this, that we are proposing here, is to induce acoustic waves in the second object with light pulses. It is known that laser can induce acoustic waves in solids (ref.6). The light energy is first converted to the energy of vibrations and then it is used to move the first object. The irradiation timing of laser pulses are tailored and induce desired elastic wave. By changing the schedule of light irradiations one can control the speed and direction of the motion.

This method has an advantage that the light doubles as the method to convey energy and the control signal. In the case of NASA's light plane, light is used to transmit just the energy, so the control of a motor has to be done by a separate channel of transmission such as a radio wave.

Conclusion

We showed that a conversion of light energy into mechanical energy will potentially be used to manipulate macroscopic objects. The light energy has to be absorbed and therefore it would require at least two objects to induce relative motion between the two objects. We proposed a new scheme that uses pulsed light to induce acoustic wave for the energy conversion. The induced elastic wave is then used to move the other object. This can potentially lead to light-weight, efficient light-driven actuators.

6374A-02, Session 1

Light driven polymer actuators for propulsion and light control

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New light-driven actuators based on polymer films are described. The actuators employ the photomechanical bending of the polymer film caused by low power (10 mW and less) laser radiation. The photomechanical effect combines various physical mechanisms, such as anisotropic thermal expansion, converse piezoelectric mechanism along with photovoltaic and pyroelectric ones, while the mechanism of thermal expansion is dominant for slow motion. The static force applied by the actuators to external objects was measured with a torsion balance. It is proportional to the power of laser beam and could be as high as 10-4 N for a 50-micron film illuminated with a 10-mW laser beam. The frequency of the periodical motion of the actuator is inversely proportional to the square of its length. For millimeter-size actuators, frequency reached 1 kHz. Possible applications of the actuators to propulsion and light control are discusses. Experimental adaptive optics components, such as wavefront correction mirrors, photonic switches, and micro-motors are discussed.

6374A-03, Session 1

Positioning control of nafion-Au ionic polymer metal composite: the effect of the driving ion on the deformation patterns of IPMC

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Nafion based Ionic Polymer Metal Composite (IPMC) is one of the promising plastic actuator for artificial muscle. The positioning control of IPMC, however, is generally considered very difficult since the initial deformation of IPMC decreases rapidly. In this study, the deformation patterns of the Nafion (N117, NF115, NF112) based Au plated IPMC was investigated. If the Nafion film is thinner, or if the concentration of the Na+ driving ion is lower, IPMC shows the following "reverse direction" type deformation pattern. In this case, if a step voltage is applied to the IPMC, IPMC initially deforms to the positive electrode side, then the displacement was gradually decreased, and the residual deformation is finally appeared to the negative electrode side. The other deformation pattern is "same direction" type one. In this case, if the Nafion film is thicker or if the concentration of the Na+ ion is higher, IPMC first deforms to the positive electrode side, then the displacement was slightly decreased and the residual displacement is appeared to the same positive electrode side. The same direction type IPMC can be controlled its displacement by the common integral control method. In the case of the reverse direction type, the displacement can also be controlled by the integral control method if the changing speed of the application voltage is regulated to avoid the generation of the initial deformation. The direction of the displacement and the applied voltage is contrary between these two types. The control properties and the conditions are examined into details.

6374A-04, Session 1

Optical driving of actuator using poly-vinylidine difluoride cantilever

Y. Mizutani, S. Nishimura, Y. Otani, N. Umeda, Tokyo Univ. of Agriculture and Technology (Japan)

An optically driven actuator has a feature of a non-contact for applying

light energy remotely. We propose a new optical driving of actuator with three Poly-Vinylidine DiFluoride (PVDF) cantilevers as a leg and polymer film as a body. The cantilevers are made of PVDF coated with silver on one surface. The PVDF is ferroelectric polymer with pyroelectricity and piezoelectric effect. When laser is irradiated on one side of the cantilever, electric field is charged along cross-sectional field. A mechanical distortion caused by piezoelectric effect is occurred. We measure time response and generative force of the cantilever. The optically driven actuator is moved by its slip-stick effect.

6374A-05, Session 2

Orientation-independent differential interference contrast microscopy

M. I. Shribak, S. Inoue, Marine Biological Lab.

The image in a regular DIC microscope reflects the orientation of the prism shear direction and the optical path gradients in a phase specimen. If the shear direction lies parallel to the specimen boundary no contrast is generated. Also a bias retardance is generally introduced, which creates a gray background and reduces image contrast. Here we describe the theoretical foundation for a new DIC technique, which records phase gradients independently of their orientation and with the digitally generated gradient magnitude image as well as the optical path distribution image free from the gray background. Separate images can show the magnitude distribution of the optical path gradients and of the azimuths, or the two images can be combined into one picture e.g., with the brightness representing magnitudes and color showing azimuths respectively.

For experimental verification of the proposed technique we investigated various specimens such as glass rods embedded in Permount, Siemens star nano-fabricated in 90-nm thick silicon oxide layer, Bovine pulmonary artery endothelial cell, etc, using regular DIC optics on a microscope equipped with a precision rotating stage. Several images were recorded with the specimen oriented in different directions, but with the prism bias unchanged, followed by digital alignment and processing of the images. The results demonstrate that the proposed DIC technique can successfully image and measure phase gradients of transparent specimens, independent of the directions of the gradient. The orientation-independent DIC data obtained can also be used to compute the quantitative distribution of specimen phase or to generate enhanced, regular DIC images with any desired shear direction.

We are currently developing a new device using special DIC prisms, which allows the bias and shear directions to be switched rapidly without the need to mechanically rotate the specimen or the prism (US Patent Application 2005-0152030). With the new system an orientation independent DIC image should be obtained in a fraction of a second.

6374A-06, Session 2

Analysis of mechanical characteristics by birefringence microscope

M. Ebisawa, Y. Otani, N. Umeda, Tokyo Univ. of Agriculture and Technology (Japan)

Mechanical properties of polymer and bio materials have interesting characteristics in fields of a chemical industry and a?\@mechanical engineering. There are requirements to analyze change of internal structure in stress. Many samples in various stress conditions give us interested information analyzed by a microscopic birefringence measurement. We propose a birefringence measurement system for visualization of internal structure and to analyze the relation between given stress and birefringence distribution. This measurement system consists of a He-Ne laser, polarizers, half-wave and a quarter-wave plate. We can obtain retardation and azimuthal angle of birefringence by changing combination of rotating angle of half-wave plate, quarter-wave plate and analyzer.

6374A-08, Session 2

Simultaneous measurement of nanometric longitudinal displacement and micrometric lateral displacement by using one line CCD camera

M. Adachi, Y. Nishide, Kanazawa Univ. (Japan)

The Michelson interferometer using a dual-frequency laser is known as an optics system to accomplish a heterodyne detection technique of nanometric displacement. This accurately measures displacement over a wide range with long working distance and is used in many kinds of precision engineering field. However, this measures only one component of displacement. When longitudinal displacement and lateral displacement are required to be measured simultaneously, two heterodyne-detection systems should be used.

This paper proposes a displacement measurement technique of 2 components by using a frequency-stabilized laser and one high-speed line CCD camera. A laser beam is divided to two beams as the Michelson interferometer. One beam is reflected by a corner reflector working as a reference mirror, and the other beam is also reflected by another corner reflector attached on an object moving mainly along the beam direction (z direction). The reflected two beams are superimposed and expanded by an objective lens. Then, the expanded beams pass through both a wedge-shape birefringent plate and a polarizer making an interference pattern has lateral fringes. This fringe pattern has a single peak in an envelope curve of light intensity change. With this optical layout z-displacement (along the beam) of the object changes fringe phase while keeping a fringe envelope curve, and x-displacement (along perpendicular direction to the beam) of the object moves fringe envelope curve laterally while keeping fringe phase. Therefore, capturing the fringe pattern with a high-speed line camera and extracting phase change and the peak position of the fringe envelope curve, we can simultaneously measure nanometric z-displacement and micrometric x -displacement with a long working distance.

From our experiments using 2048-pixel line CCD camera with a frame rate of 10KHz, z-displacement of the object was measured with nanometric resolution and x -displacement was measured with few-micrometer resolution with every 0.1msec time interval.

6374A-09, Session 2

High-sensitive MEMS acoustic sensor using PMN-PT single-crystal diaphragm

S. Lee, H. J. Kim, K. Park, Electronics and Telecommunications Research Institute (South Korea)

As the telecommunication technology grows, mobile terminals such as PDP and PMP are required to have higher quality of image, video, and sound. Beyond the human voice communication, sound contents are extended to natural musical range. In order to transduce higher quality sound signal, more sensitive acoustic sensors are needed.

Condenser type microphone is most available. It has the advantage of high quality and low cost for manufacturing. However, it has the disadvantage of high bias voltage requirement, and it still has difficulties to cover both high and low frequency range simultaneous.

In this paper, we propose high sensitive acoustic sensor for mobile terminal. In order to increase the sensitivity we used PMN-PT single crystal material as a diaphragm. It has bigger dielectric coefficient than other piezoelectric materials. And we also design multi-channel structure to cover from low frequency to high frequency characteristics. The manufacturing processes are as follows. PMN-PT thin wafer is glued to silicon wafer. From back side etching, PMN-PT single crystal membrane is acquired. Bottom electrode is patterned at the back side silicon. In order to control the natural frequency of diaphragm, we control the membrane thickness with dry etching. After dry etching, we deposit a metal layer and pattern the electrode. With this process, higher sensitive PMN-PT diaphragm is obtained. 4-channels acoustic sensor is manufactured. Each channel has its different frequency range which covers broad frequency range. From the experimental results of sensitivity, diaphragm deflection measurement, the feasibility is proved.

6374A-10, Session 3

PMN-PT piezoelectric near field optical probe for data storage

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We report a novel probe which allows near-field optical data storage with a spatial resolution below the Abbe limit. For the development of the new near-field optical cantilever probe, we use a new generation

oxide material known as relaxor ferroelectrics that exhibit extraordinary piezoelectric properties. The material, the single-crystal solid-solutions (1-x)Pb(Mg1/3Nb2/3)O3-xPbTiO3 (PMN-PT), has been shown to possess piezoelectric coefficients and electromechanical coupling responses significantly larger than conventional ceramics. Thus, a four-fold enhancement in piezoelectric coefficients (up to d33 = 2,000 pm/V) and much higher efficiencies in electrical to mechanical energy conversions (better than 90% as opposed to 60%) have been found.

The near-field optical writing with normal NSOM (near-field scanning optical microscope) probes uses tapered optical fibers having sub-wavelength optical apertures. The optical probe must be within about 10 nm of the sample surface. This is accomplished in most NSOM systems by using a sophisticated shear-force detection system to regulate the gap between the probe and the surface. Recent attempts using AFM cantilever-style probes have shown improved transmission efficiency although fabricating such a high-throughput-aperture on a traditional silicon cantilever tip remains a major challenge for the AFM cantilever-style near-field optical tip technique. To take the advantages of the cantilever-style probe fully, a high-throughput aperture need be patterned on the silicon cantilever directly. Furthermore, the cantilever tip motions must be controlled like AFMs. Therefore, one of the drawbacks is in the complexity of the system design since it would use two optical beams for the writing and the cantilever position control. In this research, by the use of an advanced relaxor ferroelectric material (PMN-PT) and MEMS fabrication process, we propose a piezoelectric cantilever-style probe having a high-throughput aperture with embedded deflection sensor. The high throughput is achieved from the fact that the PMN-PT thin film is transparent and suitable for making high numerical aperture (NA) micro-lenses.

In this paper, we describe the fabrication of the prototype near field optical cantilever probe using PMN-PT single crystal material. The prototype probes is miniaturized through the fabrication of freestanding single crystal PMN-PT films and patterning them by photolithography, chemically assisted ion beam etching (CAIBE) and focused ion beam (FIB) machining processes. We were able to successfully fabricate 10 * m PMN-PT micro-lenses with less than 100nm apertures. Furthermore, the integration of the cantilever with embedded deflection sensor allows more reliable and better control of the aperture-sample distance than that obtained by traditional NSOM shear-force detection method.

Initial tests done in our laboratory have shown that the prototype relaxor ferroelectric-based microlens yields the output beam strength of 1.83*10-7 through a 50nm aperture. In addition, a PMN-PT cantilever with embedded sensor was tested in our lab. The cantilever was mounted on a homemade AFM stage and non-contact mode scanning tests were conducted. We were able to find that the cantilever with embedded deflection sensing mechanism effectively regulates the gap between the probe and the surface.

6374A-11, Session 3

Real-time high-displacement amplified bimorph scanning mirror

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Introduction:

This paper provides an overview of recent research in the use of MEMS actuators for beam steering applications, including optical coherence tomography (OCT). Prototype scanning devices have been fabricated out of polyimide substrates using conventional integrated circuit technology. The devices utilize piezoelectric bimorphs to mechanically actuate a torsion mirror structure made of polyimide. The material properties of the polyimide allow very large scan angles to be realized in the devices while using low voltages.

Method:

The device is a table with an attached mirror suspended between two small torsion hinges. These torsion hinges are fixed at one end to the support structure. The devices were designed with several different table sizes (2 mm by 2.25 mm and 1mm by 1.25mm). The hinges of the structure are 3um thick, 250 long, and of three varying widths (90um, 135um and 180um). The mass of the mirror and width of the hinges was varied in the prototype devices allowing us to develop devices of different resonant frequencies for use in real time imaging systems. The mirrors used for all of the devices are made of gold-coated single crystal silicon. The table and attached mirror pivot about the torsion hinges when the structure is subjected to a forced vibration. This forced vibration is generated by a piezoelectric bimorph attached to the base of the device. The mirror and support structures were modeled using one-dimensional beam theory and fundamental vibration mechanics. Analytical models have been developed that predict the resonant frequency of the device as well as the angular displacement of the mirror. Finite element modeling (FEM) has been done using ANSYS. These FEM models closely reflect the actual operation of the prototype devices. These models are currently being used to design and fabricate multiple devices on a single wafer with minimal post processing requirements. The optical displacement of the devices was determined by using a calibrated target with a grid printed on it. This target was placed a known distance from the mirror on the device. A 3mW HeNe laser was reflected off of the mirror and scanned across the target. Displacements were measured by tracing the path of the beam across the calibrated target as the bimorph was driven at varying frequencies and voltages.

Results:

Prototype devices have demonstrated optical scan angles of 60-90 degrees with applied voltages of 10-80V. The prototype devices had resonant frequencies between 11-55Hz. These prototype devices have been used in imaging systems operating between 11-55Hz.

Conclusion:

Based upon these current models, further refinements can be made to the design to produce specific resonant frequencies for use in a multitude of applications. The measured resonant frequencies and optical scan angles show that these devices are appropriate for real time imaging. Our ANSYS models accurately allow us to predict changes in the structures behavior based upon changes in the size of the mirror that is used as well as the hinge dimensions. The results of our various ANSYS models closely predict the measured values we have obtained in the lab. We are developing methods to fabricate the entire device on a single silicon wafer using standard processing techniques. In addition, these devices can be fabricated in bulk, reducing their cost and potentially making them disposable for use in a multitude of applications to include biomedical imaging applications.

6374A-13, Session 3

Optimization of electrostatic side-drive micromotor torque using new rotor-pole-shaping technique

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This paper reports an improved design of electrostatic side-drive micromotors. In the new design, we optimized the driving torque for the same dimensions of the micromotors. Driving torque is improved by more than 30% of the original driving torque reported in previous published work for 800 um diameter micromotor. Torque improvement has been achieved by a new technique of shaping the rotor poles of the micromotor with large dimensions. Up to our knowledge; all designed and fabricated micromotors have the regular circular-pie shape. We are presenting to the first time a new optimized design of the rotor poles different from the regular shape of previous published micromotors based on reshaping the rotor poles of the micromotor.

6374A-14, Session 3

Liquid crystal optics for laser beam modulation

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Liquid crystal devices are suitable devices for laser beam modulation since its half-wave voltages are only around 2 Vrms. In this research, we will present liquid crystal laser beam deflectors for laser manipulations. The ITO electrode pattern of this device looks like gratings but each electrode is connected with high resistive electrode. So we can apply voltage patterns like staircases to liquid crystal layers using only three levels of input voltages. Then phase distribution patterns like quantized prisms can be achieved and we can control prism angles by changing the applied voltages. The advantage of this ITO structure is that we can use conventional mass-production methods of liquid crystal devices. The thickness of the liquid crystal layer is 20um and theoretical maximum phase modulation is about 4um. Using this device, we can achieve the deflection angles of 0 to plus-minus 1 mrad with a 2mm aperture and response time is around 500ms. The transmittance of the devices is over 90 % and its fluctuation is less than 2 %. Further more, we analyzed the inflation of

the liquid crystal layers by temperature change which causes undesired lens effects and achieve the optimal mechanical designs of the liquid crystal devices to avoid the phenomena. We will also present a recent result of liquid crystal active lenses for laser beam manipulations along with optical axis using the same technologies.

6374A-15, Session 3

Reconfigurable microfluidic chip based on a light-sensitive hydrogel

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Microfluidic chips are highly integrated devices that permit minute amounts of fluid to be handled and manipulated in a precise manner. Often these devices perform several functions on the same substrate material including fluid transport, directional flow, pumping, sample preparation, separation, mixing, detection, and in situ chemical reactions. Common substrate materials include glass, silicon and polymers. Glass is often used because it is hydrophilic (attracts and holds moisture), chemically inert, stable over time, optically clear, non-porous, and low cost. Unfortunately, the design features embedded in a glass or silicon microfluidic chip are passive elements because the geometry of the various channels, chemical reactors, and fluid reservoirs are all fixed in the material at the time of microfabrication. One area of research is to create an active microfluidic substrate that would permit changes and controlled modifications to the chip configuration while performing the analysis. For example, the dynamic control of the microchannel geometry and pathway would enable the analyst to regulate both the volume and amount of time it takes for the fluid to be transported from the reservoir to the mixer or diffusion chamber. A reconfigurable microfluidic chip substrate based on a photo-responsive hydrogel is described in this paper. This light sensitive hydrogel is a cross-linked polymer network based on a blend of poly (vinyl alcohol) with the retinal protein bacteriorhodopsin (bR). In the bulk aqueous phase, the bR molecule acts as a light-driven proton pump. The absorption of a photon by the molecule initiates the isomerization of retinal from all-trans to 13-cis conformation, followed by a proton transport across the cell membrane. The proton transport starts with the release of a proton in the L to M transition and ends with a proton uptake in the following M to N transition during the photocycle. When exposed to visible light with a peak response at 568 nm, the bR molecules undergo the multistage photocycle in less than 16ms and cause the protons to be pumped into the surrounding medium. The diffusion of similarly charged ions through the hydrogel generates an electrostatic repulsive force which increases the osmotic pressure within the polymer network causing the hydrogel to swell. The hydrogel must be contained in an optically clear, non-porous, chemically inert and hydrophilic membrane that prevents inadvertent mixture of fluids. A scanning light source becomes the trigger mechanism to induce local deformations in the hydrogel volume and, thereby, trace out the reconfigurable microchannel pathways. An experimental study on the performance of the photo-responsive hydrogel will be presented and the factors that control its application to modifying the geometry and path of microchannels will be discussed. Current limitations and related fabrication issues will be summarized.

6374A-16, Session 4

Liquid crystal laser manipulation system for controlling microscopic particles

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Optical manipulation technique uses one or several laser beams that are highly focused into microscopic particles. Through the movement of the laser beam, the particles at the focal spot can be manipulated [1]. Usually the manipulation of the trapped particles requires certain mechanical movements, which are performed by adjusting the objective lens and some mirrors to scan the laser beams.

Recently, we demonstrated three-dimensional (3D) particle manipulation by using the composite lens of an objective lens with high numerical aperture and a liquid crystal (LC) lens that has two functions of variable focal length and beam steering by applying a control voltage [2]. The captured particles such as polystyrene balls in diameter of 11 microns can be shifted in the longitudinal direction as well as the transverse directions without the use of any mechanical parts.

In this work, we propose a novel optical manipulation system for controlling 3D trapping and rotating microscopic glass rods using an LC device.

The LC device with eight-divided circularly hole-patterned electrodes has three functions of an anamorphic lens property in addition to both the variable focal length and deflection properties. Adjusting the control voltage to the LC device, the laser beam can be focused with any elliptical cross section. The slender object aligns to the major axis of the elliptically shaped laser beam spot.

An elliptical beam was used to apply a torque to the captured glass rod particles in a diameter of 11 microns and length of about 40 microns dispersed into the water. The captured particles rotated clockwise or counterclockwise during the application of the rotating control voltage to the LC device. Furthermore, the position of the trapped objects could be shifted.

We have proposed a laser manipulation system with 3D controllable and rotatable trapping using an LC device with electrically controllable elliptically focused laser spot.

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6374A-17, Session 4

Imaging technology of 3D distribution for sugar chain on single living cell membrane

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We study on the imaging technology of three-dimensional distribution for sugar chain on single living cell-membrane. This technology can observe the entire cell surface. To observe the cell surface, the local area image of cell-membrane is taken by TIRF (total internal reflection fluorescence) microscopy. And by scanning the whole cell surface area, we can obtain the image of the entire cell membrane. These observed local area images can be converted into an entire surface image by the pattern matching processing. For this scanning technology, we propose the proximal two beam optical tweezers to rotate the single floating cell. This proximal two beam optical tweezers can rotate the floating single cell in the nutrient medium by light pressure. Two beams illuminate the single cell at proximal two points from below and above. The cell is trapped at the center of these two focal points. At the same time, light pressures that are generated at two focal points are made to act as rotational torque. Conventionally TIRF microscope is well known as the observation technology for the cell-membrane using the evanescent light as the exciting light. We can observe the local area images of the fluorescently labeled sugar chain that binds the glycoprotein. Using the proposed optical system, we can obtain the fluorescent distribution images on the entire cell-membrane.

6374A-18, Session 4

Laser irradiation induced resonant vibrations in solids

B. V. Richert, H. Okamura, International Christian Univ. (Japan)

Please refer to the atteched word document for a detailed abstract.

6374A-19, Session 4

Light-driven micromanipulator and its application for 3D fabrications

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An optical actuator has some interesting characteristics, such as no generation of magnetic noise and receiving the energy remotely. A novel micromanipulator by photothermal effect is proposed. It consists of three optical fiber cantilevers. One end of the fiber is cut for a bevel and painted with black color. A photothermal effect is occurred responding to the incident beam at the end of the optical fiber. It can manipulate a sample and move it in the arbitrary place in 3D space. We succeed to fabricate the 3D structures.

6374A-20, Session 4

Optimal actuation of a MEMS cantilever by a laser beam

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A beam of light can exert sufficient radiation pressure to move a micro-structure. Ref. [1], [2], [3] present experimental evidence of actuation by radiation pressure. Several applications of optically actuated MEMS cantilever, such as photodetector, optical information processing, analog computation are investigated by researchers [4], [5].

In this paper, we analyze the steady state deflection of a singly-clamped, polysilicon micro-cantilever on which a CW laser beam is incident normally. We assume that the microstructure is overdamped and under the action of the laser beam searches a steady deflection without any oscillations. We show, through analysis and simulations, that there exists a point of incidence of the laser beam that produces the maximum steady-state deflection of the cantilever tip. An expression for the point of incidence corresponding to maximum deflection is derived. We calculated the temperature increase due to the CW laser beam. The effects of changes in material properties due to laser heating are found to be negligible. The knowledge of the optimum deflection under optical actuation is helpful in designing opto-mechanical micro systems such as switches.

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6374A-34, Poster Session

Development of PC-controlled laser manipulation system with image processing functions

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Introduction:

Micro/Nano manipulation technology for micro/nano mechanical systems (MEMS/NEMS) and Lab-on-a-Chip is currently area of intensive research. Laser trapping of micron-sized dielectric particles was first demonstrated by Arthur Ashkin in 1970 [1]. This technique has been further extended and widely used for non-contact micro/nano manipulation in various fields such as physics, chemistry, biology and others [2]. The ability to manipulate small transparent objects without physical contact, in contrast to mechanical micro-hands, allows for many interesting studies on biological systems by applying pico-newton forces to the objects. However, the control system and user-interface of a conventional laser trapping system is too poor to manipulate objects in 3-dimensional working space, if the intention is to dexterously or automatically manipulate the objects in real time. We have developed a 3-beam laser trapping system with excellent user-interface, real-time image processing functions and micro-surface-processing beam. In this paper, the system configuration of the developed system is described, and a concept of automated non-contact micromanipulation based on visual information and its suitable application areas are proposed. The results of several demonstrations, for example automatic transportation of micron-sized spheres and 3-dimensional (3-D) manipulation of micron-sized non-sphere shape objects, are also described.

Developed System and Results:

The laser trapping source are continuous wave (cw) Nd:YAG laser with wavelength 1064nm and cw Cr:Forsterite laser with wavelength 1250nm, and the former laser beam is split into two beams (horizontally and vertically polarized beams). The micro-surface-processing beam is a third harmonic beam of pulsed YAG laser. These three trapping beams, the surface processing beam and visible laser beams (He-Ne laser with wavelength 633 nm), which form the indicator of each trapping beam, are introduced coaxially into an optical microscope through a relay lens, a dichroic mirror and an oil-immersion objective lens. The 3-D focal position of each trapping beam is independently controlled; that on the X-Y axes by a set of the personal computer (pc) controlled galvano mirrors and that on the Z axis by a lens on a linear motorized stage which can be moved parallel to the optical axis. We can specify the focal positions of the trapping beams by real-time man-machine communication functions using a pointing device (that is, a pc's mouse "click-and-drag" procedure). All the behaviors proceeding in the micro environment are monitored through a color CCD camera and shown on the computer display along with additional information (for example, approximate focal positions of invisible trapping beams, scanned beam trajectories) obtained or generated by a real-time image processor.

In our automatic trapping and transportation experiment, positions of 3-mm-diameter dyed polystyrene micro spheres in an aqueous solution were detected by real-time image processing technique, and then trapped and transported to the destinations one by one. In another experiment, a rod shaped material (Aluminum borate whisker) in an aqueous solution was stably trapped on XY plane by simultaneous irradiation of two beams at tip position on either side of the rod, if in the case of irradiation of one beam the trapped rod rotated in the beam axis (Z axis). The subsequent manipulation of the trapped rod on XY plane was easy by user-controlled click-and-drag procedure.

Conclusion:

We have developed the 3-beam laser trapping system with excellent user-interface and real-time image processing functions, and demonstrated the real-time automatic transportation of micron-sized particles using pattern recognition techniques. The laser trapping combined with the real-time image processing and control technique can be used to actuate versatile micro fluidic devices.

Acknowledgement: This work was partly supported by Grants-in-Aid for Scientific Research (C) from Japan Society for the Promotion of Science.

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6374A-35, Poster Session

Low-cost deformable mirror for laser focussing

W. Greger, T. Hoesel, T. Fellner, A. Schoth, C. Mueller, J. Wilde, H. Reinecke, Albert-Ludwigs-Univ. Freiburg (Germany)

Introduction

Deformable mirrors are being used in a broad range of applications. Some examples of high degree-of-freedom mirrors are the correction of blurred wave fronts for ground-based telescopes [1], and the wave front correction of laser beams [2]. These mirrors usually require expensive actuator arrays and closed loop control systems for proper deformation of the mirror. In addition to the applications mentioned above there are many others, such as spherical correction [3], focussing [4], or beam shaping. Here, low degree-of-freedom mirrors are much more suitable than high degree-of-freedom mirrors, because the first type is mostly cheaper and doesn't need a complex control-loop system.

In this paper we present a new approach for low degree-of-freedom deformable mirrors considering a laser-focussing mirror with a variable focal length as example. Due to its application - the focussing of a laser beam - the mirror's surface must keep a parabolic shape for all focal lengths. This is achieved by a local variation of the mirror's section thickness. In order to keep costs low, the mirrors are fabricated in polymers.

Method

The deformation of a circular mirror is given by the plate theory [5]. Defining the surface function as a circular parabolic (angle of incidence equal 0°) gives the solution of the radial dependent thickness profile.

For a center actuated mirror with a radius of 10 mm, a maximum deflection force of 2 N, a minimum focal length of 100 mm, a Young's modulus of 2.4 GPa, and a Poisson's ratio of 0.417, the thickness varies in between 350 μm (mirror's boundary) and 850 μm (mirror's center).

In order to minimize production costs, they are fabricated by using polymer technology. For concept testing and design verification, hot embossing technology was used. For mass production of the mirror, the injection molding process was evaluated. For both technologies, we used Polycarbonate (PC). Due to the initial transparency of the polymer, the mirror devices were coated with a thin (100 nm) reflective gold layer. For deformation of the mirror, an electromagnetic actuator was glued at the center of the mirror's backside.

Results

For deformation measurements, a functional demonstrator was fabricated. This demonstrator consists of the gold-coated mirror device made from PC, and an electromagnetic actuator for deformation of the mirror. Applying the maximum power of 3 Watt (supply voltage 12 V), the actuator reaches the maximum tractive force of about 2 N. In order to characterize the actual deformation function for different focal lengths, the actuator current was varied between 0 and 200 mA. The deformation of the mirror was measured using a Werth multi-sensor 3D coordinate measuring machine.

The measured deflection profiles were fitted using a parabolic fit. The mean deviation between the measured data and the curve fit is less than 2 μm (for a focal length of 100 mm).

With our laser measurement setup a collimated laser beam with a wavelength of 670 nm and a waist diameter of 14 mm could be focused down to a 0,8 mm spot diameter. The focal length could be varied in a range from 0,1 m to 1 m.

Conclusion

A new approach for low-cost deformable mirrors is presented. The deformation function is achieved by a local variation of the mirror's section thickness. The mirror reported in this paper supports a circular parabolic deformation function with a variable focal length. The mirror is fabricated from polymeric materials, using the hot embossing process and the injection molding process. For deformation of the mirror, an electromagnetic actuator was used. The focal length could be varied within a range from 0,1 m to 1 m. A laser beam with a waist diameter of 14 mm could be focused down to a 0,8 mm spot.

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6374A-36, Poster Session

The simple and practical variable optical attenuator using a piezoelectric sheet containing an optical fiber

S. Kim, S. Kang, W. Kim, H. Kang, H. Jeong, Y. Cho, Korea Institute of Industrial Technology (South Korea)

In this letter, we proposed a simple variable optical attenuator (VOA) using a piezoelectric sheet. We can change the deflection of the sheet by controlling the applied voltage on the electrodes of the sheet, which causes the optical loss to be dependent on the applied voltage. The optical fiber is attached on the piezoelectric sheet. The required voltage range in our previous work using a ceramic tube was about from 0 to 600V DC but it in this letter using a piezoelectric sheet is dramatically reduced to from 0 to about 60V DC to achieve the same dynamic range. The lower voltage range makes our proposal structure more practical. The numerical analysis about the optical loss related to the various mechanical offsets is also investigated. Our proposed structure can be a good candidate for a simple and practical variable optical attenuator in optical communication system field.

6374A-37, Poster Session

A novel capacitive type miniature microphone with a flexure hinge diaphragm

H. Kim, Electronics and Telecommunications Research Institute (South Korea)

Recently, most miniature microphones are adopted by diaphragm-based capacitive type because of the flat frequency response, small size, high signal-to-noise ratio and low power consumption. However, these capacitive type microphones have typically suffered from low sensitivities. The sensitivity of a condenser microphone is determined by the diaphragm mechanical sensitivity and the electrical field strength exerting across the capacitor gap. Thus, so far, a lot of excellent membrane designs have been presented to reduce tensile stress in the diaphragm and the implementation of a charge-storing layer (the so-called electret) has been introduced to replace the external bias and reduce the power consumption.

In this paper, we present a novel, highly sensitive capacitive type miniature microphone with a flexure hinge diaphragm. The diaphragm-based microphones have been fabricated on 5" SOI wafers in a production environment and were realized in one single chip by use of sacrificial layer. The devices have thin electroplated membranes as the active deflectable diaphragms, which are patterned with the flexure hinge structure. And the thick perforated backplates are fabricated by an electro-chemical etch-stop technique and optimized boron implantation at a surface of silicon.

With a flexure hinge diaphragm area of 1.5 mm x 1.5 mm, the measured sensitivity of microphones were higher than 10 mV/Pa under 15 V dc bias by using a Dynamic signal analyzer (model SR785). And the displacements at the center of these diaphragms were measured to be several times, compared with flat diaphragms, by using laser Doppler vibrometer (LDC). The miniature microphones have obtained -3 dB bandwidth of nearly 20 kHz by proper design of the flexure hinge diaphragms.

6374A-38, Poster Session

Two-dimensional magnetic force actuator using temperature sensitive ferrite driven by light beam

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Two-dimensional actuator has a feature of a non-contact for applying light energy remotely. It consists of a magnet as a movement, an acrylic plate and the temperature sensitive ferrite mounted in two-dimensional array on the plate. A curie temperature of the ferrite is set about room temperature. For moving the magnet, two ferrites in the opposite direction are irradiated by the laser. A magnetic force decreases by photo-thermal effect. Furthermore generating more strong force, a thickness of the plate and ferrite is optimized by analyzing static magnetic field. As a result, the movement is controlled in the two-dimensional area.

6374A-39, Poster Session

Liquid pressure varifocus lens by fibrous actuator

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A lens is an important element in optical technologies. It is required for the function of focusing and extension of the beam. Most of lenses are generally made of glass or plastic. Therefore it is necessary to have a mechanism to adjust a focal point to the optimum position in order to maintain energy density. A precise actuator for adjusting the focal position is required, because the focal length of the solid lens is a constant value. Moreover, it is impossible to move quickly because of

its bulk and weight. In this paper, we propose a liquid pressure varifocus lens that overcomes the problems of conventional variable focus lens. The liquid pressure varifocus lens consists of a thin polymer film, liquid, and a fibrous actuator. It can be continuously changed its shape by driving the fibrous actuator. The optical characteristics and response time of the liquid pressure varifocus lens are measured. We demonstrate an optical element for YAG laser processing as its application.

6374A-41, Poster Session

Polymer-based 1x2 power splitter for a plastic optical fiber

H. Jeong, Y. Cho, S. T. Kim, Korea Institute of Industrial Technology (South Korea)

This paper presents a polymer-based 1×2 power splitter for an optical communication based on the plastic optical fiber. To find out optimum parameters of a power splitter, mode propagation along the splitter was theoretically analyzed using BPM(Bema Propagation Method) and the results show that the distance between two arms at the output port of a splitter should be kept below 100μm in order to increase the output power. The planar lightwave circuit device was fabricated by a hot embossing or nano imprint lithography process followed by a spin coating process. The core size and the length of a power splitter were 210μm×210μm and 2cm, respectively. The measured surface roughness of core/cladding using the AFM(Atomic Force Microscope) was under 100nm. The characteristics of a fabricated power splitter was conducted using a 850nm VCSEL(Vertical Cavity Surface Emission Laser) source and 50:50 power splitting performance was obtained.

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6374B-21, Session 5

A robust vision-based technique for human arm kinematics identification

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Biomechanics of human movement can be defined as the interdisciplinary field which describes, analyzes, and evaluates human movement. Motion, independent of forces, is described by kinematic parameters (usually using Denavit-Hartenberg convention) that have been used widely in biomechanics fields. Examples of these fields include robotics, human motion studies, and biomechanics structure's design and control such as exoskeleton and artificial human arm. A common way to precisely measure the joints' movements is using a motion capture system. Until now, the most successful motion capture technology is optical motion capture; this is due to its highly accurate measurement of small reflective markers that are attached to some relevant body landmarks. Therefore, the most commonly used motion capture techniques employ optical methods to record a subject's motion. This paper addresses the problem of estimating the human arm kinematics parameters from video or captured images of human arms. We introduce a new robust framework that leads to reliable and accurate estimation of shoulder and elbow center of rotations along with the arm kinematics parameters. This is done using few captured images or video frames. The proposed algorithm does not require high fidelity calibration of estimated parameters after first estimation iteration since the error is lower than the visual positioning system. Also, the algorithm is not computationally intensive since it operates by minimizing a function that represents locus of center of rotation and axis of rotations in a 3D-space. The error sources in practical experiments and the sensitivity of the algorithm to these error sources have been discussed.

6374B-22, Session 5

A fuzzy adaptive PD controller based microassembly system

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As microelectromechanical systems (MEMS) devices become more functional and more complex, the scaling of microparts leads to complications in their assembly. The conventional MEMS fabrication technique can not meet these demands, and machine vision technique has been utilized in microassembly[1][2]. Especially the visual servoing technique among them has become a main research method[3].

Visually servoed assembly has been shown to effectively compensate for uncertainty in the calibration of camera-lens systems, manipulators, and workspaces. The microassembly task is to insert an micro peg to a hole. Our approach to visual servoing is an image-based one in which the errors input to the controller are defined in image coordinates. The advantage of image-based visual servoing is that it eliminates the need to perform an explicit inverse perspective projection mapping. For image-based systems the error is defined on the image plane, and the manipulator control input is typically defined either in joint coordinates or in task space coordinates. Therefore, it is necessary to relate changes in the image features to changes in the position of the object. The image Jacobian captures these relationships.

The visual controller can derive the velocity control law based on the inverse Jacobian that will produce the desired change in the image [4]. The objective of the visual controller is to make the image error converge to zero and is the key issue in the high performance visual servoing system. Up to now simple proportional control law is used in most of the visual servoing system. However, small proportional gain results in slow response whereas large proportional gain will result in large overshoot or make the system even unstable. Therefore, it is difficult to acquire better dynamic response only with proportional control law. In this paper in order to avoid these problems we propose a PD visual controller for microassembly system. In the proposed controller the proportional part makes the system respond faster and the differential part can improve the dynamic performance.

Over the years, many techniques have been suggested for tuning of the PD parameters. Among them, the model-based tuning method appears to be very encouraging [5]. In real situations, however, highly precise and detailed modeling of the system is often difficult to achieve, because various uncertainties such as modeling error and external disturbances are involved in the system. Due to these difficulties, the PD controllers are rarely tuned optimally based on the system model and the engineers need to settle for a compromise performance. To this end a fuzzy adaptive PD visual controller is designed, based on the feature position error and the change in feature error, the PD parameters are tuned on line by fuzzy rules, thus we can get satisfactory performance which is robust to modeling error and external disturbances. The proposed controller is applied to the microassembly of micro peg and hole, and simulation and experiments are performed to investigate the feasibility and effectiveness of this method.

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6374B-23, Session 5

A method of calculating the scanning start angle and the scanning angle of aviation camera

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The scanning start angle, the scanning angle and the target's slope angle are important parameters of aviation camera. This paper analyzes the relationship of them and suggests that the current method of calculating the scanning angle is very difficult to be realized in engineering. It proposes a method of calculating the scanning start angle and the scanning angle of aviation camera according to the target's slope angle. Its main characteristics are, with reaching the overlap ratio as a premise, to calculate the scanning start angle and the scanning angle reasonably and to try to put the target into the middle of scanning range, making the valid scanning range as wide as possible. The method is very simple and is easy to be realized in engineering. According to this method, this paper gives us the relationship graph between the target's slope angle and the scanning angle.

6374B-24, Session 5

Mark position measurement by visual feedback with laser

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In recent years, in the filed of robotics area, visual feedback control has been studied. However, its application to the industrial field is not so advanced. As one of the important problems in the area of industry, there is a demand to measure the working radius of the crane truck automatically by using the robot. Here, the working radius means the distance between the center line of rotation of the crane truck and the crane hook. In this paper, what we want to do is to develop visual feedback device with laser which measures the working radius. To measure the working radius, first, we need to detect the crane hook. But, it is difficult to know three-dimensional position of hook. For

solving this problem, a CCD camera is effective as a sensor. For example, a research including position measurement based on image processing and stereo camera is accomplished. However, the target crane in our research is huge and the working radius is changed in several to 100m with expansion and contraction of the jib. Therefore, it is difficult to measure the huge object in traditional researches. Then, we develop the observation device with CCD camera and laser range finder, and propose the methods of recognition of crane and position measurement, in order to measure the working radius of crane. However there are various shapes in crane hook, so it is difficult to recognize it. Then we attempt to simplify recognition by attaching a specific mark to the crane hook and recognize and measure the position the mark. In addition the crane hook is moved by the operation of operator and pendulum movement by own weight. Then tracking control to the moving crane hook by controlling the posture of the observation device. As for the tracking control, we introduce an extended Kalman filter to reduce time delay which occurs by image capturing and image processing.

6374B-25, Session 5

Vision guided pin insertion machine inspired by human motion

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We propose an automatic pin inserting machine for wafer probe card. The wafer probe card consists of more than ten thousands of insertion holes, which make a skillful operator take all two or three days for assembly. The observation of manual repetitive operation shows that the visual guided sequence of motions decides success and quality of insertion. The vision guided motion is required for the alignment of a pin frame and a probe card to be moved on the stages. The pin frame consists of tens of pins to be cut one by one. The sequence of robotic motions is inspired strongly by manual repetitive operation in order to generate stable and damageless insertion into the card. The conventional pin inserting method cannot be successful for the wafer probe card. In addition, the gripper is very important for success of insertion. In the proposed machine, the gripper can control arbitrary gripping force by the compact-sized proportional control valve.

This paper shows the effectiveness of the proposed pin insertion machine that will replace the conventional manual assembly.

6374B-26, Session 6

Catheter kinematics and control to enhance cardiac ablation

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Catheter ablation is the preferred minimally invasive treatment for cardiac arrhythmias. Limited maneuverability of currently available catheters undermines the success of this treatment and subjects operations to prolonged repeated attempts to pace suspicious zones and ablate the arrhythmogenic substrates under ionizing radiation of fluoroscopy. To compensate for such inefficiencies, a control system that can replace operator's hand during the procedure is desired. This system should be able to direct catheter tip toward the ablation site and maintain its contact with the substrate during ablation, accelerating the process and enhancing its precision. To realize such a system, the first step is to kinematically model the catheter and to devise a control strategy to embed the kinematics of the catheter. This paper proposes a simplified approach to model and control a general single-segment active catheter as a continuum robot. In this approach, the flexible catheter is modeled as a rigid manipulator having coupled joints. Utilizing the structural coupling of the catheter, joint-variables are reduced to actuatable parameters thus lifting some of the mathematical difficulties in formulation of a control strategy for redundant manipulators. The modeling is validated through experiments with a typical steerable ablation catheter equipped with an electromagnetic tracker in vitro.

6374B-27, Session 6

An investigation of phenomenal parasitics and robust control of parallel-plate electrostatic micro-actuators

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Electrostatic micro actuators are often subject to modeling errors due to fringing field effect and deformations, called henceforth phenomenal parasitics. This leads in general to distributed parameter systems described by partial differential equations. The control of such systems requires distributed sensing and actuation, which is very hard to implement for microsystems. However, if the micro structure is modeled as a rigid body and only the main electric field is considered, the performance of the controller obtained from this simplified model might be compromised for applications where the precise positioning is required, e.g. adaptive optics. In this work, the parasitics are modeled as serial and parallel capacitors while the device is represented as a rigid body. When an appropriate robust control scheme is considered, the detailed modeling of the parasitics is not required, but only their boundaries.

Based on this idea, a robust control scheme is constructed using the theory of input-to-state stabilization (ISS) and back-stepping state feedback design. This controller is based on the model of an ideal parallel-plate actuator and is robust against parasitics and parametric uncertainties, which are considered as disturbances to the system. The stability and the performance of the system using this control scheme are demonstrated through both stability analysis and numerical simulation.

To validate the modeling of electrostatic micro actuators with phenomenal parasitics and the control scheme, we consider an interactive simulation by using COMSOL and MATLAB/SIMULINK. The MEMS module of COMSOL will be used to simulate the micro structure and to generate a SIMULINK block, which allows a seamless closed-loop simulation in the platform of MATLAB.

6374B-28, Session 6

Hybridization of neural networks and genetic algorithms for identification of complex Bragg gratings

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In this paper a novel method for investigation of inverse scattering in optical complex mediums is proposed. The proposed method is based on radial basis function Neural Networks (RBFNN) and Genetic Algorithms. Medium discrimination is performed by RBFNN and corresponding medium parameters extraction is done using genetic algorithm. In the proposed method for simplicity the Apodized, chirped and simultaneously Apodized and chirped types of mediums are considered as RBFNN library. First RBFNN discriminates medium type and then genetic algorithm extract precisely all necessary and enough discriminated medium parameters. The proposed method tries to open a new insight to inverse scattering in optical devices and systems identification. The simulated results are closely compatible with full numerical simulations to illustrate the ability of the proposed algorithm.

The problem of synthesizing or reconstructing of non-uniform fiber Bragg gratings (FBG) from the corresponding reflection coefficient is so important both in device designing for high-speed optical fiber communication such as selection of wavelength multiplexed channels, compensation of the link dispersion and optical computing. For these devices and systems, design strategy needs some standard design rules and values. For obtaining these values and rules, the design ideas should be examined in practice. On the other hand, one needs to check the theoretical idea with practical measurements. In optical domain, for example, device design with optical complex Bragg Gratings need to measure manufactured structure. For this purpose a model for medium should be assumed and optimized with numerical methods. For example, in reconstruction of optical mediums based on the measured reflection coefficient intelligence methods are used to obtain optimum medium parameters. These structures have some interesting applications such as information gathering, measurement of strain or temperature and many other applications. Several experimental techniques have been demonstrated to fabricate non-uniform gratings, permitting an accurate control of both the local grating pitch and the apodization profile along the structure. These

techniques give substantial flexibility to the grating design process. For all of these applications inverse scattering techniques is needed and the method offers a great variety of possibilities for the design of gratings. For weak gratings the synthesis problem of fiber gratings reduces to an inverse Fourier transform of the reflection coefficient. This is known as the first-order Born approximation, and applies only for gratings for which the reflectivity is small. Several modifications on the method was applied and improved its performance at high reflectivity, Fourier transform technique has been extended by Winick and Roman, yielding a better approximation and enabling the design of practical fiber grating filters. However, this synthesis procedure is approximate in nature and consequently, not reliable for the design of very complex filters.

An exact solution of this inverse scattering problem was found by Song and shin that they solved the coupled Gel'fand-Levitan-Marchenko (GLM) integral equations that appear in quantum mechanics. Their method is exact, but is restricted to reflection coefficients that can be expressed as a rational function.

However, the need to approximate the desired spectral response by rational functions is difficult and also can result in inaccuracies. To overcome this limitation, an iterative solution of the Gelfand-Levitan-Marchenko (GLM) system was proposed by Peral to synthesize arbitrary spectral responses. Some fiber grating designs calculated with this method have already been fabricated, proving the usefulness of the method. The iterative solution of the GLM equations has some weaknesses. However, the solution is approximate due to the finite number of iterations computed, which translates into considering only a limited number of reflections within the medium. This is particularly noticeable for strong gratings with discontinuities in the coupling function. Also, when specifying ideal filter responses, it is desirable to have a weighting mechanism, which makes it easier to weight the different requirements. The iterative GLM method does not support such a mechanism in a satisfactory way.

Another group of exact inverse scattering algorithms called differential or direct methods. These techniques, developed by geophysicists like Robinson and Goupillaud, exploit fully the physical properties and structure of the layered media in which the waves propagates. The methods are based again on causality arguments and identify the medium recursively layer by layer. For this reason, they are sometimes called layer-peeling or dynamic de-convolution algorithms.

Recently, several heuristic approaches have been developed for the solution of the inverse problem with the goal of designing gratings as filters for telecommunication applications. Skaar, Risvik and Cormier et al developed genetic algorithms (GAs) to obtain physical parameters of the Bragg gratings from the measured reflected intensity spectrum. Skaar and Risvik encoded the grating coupling coefficient using a real number formulation and used a Runge-Kutta algorithm to calculate the spectral response of the grating. Cormier et al reduced the spectral response calculation time using the transfer-matrix (T-matrix) formulation. This formulation is based on approximating the grating coupling coefficients as a piecewise constant function along the grating. Cormier et al characterized the Bragg grating in terms of three parameters: the length, period and amplitude of the index of refraction modulation. While this method is excellent for the design of Bragg gratings as filters, the parameterization of Cormier et al does not allow for a period variation along the grating (e.g., due to a non-constant applied strain).

In these presented works, the type of medium was well known and only extraction of medium parameters was a problem. But, there is a basic question that if there is a problem without information about medium type, how one can proceed. Here, we try to present a novel method to incorporate this problem. For this purpose combination of RBFNN and GAs is examined. In our method there are a large classes of medium types predefined to RBFNN. The RBFNN know these mediums through the learning process. Now, if there is an unknown (belongs to one of predefined medium types) reflection coefficient, which is applied to this RBFNN, based on learning process, the RBFNN recognize medium type. Now, the input vector is passed to especial GAs block corresponds to determined medium type. Now, GAs starts to determine the parameters of the recognized medium. After this process the real and extracted medium is compared together and our results show excellent compatibility. The presented method is so excellent and the library can be huge to include all practical cases.

6374B-29, Session 6

Identification of complex Bragg gratings based on optical transfer function fitting using genetic algorithm: optimization

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In this paper an optical transfer function for description of the operation of complex Bragg Gratings similar to electrical ones is presented ( ). For this purpose the Genetic Algorithm (GAs) is used to find optimum number of poles and zeros from the measured reflection coefficient. After building the transfer function according to developed algorithm in this paper, the reflection coefficient for this approximated system is obtained and compared with measured values (or full numerical simulated results). The results obtained from the approximated transfer function in these cases are so close to real data (or full numerical simulations). So, the presented method introduces an interesting approach for identification of the complex Bragg Gratings in frequency domain such as electrical system identification. Some of optical characteristics of these systems can be extracted from the approximated transfer function easily.

Optical device and system design is interesting for high-speed optical communication and computing. Investigation of the effect of system parameters and input waveform on output characteristics is so important in system engineering. Also, in optical engineering this subject is necessary for device and system design. For this purpose introducing optical system transfer function illustrating all system parameters effects on output behavior is interesting. In this paper a novel method for evaluating a transfer function for Fiber Bragg Gratings is examined. For this purpose a model for medium should be assumed and optimized with numerical methods. For example, in reconstruction of optical mediums based on the measured reflection coefficient intelligence methods are used to obtain optimum medium parameters. An analytical proposal for system input-output characteristic is so interesting from identification point of view. In this case optical transfer function can be excellent. In this paper we try to present an efficient method to extract optimum transfer function for theses structures.

6374B-30, Session 6

Physical parameters identification of nonuniform fiber Bragg gratings using interpolation method

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The Interpolation method for identification of the Apodized and Chirped Fiber Bragg Gratings is used. For this purpose, the Riccati equation for obtaining the reflection coefficient is used and numerically solved. Then for various system parameters, the maximum reflection peaks, Bandwidth of the reflection coefficient and the central frequency are determined. Then using interpolation technique three analytical equations can be extracted for the mentioned above quantities and therefore using the obtained reflection coefficient there is a map from the reflection coefficient in frequency domain to real space (index of refraction space). So, for the measured reflection coefficient, we can determine the index of refraction profile including Apodized and Chirped functions. The proposed method is effective and easily can determine the index of refraction profile.

High speed optical fiber communication systems depend critically on the design of complex filters to perform various functions such as selection of wavelength multiplexed channels or compensation of the link dispersion. The technology of ultraviolet photoinduced fiber gratings has reached now the necessary maturity to implement these filters. Several experiments have been demonstrated to fabricate nonuniform gratings, permitting an accurate control of both the local grating pith and the apodization profile along the structure. For design of these complex filters there are some interesting methods.

1. Approximate Fourier Transform method

2. Exact Solution of the problem expressed in terms of integral equations

3. Exact inverse scattering algorithms called differential or direct methods

Since the design of optical complex systems is necessary for optical applications, identification of complex optical integrated systems and

devices is so important for optimum optical integrated system design. In practice estimation of the implemented structure is so critical for scaling of the output signal and relating the measured quantity to the physical parameters. There are some published works in this domain. But, all of the presented methods are based on complex electro-optical setup. However, arranging these complex setups need more careful tuning for precise measurement. Here, we present a novel algorithm based on interpolation technique to identify the system parameters of the complex Bragg gratings. In this method, we extract three distinguishable quantities such as Maximum reflection peak, Bandwidth of the reflection coefficient and the central frequency, which are interesting and easy for measuring in practice. The proposed method can be easily implemented in all-optical domain. So, the presented method will be so high-speed for reconstruction of the medium profile.

6374B-31, Session 7

Circuit modeling of multiple quantum well laser optimized by carrier tunneling

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In this paper, the effect of carrier tunneling between wells on multiple quantum well (MQW) laser characteristics is investigated. Based on the rate equations developed for 3-levels (carrier transport between 3-D, 2-D and Quasi 2-D states) including carrier tunneling effect, a circuit model is proposed. According to simulation results with change of tunneling time three interesting regions of operation are obtained. The operation of the proposed laser doesn't change for tunneling time larger than a threshold value (0.1 nsec). For the tunneling time smaller than another threshold value (0.01 nsec) the operation of the laser strongly destroyed. For the tunneling time between the two thresholds values the operation of the laser can be optimized, which in this paper it is done for obtaining low turn on delay time, suitable operation from simultaneous filling of the wells, high output intensity and large bandwidth point of views.Nowadays high speed optical communication and computing are basic demands in industry and biology. For this purpose, high speed laser diodes, broadband optical fibers and high speed photo-detectors are necessary. Recently it is illustrated that Multiple Quantum Well Lasers (MQWL) has inherent properties such as lower threshold current and low temperature dependency, high differential gain and higher bandwidth. Also, it is demonstrated that MQWL has faster dynamics. These effective properties are excellent to introduce MQWL for high speed optical communication and computing.

For analysis of the quantum well lasers first one level rate equation was presented. In this model the interaction between quantum wells confined states and photon population has been considered. This method had some problems for description of dynamic response such as low frequency roll off degradation. So, for description of this problem, two levels model was presented. In this model transportation of carriers across optical confinement layer (OCL) was considered and it was shown that the origin of the problem is related to this phenomenon. This model had good ideas about transportation of carriers across OCL but it couldn't illustrate clearly quantum coupling between OCL (3-D) states and confined (2-D) states in well. The capturing and escaping between 3-D and 2-D states is so important for exact modeling of high speed laser diodes. For introducing suitable model to incorporate this phenomenon, the three levels rate equations proposed by. For building of this model the gateway states has been added to two levels rate equations.

For MQWL there is another interesting phenomenon related to transportation of carriers across the barriers. For handling of this phenomenon, there are two basic events including thermionic emission and carrier tunneling.

For solving of the obtained equations in each of mentioned above models the transmission line method (TLM), full numerical self consistent methods based on finite difference (FD) and finite element (FE) and circuit models have presented. From simulation point of view the circuit modeling is interesting especially there is a little problem about convergence compared other methods. Also, this type of simulation can help to total system evaluation. In this direction the circuit model for single quantum well lasers using three levels rate equations was presented by B. P. C. Tsou et al. Also, for MQWL the circuit modeling based on three levels rate equations was presented by G. Rossi et al.

For integrated laser diodes such as MQWL the tunneling effect between wells is possible. In this paper, we try to incorporate the tunneling effect to these circuit models and investigate it properties. We like study the tunneling effect on output intensity, turn on delay time, transient behavior, inhomogeneous wells filling up and bandwidth of the MQWL. In this study the tunneling time based on optimum laser operation will be adopted. So, in our treatment generally different tunneling time for each well should be considered.

In this paper the effect of tunneling process between wells in MQWL has investigated. We have shown that in present of tunneling, the output intensity and modulation bandwidth can be improved. The circuit model including tunneling effect was proposed. Our simulations have been shown that there is a band for the tunneling time (0.1 nsec) for obtaining better characteristics for MQWL. Our idea for improving the laser diode performance will be clear with increasing of the number of wells

6374B-32, Session 7

Micro-optical electromechanical system (MOEMS) for high-precision displacement sensor design using ring resonator array

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An efficient method for high precision displacement measurement based on micro scale ring resonator and MOEMS is presented. The proposed structure can be used as discrete and integrated sensor in engineering applications. Photo-elastic effect is used to convert the physical displacement to the index of refraction variation in the ring resonator array. Analytical relation for description of system transfer function is derived. Single and multiple ring resonators are examined for increase of the system sensitivity. It is shown that an array of multiple ring resonators (array) is better than single ring case. Effects of optical and geometrical parameters of the proposed structure on sensitivity are studied.

In recent years, fiber optical sensors and optical micro-systems have moved out of the laboratory and assumed a significant role in sensing and measurement of many kinds. These optical techniques are important to a broad range of applications, including biomedicine, environmental sensing, mechanical and industrial measurement and art preservation. optical techniques have been used for sensors and especially high-precision sensors design. Among all integrated optical elements optical ring resonators are interesting elements for integrated applications from sensors to signal conditioners. In this paper displacement sensor design based on ring resonators is examined. Here really a micro optical electromechanical system (MOEMS) for high-precision displacement measurement is presented. The proposed method has many advantages over other proposed methods. First an integrated sensor doesn't require any alignment while it can be used for wide applications. Secondly, integrated sensors are suitable due to their compactness, simplicity and potential for mass production. It should also be mentioned that integrated sensors such as piezoresistive sensors have less sensitivity than external sensors such as optical levers. Using an integrated optical sensor, we expect to achieve sensitivity as high as that of external sensors. Integrated optical devices can be inexpensive and they can be used in harsh environments such as ultra-high vacuum (UHV) systems and electromagnetically active environments. Recently there have been several studies on integrated optic pressure sensors, biosensors, temperature sensors and strain sensors. These sensors consist of an integrated optical device, such as Mach-Zehnder interferometer, a directional coupler and a ring resonator, whose transmission characteristics change due to external effects. In this paper an interesting displacement sensor based on array of ring resonators is investigated. Coupled mode theory for extracting input-output transfer function is used. It is shown that applied displacement introduces stress on the implemented ring resonators and then the changed index of refraction will change the output intensity and frequency response. Based on the output profile and related important characteristics high precision displacement can be measured. For the proposed structure sensitivity about can be obtained.

6374B-33, Session 7

Tunable dispersion management using thermo optical effect in ring resonator

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Dispersion is important in most optical applications such as optical communications including all accessories and optical sensors. Optical pulse broadening and chirping are main disadvantages of dispersion effect. Dispersion cancellation in these applications is serious. Dispersion compensators are widely spread and there are more methods for realization of that. In this paper a novel dispersion compensator system based on thermo optical effect is introduced. Our proposal include three layers such as metal, buffer and waveguiding layers. The metal layer is biased with external control voltage (V_C(t)) and current carrying inside metal layer introduces power dissipation and create temperature variation. With external control voltage temperature can be controlled. The generated temperature changes the index of refraction and ring length. Our proposed device is so sensitive that one can control the dispersion quantity with small temperature variation as small as 0.01 0C. These quantities are used for introducing tunable dispersion management system.

In this paper, we report some interesting simulation results illustrate ability of the proposed structure for high sensitive thermo optical control and tuning of dispersion quantity. Our simulations present the ability of the proposed structure from effect of the tolerance of elements point of view on the output quantities, the sensitivity of the device, integratibility and etc. Also, the proposed structure have other applications such as integrated optical delay line.

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6375A-01, Session 1

Hardness measurements of metals with the complex refractive index

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Mechanical properties of metals are related with its crystalline structure. Particularly hardness of a given piece of metal is a result of its crystalline structure and chemical composition. In the same way, interactions between electromagnetic radiation and a sample of metal is function of its metallic structure. Given this two facts we propose in this work to relate the property of hardness with the complex index of refraction of metals. This relation gives a new non destructive method for measurements of hardness. Our technique for measure the complex index of refraction is based on the rotation of the polarization vector. Given the random profile of the surfaces and the use of extended sources of radiation, the method of measurement considers the concepts of the degree of polarization of the light and of the light partially polarized.

We will show experimental results for a commercial kind of steel, which were divided in a number of samples. Some samples were treated thermally in order to reach different hardness. Measurements of hardness were carried in Rockwell scale. The relation shape between the refraction index and the hardness is discussed.

6375A-02, Session 1

Characterization of gradient residual stress for curvature improvement of MEMS-based infrared detector structures

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MEMS-based infrared detectors have gained increasing interest because of the potential of reaching a noise-equivalent temperature difference approaching the theoretical limit. Each pixel of such an infrared focal plane array (FPA) consists of two bimaterial actuation components of SiNx/Al. As-fabricated bimaterial SiNx/Al cantilevers are always curved because of the imbalanced residual stresses. Previous study has demonstrated that rapid thermal annealing (RTA) is a valid approach to modifying average residual stress in both SiNx and Al films, while the characterization of the average residual stress in each layer is not sufficient so that the gradient stress must be included in the analysis. However, the theory for the arbitrarily gradient residual stress-induced deformation of multilayered structures is still not fully developed. Therefore, this paper first presents a theory to relate the gradient residual to the resultant bending deformation of multilayered structures and then uses this theory to determine the gradient residual stress in SiNx/Al infrared detectors structures prior to and after the RTA treatments. In our experiments, bimaterial SiNx/Al infrared FPA is fabricated with a surface micromachining module with polyimide as a sacrificial material. The 200 nm-thick Al film is deposited with an electro-beam (Ebeam) system and the 200 nm-thick SiNx film with a STSTM plasma-enhanced chemical vapor deposited (PECVD) unit. The approach presented in this paper also has the potential of helping the curvature improvement of other MEMS cantilever structures (e.g. micromirrors).

6375A-03, Session 1

An active imaging system using micromachined membrane deformable mirror

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Normal imaging systems have fixed PSF for a given object point but if we can control it to a desired shape, many interesting applications can be made. One solution of this is to lay active component in the pupil plane so that it can modulate wave front of incominig light. Vincent Laude proposed twisted-nematic liquid-crystal pixilated active lens[1] which has LC-SLM in the pupil plane. In his paper, he analyzed characteristics of the system and demonstrated phase images on the LC-SLM for basic functionalities such as image shift and focal length change. Although an LC-SLM provides pixel level phase control in limited range so that one can modulate incoming wave front with very high degree of freedom, there are several inherent problems to be used in general case[1]. First, much chromatic aberration should occur in that system, because it modulates refractive index of the pixels. Second, because of the pixelated nature of LC-SLM, high order diffraction ray degrade the image quality. Third, due to complicated combination of aliasing and quantization, ghost image appears to corrupt the image.

We propose an active imaging system which uses a deformable mirror in the pupil plane instead of LC-SLM to avoid these problems. A mirror does not suffer from chromatic aberration and continuous mirror surface does not cause troublesome diffraction beam. Furthermore, there is no ghost image, either. Main inferior points of deformable mirror to LC-SLM are limited capability of controlling wave front. We can not control the surface shape pixel by pixel as one can do with LC-SLM. Only tens of actuators are attached at the backside of the deformable mirror and they are coupled by membrane mirror. Moreover, the deformation of the mirror surface is also very limited. But for simple manipulations, like focus control, image shift or low order aberration compensation, we do not need very complicated mirror shape, so when we consider only small variation of optical system characteristics, using deformable mirror can be a better solution for wave front manipulation.

The basic concept of configuring our system is the same as that of Laude's[1]. The active component, deformable mirror is placed in the pupil plane and modulates incoming wave front. We place it at the conjugate of the objective lens. Rays that pass through two lenses are reflected by the deformable mirror and go into the imaging system. The required input voltages to get desired mirror surface for focal length change and image shift are calibrated using laser and wave front sensor with reference mirrors in feedback loop and a lookup table is made to relate the input voltages and image plane shift.

Finally, to show one possible application of the proposed system, it is shown that the system can be used to enhance image resolution which is limited by CCD cell size. In theory, it is possible to reconstruct p times higher resolution image by taking p * p images from slightly different position so that the same object is imaged at different position of CCD cell by integer multiples of a/p where a is the CCD cell dimension[2,3,4]. To take multiple images, Poletto used precision stage to translate mirror[3], and Vincent Laude used phase image on LC-SLM[4]. In this system the deformable mirror is used to shift image plane. The multiple images are combined to make intermediate image and it is processed by deconvolution step to get a high resolution image. We discuss the result in comparison with previous works.

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6375A-04, Session 2

Design of liquid crystal Fresnel lens by uneven electric field

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Introduction

Liquid crystal spatial light modulators are widely adopted by the flat-

panel display industry. Applications of liquid crystal devices in other fields may include illumination control for various sensing instruments as well as active optical interconnect. As a key device for actively modifying and manipulating the optical fields for these applications, some types of liquid crystal lenses and phase gratings have been investigated. Adequate aperture size, simple construction and low operating voltage are desired for these devices. This paper describes the design of liquid crystal (LC) Fresnel lens to address these issues.

Method

There are two configurations for the LC Fresnel lens proposed here. The first employs an uneven polymer structure on one of the two transparent substrates that sandwiches an LC layer. The cross-section of this structure copies that of a conventional Fresnel lens. A transparent electrode is placed either on top of the structure or between the substrate and the structure. Another transparent electrode is placed on the other substrate. When a bias is applied between the two electrodes, an uneven electric field is generated inside the LC layer. According to how the LC molecules are aligned, the retardations are varied and the wavefront of an incoming light is modified. The second configuration employs one uniform electrode on one substrate and one or more partial electrodes on the other substrate. Electric field distributions are controlled by the positions of these electrodes.

We have used a commercially-available software package (LCD Master from Shintech Ltd., Japan) for simulating the behavior of LC molecules under two-dimensional electric fields. Here, the motion equation for LC directors and Maxwell's equation for an electric field are solved simultaneously by adoption of a finite-difference algorithm.

Results

In the first configuration, we set the gap between the two substrates, the maximum thickness and the radius of the polymer structure to 10 * m, 5 * m and 100 * m respectively. A homogeneous alignment and two types of hybrid alignment are assumed for analyzing the behavior of nematic LC molecules. The LC director distributions are calculated for several bias settings up to 20 V, from which we obtain retardation distributions along the radial direction for a normally-incident light. The hybrid alignment (vertical on the polymer-side and horizontal on the other side) gives a retardation distribution best-resembling that of a lens. This is so for the two cases of the electrode positions. Therefore, we expect that the LC device functions as a switchable lens. In our design example, the focal length ranges from 2 cm to 8 cm. A similar simulation result is obtained with the second configuration utilizing multiple patterned electrodes without polymer structures. Because the LC retardation distributions in these LC devices are not an exact copy of a corresponding lens, we expect some levels of distortions in case of imaging applications. These distortions are less important for non-imaging applications.

Conclusion

Liquid crystal (LC) devices can be embedded in various systems such as sensor instruments and illumination and interconnect applications. They provide active optical functions such as focusing, deflecting and diverging. Here, we have proposed two configurations for a LC Fresnel lens. Both utilize uneven electric field inside an LC layer, which generates non-uniform LC director distribution and leads to wavefront control for an incident light. We have analyzed the director distributions of the LC molecules. The simulated bias-dependent retardation distributions along the radial direction suggest successful operation as a variable-focus lens.

6375A-05, Session 2

Phase retardation symmetric design

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Design of a graded index refractive element, based on a symmetric solution of the phase retardation method, that allows resonant scanners to scan proportional to t instead of sin (t), is described.

6375A-07, Session 3

Simultaneous measurement of film surface topography and thickness variation using white-light interferometry

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1. Introduction

The technique of surface profile measurement utilizing optical interference is widely used in the industry as a non-contact and non-destructive method to quickly and accurately measure the profile of microscopic surfaces. However, it involves a shortcoming of being unable to obtain an exact surface profile in measurement if the surface to be measured is covered with a transparent film. This is because the interference beam coming from the back surface of the film works as disturbance.

This paper introduces the result of a study about a signal-processing algorithm to realize measurement of the profile of surfaces covered with a transparent film by means of White-Light Interferometry, and it also describes a non-contact "Film Profiler", SP-500F, which incorporates the algorithm.

2. Method

In the Vertical Scanning White-Light Interferometry, two peaks appear in the interference waveform if a transparent film exists on the surface to be measured. The author developed a practical and robust algorithm, named the KF algorithm, that detects plural peak positions in the interferogram. This algorithm at first calculates the interference amplitudes from interferogram. Then the optimal threshold for peak separation is obtained using Otsu's automatic threshold selection method, which is popular in the field of image processing. From the peak positions determined for each of the separated peak regions and the known refractive index of the film, the surface height, the back surface height and the film thickness are obtained.

3. Results

A non-contact 'Film Profiler', SP-500F, was developed and tested. It has a lower limit to measurable film thickness. Oxide films with 0.5-2 microns thickness on a Si wafer were measured, and the minimum measurable thickness was found to be about 0.8 microns. A step in oxide film formed on a Si wafer was measured. The measured surface step was 2.9 microns, and the film thickness was 4.0 microns in the thicker area and 1.1 microns in the thinner area. These thickness values completely agreed with the measurement by ellipsometry. It is also shown that the back surface was correctly measured as a flat surface, with the supposed refractive index of 1.46. As a repeatability test, an oxide film formed on a Si wafer was measured repeatedly. The measurement of film thickness produced the following data without any area averaging: the mean value = 4.609 microns; the standard deviation(sigma) = 17 nm; and the CV value = 0.36%. Other applications include photo-resist, over-coat film, water droplet, and cell gap.

4. Conclusion

An algorithm has been devised that can automatically detect the positions of two contrast peaks in an interferogram generated by vertical scanning white-light interferometry. Using this algorithm, we have developed a non-contact 'Film Profiler', SP-500F, which enables simultaneous measurement of the front and back surface topography and the thickness variation of a transparent film. This development enables the following measurement, which conventionally could hardly be available:

(1) Profiling of a surface covered with a transparent film,

(2) Profiling of a bottom surface through a transparent film, and

(3) 2D measurement of film thickness distribution.

This system has already been introduced and effectively used in semiconductor and LCD manufacturing processes.

6375A-08, Session 3

Development of super-resolution optical inspection system for semiconductor defects using standing wave illumination shift

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Semiconductor design rules and process windows continue to shrink, so we face many challenges in developing new processes such as 300mm

wafer, copper line and low-k dielectrics. The challenges have become more difficult because we must solve problems on patterned and un-patterned wafers. The problems include physical defects, electrical defects, and even macro defects, which can ruin an entire wafer rather than just a die. The optics and electron beam have been mainly used for detecting of the critical defects, but both technologies have disadvantages. The optical inspection is generally not enough sensitive for defects at 100nm geometries and below, while the SEM inspection has low throughput because it takes long time in preparing a vacuum and scanning 300mm.

In order to find a solution to these problems, we propose the novel optical inspecting method for the critical defects on the semiconductor wafer. This method contains a combination of standing wave illumination shift with the piezoelectric actuator, dark-field imaging and super-resolution-post-processing of images. It is expected that the inspection system?fs resolution exceed the Rayleigh limit by the method. Additionally the method is optical one, so we can expect to develop high throughput inspection system.

In this report, we developed the experimental equipment for the super-resolution optical inspection system, we performed experiments for standard particles scattered light detection, and we made discussions on resolution enhancement of the method.

6375A-09, Session 3

Evaluation of laser trapping probe properties for coordinate measurement

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For past decades Micro-System Technology (MST) has been developed and size of components on micro-systems has been decreasing. Coordinate Measuring Machine (CMM) has been widely used for evaluating 3D shape of mechanical components. Regarding a commercially used CMM, a typical measuring range is (1m)3 and measuring accuracy is 1mm. Thereby microcomponents are so small that their shape cannot be measured by using a conventional CMM. Specifications of CMM must be downscaled in order to measure microcomponents. However, a matter of manufacturing measuring instruments due to downscaling and the scaling effect cause infeasibility of coordinate measurement. Based on such background, a concept of nano-CMM was proposed. According to the concept, all specifications of nano-CMM are 1/100 or 1/1000 of specifications of conventional CMM; for example, a measuring range is (10mm)3 and accuracy is 50nm. Therefore, to realize nano-CMM following points should be considered; innovative developments of position detecting probe system, an enhancement of a structure and exact calibrations of the overall system.

A purpose of this study is to establish the nano-CMM. For that purpose, innovative concepts should be devised in order to fulfill harsh specifications for nano-CMM. This is because a simply miniaturized CMM cannot cover performances of nano-CMM. On coordinate measurement, detected points determine geometrical quantities of a measured specimen, that is, distances and positions of detected points are important. Thus, a position detecting probe system plays an important role for overall high accuracy in coordinate measurement.

In this paper, a first prototype of the nano-CMM with the laser trapping probe was built. Notable point is the probe system. We propose laser trapping probe as a position detecting probe for the nano-CMM. It is a kind of tactile probe. A micro-glass particle is trapped in air and is oscillated transversally by deflecting a laser beam. When this vibrating probe is coming close enough to a sample surface, viscous drag force working toward the probe acutely increases. This causes phase lag between vibration of the probe particle and the deflection of laser beam. This phase lag changes a distance between the probe particle and a sample surface. Therefore a position on sample surface can be detected by monitoring the phase change. Outstanding features of laser trapping probe is mainly following; extremely small measuring force, high sphericity of a probe, ease of controlling probe property depending on laser condition and high sensitivity of detection. On fundamental investigation, it was confirmed that this probe could detect the edge of an as-cleaved silicon wafer with the measuring accuracy of better than 30nm. In the prototype, laser trapping optical system was designed to be accommodated in a compact unit and the unit was installed at the nano-CMM. In terms of this laser trapping probe unit, fundamental functions, characteristics and finally properties as a position detecting probe were investigated.

Before implementing coordinate measurement with the nano-CMM with laser trapping probe, optimization of vibration conditions of a microprobe particle have to be carried out. This is because each probe particle has slightly different shape and mass. So, in order to detect a sample surface sensitively, optimal parameters of vibration conditions are required to obtain. That procedure is so-called parameter tuning. Procedure of the parameter tuning is divided three phases. On first phase, it is confirmed to trap a silica particle with a diameter of 8mm in air and to obtain probe signals with a photo detector via backscattering light from the probe particle. On second phase, it is verified whether or not a probe particle follows a deflection of laser beam by comparing a vibration of probe particle and the deflection of laser beam. On last phase, frequency response of a probe particle is studied in order to find a resonance frequency of a probe system itself. Based on the procedure, optimal probe conditions are found out. After parameter tuning, probe behaviors approaching sample surfaces with different shapes are investigated by using artifacts. This investigation makes it possible to determine important parameters for probing. Properties of the laser trapping probe lead well-designed measurement strategies.

6375A-10, Session 3

Measuring shapes of three-dimensional objects by rotary focused-plane sectioning

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This paper presents a new method of measuring a 3-D shape based on a scheme of shape-from-focus. Principles of 3-D machine vision for handling and shape inspection of objects are classified into triangulation and shape-from-focus. Stereo vision and light-plane sectioning belong to the former. Shape-from-focus is usually implemented in two ways of focused-plane sectioning. One is to translate either object or image sensor along an optical axis so that a focused-plane can scan the object [1]. The other is to adapt imaging optics to focus on a measurement point using a varifocal lens or mirror [2] while both of the object and the image sensor are fixed. We devised a new shape-from-focus method useful for modeling a robotic work space. In the new method of focused-plane sectioning, the focused-plane was rotated around the axis of rotation to be able to scan omni-directionally and obtain panoramic range data on the space where works were located.

The focused plane was inclined typically at 6 degrees to the optical axis of an image-taking lens with a 2-D image sensor inclining to the optical axis at 54 degrees in order to sweep the object by rotating the optical system around the rotation axis set vertically to the optical axis at the front focal point. In rotary focused-plane sectioning, an object contour is produced as an intersection line of the focused-plane and the object surface. The contour was determined by detecting the pixel having the maximum value of focus-measure among pixels corresponding to the same measurement point in a series of focused-plane images, which were taken at a rotation pitch of 0.02 degrees during sweeping the object by the focused-plane. Adoption of telecentric optics in image space ensured that the pixel having the maximum focus-measure was detected correctly and automatically by checking the pixels in turn at the column numbers different from each other by a constant number in the same row in the direction of rotation among the focused-plane images. The difference of the adjacent pixels checked in column number is defined by the rotation pitch, focal length of the lens, inclination angle of the image sensor, and the pixel pitch. In our case, the column interval for checking focus-measure values was 5 pixels. The 3-D coordinates of the measurement point could be determined from the address of the focused pixel and the rotation angle at which the focused-plane image including the focused pixel was captured. We presented the complete formulation for contour detection.

We also presented experimental results to demonstrate the performance and precision of rotary focused-plane sectioning. We found that astigmatism of the imaging lens was a major factor of systematic errors in detection of 3-D coordinates and that the errors depended on direction of each contour. A difference of the horizontal and vertical edges in range was 20 mm at a distance of 730 mm in the measurement system using an imaging lens with a focal length of 52 mm (EL-Nikkor, NIKON) and a high- resolution monochrome CCD image sensor with 1392 x 1040 pixels (4.65 μm x 4.65 μm/pixel). Output of the Sobel operator of 5 x 5 in size was used as focus measure. This is important in contour-based shape-from-focus at a

long range. We devised an effective correction method, where the coordinates of a contour point were corrected by detecting an edge direction of a contour image using the Sobel operator and interpolating the corrected range and azimuthal angle of the contour point between the predetermined ranges and azimuthal angles of the horizontal and vertical contour-points using the contour edge direction. Finally, position errors in an azimuthal plane were reduced to less than 0.5 mm and range errors were less than 9 mm for an edge direction of 45 degrees at a distance of 730 mm. We used the contour-based shape-from-focus method by rotary focused-plane sectioning successfully to measure a geometric object 57-mm high and 70-mm in diameter with cylindrical and conical surfaces without texture and a miniature of a porpoise 147-mm long with free-form surfaces and to produce the 3-D contours of the objects. They were located at the distances of 700 mm and 750 mm, respectively.

Rotary focused-plane sectioning was proved to be free from both the dead angle due to the need of simultaneous observation from two different viewpoints in triangulation and unreliability in binocular-image processing to detect disparities in stereo vision. Moreover, our new method could produce a panoramic range data by rotation of the focused-plane at a wide angle and could obtain the contours of 3-D objects with reflective surfaces using non-directional lighting. The performances were done by simple and versatile image-processing for detecting pixels in focus, although it needed massive computation, which promised to be done fast by using an FPGA processor.

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6375A-25, Poster Session

Precision laser beam movements assisted by sensors

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Engineering, Medical fields and a lot of other activities require the supervision of linear or angular movements, in order to ensure the necessary precision.

The author who cooperates with a German sensor company studied how to apply some types of sensors suitable to their research.

The main problems were movements of hands and legs, for some specific body disabilities, reciprocal position between two or more teeth and other problems related with precision micromachining.

Many persons are prescribed to do exercises, in which the hand(s) or the leg(s) will be active in an established manner and space, may know if the movements are correct done in order to not surpass the established limits. Immediately an optical or sonorous signal is activated when the limits of the fixed movement are not correctly and automatically stopped if the subject is itself unable to stop. The same is with the angular removals.

Authors proved the described montages. The laser source was a so called “laser pointer” fixed on the moving part of the body - hand or leg - and on a frame settled in front of the laser pointer was mounted a photo-sensible contour having established shape and dimensions.

The role of the sensors is to amplify the optical control security. The whole system could run only optical, only with sensors or with both together. Authors compared the three possibilities.

6375A-26, Poster Session

Expansion of measuring range of stereovision system based on Mono-MoCap

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In the previous paper, the authors achieved a 3D motion capture system by using one camera with triangle markers, named as Mono-MoCap (MMC). The camera parameters were calibrated by means of the modified Direct Linear Transformation (DLT) method. The relation between the image coordinate value and the absolute coordinate value was expressed by the calibrated camera parameters. The absolute coordinate values of apexes of a triangle marker were calculated on the basis of the perspective n point (PnP) problem.

By putting a triangle marker on each human joint, MMC could capture a human walking motion, and MMC had the wider measuring range than the stereovision system in the parallel plane of the image frame.

This study aims to improve the measurement accuracy of MMC and expand the measurement range of stereovision system by fusing both motion capture systems.

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6375B-11, Session 4

Triangular phase-shifting algorithms for surface measurement

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1. INTRODUCTION

The fringe projection technique is a widely used method for three-dimensional (3-D) object-shape measurement. To increase the measurement resolution, phase-shifting methods have been implemented in fringe projection methods to extract phase information. The algorithms to retrieve the phase distribution based on projecting a sinusoidal fringe pattern have been widely established. A new method that combines digital fringe-projection of a triangular gray-level-coded pattern with application of an intensity ratio-to-height conversion algorithm has recently been developed. The algorithm is based on the traditional phase-to-height conversion algorithm in the sinusoidal phase-shifting method. Compared with the traditional sinusoidal phase-shifting-based method with the same number of phase shifts, the processing speed is expected to be faster with similar resolution. The minimum number of measurements required to reconstruct an unknown 3-D object is two, which is less than the minimum number of measurements requirement for the traditional sinusoidal phase-shifting method. In this paper, the triangular phase-shifting method and intensity ratio-to-height conversion algorithms are developed for different number of phase shifts, to explore the trade-off between increased number of measurements for accuracy and the higher cost of processing.

2. METHOD

In the triangular phase-shifting method, a triangular pattern coded with gray levels is generated by software and used for projection. The measurement technique is developed for triangular pattern phase-shifting by two steps, three steps, four steps, etc. to reconstruct the 3-D object. The phase shifting algorithms to retrieve the intensity ratio, which are essential to obtain the height of the object, are developed for each method. A triangular shape intensity-ratio distribution is computed from the captured triangular patterns. Removing the triangular shape of the intensity ratio through the full pattern pitch generates an intensity-ratio ramp. Measurement resolution can be increased by using multiple triangular fringes. In this case, the intensity ratio is wrapped into the range of 0 to 4, 0 to 6, 0 to 8, etc, for different phase-shifting methods. The unwrapped intensity-ratio distribution is obtained by removing the discontinuity of the wrapped image with an unwrapping method modified from that used in the sinusoidal phase-shifting method. An intensity ratio-to-height conversion algorithm, based on a traditional phase-to-height conversion algorithm in the sinusoidal phase-shifting method, is then used to reconstruct the 3-D surface geometry of the object.

3. EXPERIMENT AND RESULTS

To verify the performances of the proposed approach, a flat plate was measured by the triangular phase-shifting method. The plate was measured first at the reference position, and then the plate was moved 10 mm toward the camera, and measured again. The root-mean-squires errors of the depth calculation between the two positions were obtained. The measurement results indicated that more phase steps usually can generate higher accuracy in 3-D shape reconstruction. However, it also depends on whether the pitch of the triangular pattern can be evenly divided by the number of phase steps, as the number of pixels in the image are integral. A human mask was also measured and the 3-D object reconstructed to demonstrate the effects of the increase in the number of phase shifts and images required for the 3-D reconstruction.

4. CONCLUSION

The triangular phase-shifting approach was developed for increasing number of phase shifts and images processed for 3 D object reconstruction. More phase steps generate higher accuracy in 3-D shape reconstruction; however, the digital fringe projection generates phase shifting error if the pitch of the pattern cannot be evenly divided by the number of phase steps.

6375B-12, Session 4

Repeated phase-offset measurement for error compensation in two-step triangular phase-shifting profilometry

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1. INTRODUCTION

Based on digital fringe-projection, intensity-ratio, and phase-shifting techniques, a new 3-D shape measurement method, called two-step triangular phase-shifting method, has been developed. Compared with the traditional sinusoidal and trapezoidal phase-shifting methods, this method involves simple computation of the intensity ratio and fewer images required to measure the 3-D object, leading to reduced processing. It also has a better depth resolution and less ambiguity problems compared to traditional intensity-ratio based methods. However, measurement accuracy is limited by the effects of gamma non-linearity and defocus of the projector and camera.

This paper presents an improved two-step triangular phase-shifting method developed to reduce the measurement error, generated mainly by the gamma non-linearity and defocus of the projector and camera. In this method, two-step triangular phase-shifting is carried out twice, the second time with a phase offset in order to compensate for errors occurring in the first measurement.

2. METHOD

To improve the measurement accuracy of the previously developed two-step triangular phase-shifting method, measurements of a flat plate were first made using a series of triangular patterns generated with different minimum intensity values ranging from 0 to 80, at increments of 20. The triangular projected pattern with a minimum input intensity value of 40 had the greatest reduction of the effect of defocus and generated the highest measurement accuracy. Due to the defocus of the projected lighting and the gamma non-linearity of the image projector and camera, the resulting profile of a measured object results in an error in the form of a wave. The frequency of the error wave in a pitch of the triangular pattern is 4. To compensate for this error wave, the object is measured twice by the two-step triangular phase-shifting method. For the second measurement, a phase offset of one eighth of the pitch is introduced relative to the first measurement. For this second measurement, the peaks and valleys of the error wave are reversed from that of the first measurement. Averaging of the two measurement results for the complete image, therefore countervail the wave error of each other for the complete 3-D surface.

3. EXPERIMENTAL RESULTS

To verify the performance of the repeated phase-offset measurement for error compensation in the two-step triangular phase-shifting method, a human mask was measured with both two-step triangular phase-shifting method and the repeated phase-offset measurement method. The measurement results indicated that the reconstructed surface of the human mask was smoother with the repeated two-step triangular phase-shifting method and error compensation, than with the single measurement. To quantify the improvement in measurement accuracy of the repeated-measurement method, a flat plate a distance of 25 mm from a reference plate was measured and root-mean-square (RMS) errors of the depth calculated. The measurement accuracy using the repeated measurement for error compensation increased by approximately 27%.

4. CONCLUSION

The two-step triangular phase-shifting method was significantly improved using the repeated phase-offset measurement approach. The experimental results demonstrated that this method can significantly decrease the measurement error that results from gamma and defocus non-linearity errors of the projector and camera.

6375B-13, Session 4

An active vision sensor system employing adaptive digital fringe pattern generated by DMD pattern projector

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In these days many 3D sensor systems such as stereo vision, optical triangulation sensor and moiré technique have been developed and researched to measure 3D scene environment and objects. Among them the active sensing system, which utilizes the special illumination system or light projection fringe pattern, is well known for quick, fast and accurate 3D measurement. Their measurement is robust to environment illumination noise and consequently can acquire accurate result. In addition to this sensing characteristic, the sensing time is very short. With these advantages it is used for many applications.

For active vision sensor system, the main research issue is how to accurately and fast measure the objects and environments by using suitable number of laser structured lines and suitable shape of fringe pattern. Therefore, till now many methods have been suggested such as multi-laser strip projection, coded structured light projection, color pattern projection and intensity modulation pattern projection methods and so on. However, these methods have their limitations: correspondence problem, sensitive to environment illumination noise, sensitive to object surface color, etc. And these methods mainly have used analog devices such as gratings which have fixed pitch, laser structured light or phase measuring profilometry (PMP).

The main problem of these methods is that mostly they used only vertical fringe pattern with equal interval. As using this vertical fringe pattern with equal interval, the resolution difference occurs between vertical and horizontal direction. As a result, the measurement result of circular object or rotating object looks strange. Furthermore, sometimes the measurement fails since shadows, high density of the fringes, edges, over-modulation, reflection and blurred regions of the object refuse exact evaluation. If we can project different and suitable fringe pattern at these areas which bring about measurement error, we can reduce the measurement error. In this paper to overcome the above mentioned problems and project different fringe pattern at given areas, we introduce an adaptive digital pattern projection algorithm, where the fringe pattern is changed flexibly based on object shape to reduce the measurement error and to obtain the detail measured result.

In our research, therefore, in order to make a flexible fringe patterns and an application oriented pattern, Digital Micro-mirror Device (DMD) is applied. The DMD contains more than 780,000 tiny, movable square mirrors which are fabricated by MEMS technology. Each mirror can bend ±10 degree, and they can be controlled by on/off digital signal within 30 microseconds.

Our proposed sensing algorithm consists of two parts. First part is to find a 3D shape of environment or objects roughly by using sparse and simple fringe pattern with constant interval. In this process triangulation method is applied because this method is easy to implementation. The triangulation method is also robust to environment state and accurate, so that it is very good to compare the result of using simple fringe pattern with adaptive fringe pattern. Then after finding rough 3D information of objects, we make a digital fringe pattern adaptively based on the measured result obtained from previous process. The digital fringe pattern is generated under the consideration: (1) finding an object shape more detail, (2) increasing the measurement accuracy (3) verifying the first measurement result. Then the project pattern which was made in previous step based on object shape is projected to the object again by using DMD projector and we apply the triangulation method again. Finally we can acquire the accurate measurement result.

Our sensor system measures the 3D object and environment shape with adaptive fringe patterns. In this paper, a method is described how to make an adaptive fringe pattern according to the object shape and how to do the fringe projection measurement method. This is realized by a programmable DMD pattern projector. The whole system and algorithm have been verified on various experimental objects.

6375B-14, Session 5

Virtual assemblage of fragmented artefacts

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Fragmented solid objects are commonly encountered in a variety of diverse fields including industrial inspection, customized medical prosthesis design, forensic science, paleontology, and archaeology. For example, during archaeological artefact reconstruction there is little or no a priori knowledge about the exact number of pieces or the original shape of the object. In addition the pieces recovered from an excavation site are often severely damaged or discovered in isolation. Once the physical evidence has been recovered, the archaeologist utilizes field experience and cultural knowledge to reconstruct the original relic or skeleton by searching through the damaged pieces, interpreting the original artefact shapes and then connecting the various fragments to create a realistic representation of the entire object. The process of reconstructing ancient relics, such as pottery, from damaged pieces involves inspecting the piece shapes and fragment boundaries and joining the fragments with adhesives and/or additional structural support material to recreate original object appearance. Gluing actual pieces requires both precision and confidence because the process of reconstruction is essentially irreversible. To prevent further damage and enhance visualization archaeologists have begun to exploit 3D data acquisition and graphical modeling tools. The creation of multiple geometric models from digitized data is nondestructive and repeatable thereby providing the archaeologist with an opportunity to investigate alternative relic configurations from a small number of fragments. Since the reconstruction is performed within a virtual environment, the joining or “gluing” of separate damaged fragments will occur in the absence of gravity.

In this research, a computational framework based on a deformable mesh with hexahedral elements generated by a self-organizing feature map (SOFM) is being developed for interactive virtual assemblage and sculpting. The SOFM is a lattice of nodes arranged with predefined topological connections. Prior to shape manipulation the volumetric mesh is either retrieved as a shape primitive from an object database (ie. library) or created directly from representative surface points. Geometric information is then incorporated in the topologically ordered lattice as it deforms in the object space during the shape transformation process. If the constituent nodes are interpreted as point masses connected by a network of springs, then additional material properties can be assigned. The shape transformation algorithm estimates the new position of the constituent nodes due to external and internal forces at each instant in time. The external forces can be estimated and introduced to the system by the haptic rendering software. Any object with a closed surface that is topologically equivalent to a sphere or n-torus (ie. n holes) can be created. In the current version, geometric models of the fragments are handled and manipulated in the VR environment using a simple force feedback haptic tool produced by SensAble Technologies. The haptic device provides tactile cues that assist with the assembly process and permits sculpting of soft clay that has been added to the assemblage for complete 3D shape reconstruction. Results from preliminary experiments are presented to demonstrate the model generation process and the procedure for adding new material to the 3D shape model during virtual shape reconstruction. The limitations of haptic feedback in assisting the process will also be discussed.

6375B-15, Session 5

Template generation by component maximization for real-time face detection

C. A. Perez, J. I. Vallejos, Univ. de Chile (Chile)

Real-time face detection on video sequences is important in diverse applications such as, man-machine interfaces, face recognition, security and multimedia retrieval. In this work, we present a new method based on the maximization of local components in the directional image to optimize templates for frontal face detection. In the past, several methods for face detection have been developed using face templates. These templates are based on common face features such as eyebrows, nose and mouth. Templates have been applied to a directional image containing faces computing a line integral to detect faces with high accuracy. In this paper, the maximization of local components in the directional image is used to select new templates optimizing its size and response to a face in the directional image. The method selects common directional vectors in a set of frontal faces to generate the template. The method was tested on the Caltech face database using 386 images and compared to the results of the traditional anthropometric templates that contain features from the eyebrow, nose and mouth. Results show that the new templates have

significant better performance in the estimation of face size and the line integral value. Face detection reached 98% on the Caltech face database. The templates have fewer number of points compared to the traditional anthropometric templates which will lead to lower processing time.

6375B-16, Session 5

Local retouching of images by histogram-based similarity evaluation

L. Fu, S. Kaneko, T. Tanaka, Hokkaido Univ. (Japan)

In this study we aim to develop a method to improve quality of local regions that are extracted by using a histogram-based rough segmentation algorithm.

Quality of local regions in the scene is deteriorated by some ill-conditioned effects in lighting, shading, saturation, and reflection. There have been proposed many algorithms for the restoration of picture quality, which are basically pixel color transformations through look-up tables in the whole image. Pixel selection is well performed in feature spaces, such as a color space, for recovery of only the pixels expected to bear some previously specified characteristics. On the other hand, scene segmentation has been one of the important fields in image processing. But we do not have any universal methods effective to segment regions with a kind of semantics.

In many researches local regions are selected by using edge segmentation or textures, but if edges or boundaries of objects may not be well-defined, it is difficult to select the full parts of the local region accurately. So we propose a method to select the local regions by rough segmentation based on similarity evaluation of histogram on color textures. By analyzing the histogram similarity in color space such as the HSI space, we can select an area roughly surrounding the specified regions with the following two consistencies: the local or positional consistency and the color consistency in the distribution or texture. We have the estimation that if the selected areas have both the consistencies they can be retouched effectively in the both features. So from the point user selected we compute similarity based on two channel histograms of the circle and its adjacent ring every time when the radius is increased, and then by analyzing distribution of the similarities we firstly select a rough local region in circle form, next by comparing the color textures of pixels in neighboring area with histogram of the circle area we could select the local region in accurate form. In the second step, the selected region is retouched by representative methods for quality modification, such as the histogram equalization or others. In the third step, in order to minimize artifacts occurred between the selected and the neighboring regions a merging method is presented.

In this paper we have proposed a method for rough selection of the local region of image based on the histogram similarity evaluation. We have investigated this method for integrating histograms of color textures such as hue and brightness in HSI space. After improving the quality of the local region of image, we apply the merging procedure to combine the data of original image with the data retouched. Experimental results demonstrate the capabilities of the method to make the local region retouched and merged with the surrounding regions naturally. Errors in the selection were also reduced by the merging method.

6375B-17, Session 5

Using orientation code matching for robustly sensing real velocity of agrimotors

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The purpose of our research is to measure real velocities of agrimotors or working machines, such as sprayers and harvesters, driven by them in real farm fields. For solving these problems without any tachometer-type sensors which are based on proximity sensors installed on tire foils and very poor in precision in case of slipping, currently, introducing information technology can be one of promising approaches which have many side effects in this non-developed field in the view point of adopting high intelligent softwares for so called ‘precision farms’.

Therefore it is necessary to develop a high-accuracy velocity sensors which are independent of slipping and robust against many ill-conditions occurred in the real world farm fields. We propose a method to measure real velocities of agrimotors by image matching or registration. Template matching is one of the most fundamental technologies in image processing or application of image processing. However, it has been also difficult to find robust methods or algorithms for image registration. Orientation code matching, OCM, is one of the robust algorithms for many kinds of ill-conditions, such as illumination fluctuation, high-lighting, occlusions and saturation. It is proven to have large robustness for them by the theoretical analysis and many experiments with real world images. It is very important for the realization of our targets to design a system based on the robustness of OCM against brightness change due to irregular conditions such as occlusion and illumination fluctuations, which happens frequently in the real farm fields.

In the proposed method, first, we determine three templates on fixed positions in a reference image defined in the real-time and on-line image sequence taken by an IEEE 1394 camera installed vertically on the agrimotor, and then after a constant short period, a target image also captured by the same camera. Each matching or registered positions of the template in the target image are detected by OCM. We then re-calculate a velocity of a target image relative to the reference image by use of offset values of matching positions and averaging them in consideration with outlying matching. Then a traveling distance in the real farm filed is reconstructed through a simple scheme dependent on the averaged displacement, the traveling time and other parameters, such as a vertical height of IEEE 1394 camera and image resolution. For reducing the computation time, we considered about to reduce the number of matching based on pixel skipping and to estimate matching positions in accordance with the agrimotor motion for more adaptive and efficient search.

We have designed and made a pilot model mounted on working machines pulled by the agrimotors, and we have performed experimental verifications in the real fields, of which conditions were in very large difference also in weather. For the real world experiments, we prepared landmarks in the farms. Experimental results in the farm field have shown that the proposed algorithm can measure the real velocities of agrimotors even in rainy condition or in early evenings. So, the algorithm could realize a high precision and faster computation which are practically effective for the real world use. The effectiveness and efficiency of the proposed algorithm could be experimentally verified in the farm fields.

6375B-18, Session 6

Spherical imaging array based on bioelectronic photoreceptors

W. W. Wang, G. K. Knopf, A. S. Bassi, The Univ. of Western Ontario (Canada)

The capability of existing shape and scene capture systems is limited by imaging technology that require 3D world points to be projected onto planar charge-coupled device (CCD) image planes. This technology reduces the field-of-view and constrains the algorithms used to extract spatial information. In the area of mobile robotics omni-directional and panoramic visual sensors are being developed to gather image data over a wider area of the scene. These unconventional visual sensors also enable researchers to develop more efficient algorithms for optical flow, stereo, and range estimation. Unfortunately, the imaging results from omni-directional sensors suffer significant deformations that limit their effectiveness because they utilize conventional planar CCD cameras attached to convex mirror and complex lens assemblies to capture hemispherical or spherical images.

This paper will describe the advances made towards realizing an innovative spherical imaging system that exploits the fast photoelectric signals generated by dried bacteriorhodopsin (bR) films. A non-planar array can eliminate unnecessary optics and reduce distortions. Employing bR-based photodetector is an attractive alternative to silicon-based technology because it performs some signal processing at the material level and can be fabricated as an array of photosensitive elements on flexible indium-tin oxide (ITO) substrates. The array can be formed into any desired shape, including the exterior of a sphere (omni-directional) or the interior surface of a hemisphere (e.g. humanoid retinal). In this regard, purple membrane patches obtained from wild-type bR can be deposited onto a polyethylene terephthalate (PET) substrate coated with a patterned ITO layer using the Electrophoretic Sedimentation (EPS) technique. The preliminary prototype consists of a

flexible 4Å~4 pixel array and an amplification circuit. The circuit magnifies the small electrical signal arising from the charge displacement and recombination in the dried bR thin film. The measured photoelectric response of each individual pixel is approximately linear over the light power range of 200 microwatt to 12 milliwatt. The bR photocells respond primarily to visible light with a spectral peak response at 568nm. Signal response times have been observed in the microsecond range when exposed by an intense light burst.

Preliminary tests have also demonstrated that the photoresponse characteristics of the array are maintained if the flexible substrate is deformed up to a 10mm bending radius. Spatial and temporal experiments are presented to illustrate the viability of developing bioelectronic arrays for non-planar imaging systems. The initial prototype array is, however, susceptible to variations in inter-pixel response arising from non-uniform film thickness and high electrical resistance of the constituent films. The current limitations and related fabrication issues will be also summarized.

6375B-19, Session 6

Non-contact vibration analysis using innovative laser-based methodology

D. Shetty, T. A. Eppes, S. Notiega, J. Kondo, Univ. of Hartford

Due to increasing requirements in performance, in areas such as computers and automobiles, manufacturing companies have been forced to produce within tighter tolerances and perform more elaborate testing to validate their products. In the case of automotive manufacturers the measurement of vibration is essential. In the past, equipment such as strain gauges and piezoelectric accelerometers have been adequate in measuring it. However, they have had several disadvantages. One disadvantage being that the part must be mounted on the surface of the object being measured. This can result in the mass altering the frequency and mode shape of the vibrating object. Laser technology is a non-contact measuring method providing the accuracy needed to satisfy the changing requirements. This paper provides an innovative method of detecting vibration using a laser based technique. The instrument can not only measure vibration, but also gives an idea of breakthrough in drilling applications. Besides being used as a research tool, it can also be used in the education of engineers and technologists. The paper outlines the design methodology and test results.

6375B-20, Session 7

Camera pan-tilt ego-motion tracking from point-based environment models

J. Boehm, Univ. Stuttgart (Germany)

Ego-Motion tracking is an important problem in computer vision. Applications range from self-localization and augmented reality to object recognition under camera motion. We restrict the camera motion to one common motion type known as pan-tilt motion, which consist of two rotations one about the vertical and one about the horizontal axis perpendicular to the optical axis, where the rotation centre is the projection centre of a camera.

Several approaches exist which use some variation of stereo algorithms to compute camera motion from arbitrary input image sequences. These approaches compute relative motion from frame to frame, known as dead-reckoning. In contrast our approach falls into the category of absolute orientation systems, such as other landmark or model-based approaches or active beacon or GPS systems.

We propose a point-based environment model (PEM) to represent the absolute coordinate frame in which the motion is being tracked. The PEM can easily be acquired by laser scanning both indoors and outdoors even over long distances. In contrast to other model-based approaches we need no expensive modeling step but we use the raw point data for scene representation. Also the approach requires no additional active components such as IR beacons to be installed while tracking. Using intensity and range edge detection techniques we automatically extract key points from the PEM which are tracked across the image sequence. Using the orientation information extracted from previous frames we create a hypothesis image which contains the predicted locations of the key points. The hypothesis image is matched across the current input frame for exact localization. Matching is performed in the direction of the two image plane coordinate axes only. This is valid since we have restricted the ego-motion type to a pan-tilt motion. The exact location of the match is then converted to the two angles describing the pan-tilt motion.

The proposed approach results in a robust yet simple sequence of image processing procedures, mainly consisting of edge extraction and intensity image matching. Using simple image processing blocks creates the possibility of using highly optimized image processing libraries creating the real-time capability of the approach. The approach creates the advantage of computing an absolute orientation with respect to the coordinate frame established by the PEM. Using pre-defined key points extracted from the PEM makes the approach more robust against diverse motions caused by moving objects in the scene.

The natural extension of the proposed method is to lift the restrictions on the motion type and allow for free motion. However in this case the motion of the key points is not uniform but heterogeneous in the image and thus we can not match a fixed hypothesis image against a frame of the input sequence. Rather we have to track points individually using a feature tracker. This extension is expected to be more costly and less robust than the proposed method which assumes uniform key point motion in the image plane. This shall be further investigated in subsequent studies and experiments.

6375B-21, Session 7

Object tracking by block division based on radial reach filter

N. Wajima, S. Takahashi, Kagawa Univ. (Japan); M. Itoh, Hitachi, Ltd. (Japan); Y. Satoh, National Institute of Advanced Industrial Science and Technology (Japan); S. Kaneko, Hokkaido Univ. (Japan)

The technique of image processing to track the moving object on image which taken by the fixed camera is needed in the various fields. There are some problems to apply for the applications. Especially, it is difficult to track the moving objects by the influence of change of image by the time progress.

In this paper, the changes of image like the brightness and region by the time progress is described as the change of background. Then, we propose new tracking method to moving objects considering the change of background. First, the Radial Reach Filter?iRRF?jwhich is one of typical methods which detect the object is applied for the change of brightness. And then, using the radial reach information calculated by RRF and block division, the region of moving objects is detected and distinct. In addition, applying the radial reach information to calculate the amount of movement of moving object on the image, the moving objects are tracked in time series images. In this paper, we consider the method of recognition whether the same object between images on the time series images. One of the recognition methods is the method using RRF. However, RRF detects the region which has same texture. That is, RRF detects the same background. Then, we consider the figure of moving object and propose the recognition method using the radial reach information. Finally, we will give some experiments in order to show the validity of our proposed method.

6375B-22, Session 7

A vision-based billiard ball entertainment system

C. Shih, Tunghai Univ. (Taiwan)

A billiard ball vision based tracking system is designed to provide players a guiding system for placement of the hitting rod. The major goal is to increase the aiming accuracy during the hitting process to help increase the fun of playing this game. This research first presents the system setup, followed by the algorithms developed in processing the images during the tracking process of the rod and the cue balls. Then, the image calibration process is discussed to accurately correlate the ball center pixel coordinates with an actual position on the billiard table. Finally, a testing process is developed to verify the accuracy of the system in guiding the user to sink the target ball into the desired pocket.

The system is composed of a CCD camera, a vision card, a hitting rod with tagged tip, and a graphical user interface. The CCD camera is mounted directly above the billiard board table by a set of fixtures. The camera orientation is set arbitrarily. The only restriction is that the field of view must cover the entire billiard board table with minimum amount of surrounding environment pixel information enclosed. The tip of the

hitting rod is tagged with two stripes of green cloth a small distance from each other, leaving two isolated color regions different from the surrounding table color. A Pentium III PC running an interactive graphical user interface sits right next to the billiard table. The interface guides the user in placing the hitting rod in accordance with an imaginary guiding line drawn from the cue ball. The imaginary guiding line is calculated based on a well known physics law of collision given the cue ball, target ball position and the target pocket center positions. The user interface displays the table image together with all color balls' image developed under MFC. Additional to these images, the image regions where the pockets are located are also marked with red circles to allow user to pick as a target pocket. Given the selected target ball and specific pocket by user, the imaginary guiding line can then be calculated and displayed on the screen. The rest of the system contains regular billiard game sets like nine color balls and a cue ball.

Before the system can grab pictures and analyze the image, a calibration procedure is taken to correlate the image coordinates with the actual coordinates on the billiard table. A calibration board with grid pattern is printed and placed on the billiard board. The camera is then triggered to take a picture of this calibration board. The actual coordinates of the intersection point of the grid line structure on the calibration board are measured and stored in a matrix. The image coordinates of the grid intersection points are extracted using a regular thinning and edge extraction image processing algorithms. The image coordinates are then stored in another matrix. A correlation matrix is then calculated using least square error transformation. This matrix will then be used for transformation calculation between any single image coordinates and any actual coordinates on the billiard table.

The image processing steps need to first calculate the centroid position of the cue ball and the target ball. An RGB to HSV conversion is exercised for each pixel. A histogram chart is then built based on the H value for all the pixels of an empty table image. A range of H value about from 110 to 185 is selected to filter out any non-table background information. These include the environment background and possibly the balls and rod images. Some unwanted broken holes are found on the green background of the empty table image. A median filter algorithm is then followed to patch up these holes with homogeneous green color. A typical thresholding and sobel operator are used to segment out the boundaries of the table, cue ball, target balls and the rod. Tracking on the rod and balls are then made possible by finding the centroid of each of these boundaries.

A testing algorithm is devised to check for the deviation of the hitting rod from the ideal guidance line calculated using the actual cue and target ball center positions. An intensive testing plan is then exercised to verify the success rate with respect to the deviation value each time the cue ball is hit. Within a deviation tolerance of 1 degree will always guarantee a success hit.

6375B-23, Session 7

An edge tracking approach for tape substrate (TS) pattern inspection based on skeleton information

Y. J. Roh, C. W. Kim, H. H. Lee, D. H. Jeong, LG Electronics Inc. (South Korea)

We introduce a novel inspection system for tape substrate(TS) product and an inspection method. Since TS product is a high-density printed pattern on thin and flexible substrate, it requires high resolution imaging system and precise mechanisms. In the developed system, a reel to reel tension controlled system feeds tapes into inspection zone, where high resolution images (16,000 pixels/line) are acquired by line scan cameras.

From the image, undesired particles or pattern errors such as open/short, nick and protrusions are detected by comparing it with a master pattern image. In practice, however, even the patterns that do not contain defects are not perfectly identical to the master one. The discrepancy comes from mechanical issues during image acquistion and producing process also, which makes it difficult to inspect the fine pitch patterns in a reliable manner.

To inspect the pattern in the presence of local discrepancies, we propse an edge tracking inspection method based on skeleton infomration. Since the patterns by themselves are collection of lines, we can get a connection graph model through a skeleton process in the reference image. The connection graph approach is a robust method for inspecting pattern open/short defects in the presence of local image discrepancies. In the inspection step, the corresponding connection graph is obtained by edge tracking method instead of skeleton. By utilizing edge-tracking method, we can reduce computation time drastically, and can detect boundary defects such as pattern nick and protrusions as well.

In the final manuscript, we will present the experimental results and show its usefulness in our application.

6375B-27, Poster Session

Development of macro defects inspection system for TFT-LCD color filter glass

H. I. Son, C. J. Jeon, Y. I. Kim, SAMSUNG Electronics Co., Ltd. (South Korea)

This paper presents a new systematic methodology for automatic inspection system of macro defects of TFT-LCD color filter glass. This inspection system can image macro defects that is not shown and not detected in the other macro defects inspection system. The contribution of the paper can be summarized as follows.

This paper establishes a new automatic inspection system focused on industrial application. In comparison with the manual inspection system, the proposed system allows less inspection time and high productivity because it does not depends on the sensitivity and experience of human operator. And compared to the other automatic inspection system of macro defects, we can image the special macro defects using new optical system we designed for example column spacer type macro defect that is hard to be detected. Finally, the proposed algorithm is very efficient for real-world problem.

Inspection algorithm proposed in this paper can not classify the type of macro defects. To more effective monitoring of manufacturing process the additional algorithm for classification of various macro defects is needed.

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6376-01, Session 1

Three-dimensional nanostructure fabrication

S. Matsui, Univ. of Hyogo (Japan)

Three-dimensional nanostructure fabrication has been demonstrated by 30 keV Ga+ focused-ion-beam chemical-vapor-deposition (FIB-CVD) using a phenanthrene (C14H10) source as a precursor. The deposition film is a diamondlike amorphous carbon. Producing of three-dimensional nanostructure is discussed. Free-space-nanowiring and nanomechanical devices with 0.1μm dimension are demonstrated as parts of nanomechanical system.

6376-02, Session 1

Low-temperature bonding of a LiNbO3 waveguide chip to a Si substrate in ambient air for hybrid-integrated optical devices

R. Takigawa, E. Higurashi, S. Tadatomo, The Univ. of Tokyo (Japan); S. Shinada, T. Kawanishi, National Institute of Information and Communications Technology (Japan)

Combining lithium niobate (LiNbO3) with silicon (Si) is attractive because LiNbO3 is one of the most widely used electro-optics materials and Si is the most frequently used material in the microelectronic industry for ICs, MEMS, and optoelectronic packaging. However, the bonding of a LiNbO3 chip to a Si substrate is considerably difficult by conventional bonding methods because of serious coefficient of thermal expansion mismatch between LiNbO3 and Si. In this paper, we report the low-temperature bonding of a LiNbO3 waveguide chip with Au thin film to a silicon (Si) substrate with Au thin film for integrated optical systems.

The bonding was achieved by introducing the surface activation by plasma irradiation into the flip-chip bonding process. After the Au thin film (thickness: 500 nm) on the LiNbO3 chip (6 mm_6 mm) and the patterned Au thin film (thickness: 2 μm) on the Si substrate (12 mm_12 mm) were cleaned by using an Ar radio frequency (RF) plasma, Au-Au bonding was carried out in ambient air with applied static pressure (~50 kgf). The LiNbO3 chips were successfully bonded to the Si substrates at relatively low temperature (100°C). When the bonding temperature was increased higher than 150 °C, LiNbO3 chips cracked during the bonding. The tensile strength of the interface was estimated to be about 10 MPa, which was enough for use in optical applications. This result shows the potential for producing highly functional optical devices and for the low-cost packaging of LiNbO3 devices.

6376-03, Session 1

Tunable micro-electromechanical grating in silicon

Y. Peter, F. B. Koné, N. Godbout, École Polytechnique de Montréal (Canada)

Gratings play an important role in optical systems and devices. Diffraction gratings are used as multiplexers/demultiplexers (MUX/DEMUX) in wavelength division multiplexing (WDM) systems. They are also widely used in spectroscopy. Fiber Bragg gratings, used as selective reflectors, are a key element in optical fiber communication. Gratings are usually static and their properties are defined once during fabrication. Dynamically tuning the optical properties of gratings is highly interesting. It has been a driving motivation for research for several years. Fiber Bragg gratings have been tuned thermally and mechanically. To date, no simple, fast, easily controllable way of tuning gratings has been demonstrated. We propose a solution for simple, fast and easily controllable way of tuning silicon gratings using Micro Electro Mechanical Systems (MEMS). MEMS have been previously used to tune external cavity lasers (ECLs). Tuning is achieved through a rotation of either the grating or a mirror associated with the grating. While controlled rotation of out-of-plane elements is used in existing MEMS based ECLs, a simpler solution is to deform the grating itself. Basically the idea is to deform mechanically a silicon grating using electrostatic actuators, enabling pitch tuning over a large proportion (more than 50% is easily achievable with our approach). Moreover we can change the spacing of individual layers within the grating. Bragg grating, springs and actuators are realized by silicon micro/nano machining on a silicon platform enabling full integration and passive alignment of all optical components. Applications range from ultra-sensitive displacement sensors, to telecommunications and biology.

6376-04, Session 2

Constitutive chemical biology

S. Nakabayashi, Saitama Univ. (Jordan)

We have succeeded to achieve the functional non-linear electrochemical network mimicking the motion of the jerry fish and the pacemaker activity in the upper urinary tract. Recently, we completed the optical microsurgery platform by which the transient calcium traveling wave was excited by the repairable opto-perforation on the endoplasmic reticulum of A253 cell. We are now expanding the laser surgery platform to work under the far-field irradiation, which enables the ensemble surgery; for example, specific destruction of mitochondria of dictyostelium discoideum. The far-field surgery will be accomplished by the supra-molecular assembly consist of semiconductor nano-particle surrounded by bio-conjugated linker and the oligo-thiophene molecular wire. Combining both of the reconstructive (non-linear electrochemistry) and deconstructive (laser surgery) efforts will shed substantial light on the biological circuit.

6376-05, Session 2

Chemical and biological detectors using ultrahigh-Q microresonators

A. M. Armani, K. J. Vahala, California Institute of Technology

Recently, a method for fabricating planar arrays of optical microtoroid resonators with quality factors greater than 500 million was developed. These devices have previously demonstrated Raman and OPO lasing and radiation pressure induced oscillations. When immersed in an aqueous environment, these devices are able to maintain their ultra-high Q factors by operating in the visible wavelength band, enabling very sensitive chemical and biological detection. The fabrication and optical properties of these devices will be described. These devices have performed both chemical and biological detection. Systems which have been detected include D2O in water and a variety of biological molecules. Sensitivity limits will also be discussed.

6376-06, Session 2

Micro-optomechanical devices for medical endoscope applications

H. Toshiyoshi, M. Nakada, H. Fujita, The Univ. of Tokyo (Japan); K. Isamoto, C. Chong, Santec Corp. (Japan)

We propose an all-optical fiberscopic endoscope for medical diagnosis by using a MEMS optical scanner with the wavelength-division multiplex approach. An infrared light of 1.3 microns is used for medical inspection through the endoscope fiber, and it is scanned over the tissue of interest by using a MEMS scanning mirror. The mirror is electrostatically operated not by using external voltage line but by co-located photovoltaic cell, which generates operation voltage from another input light of 1.5-micron-wavelength. The entire sensor head (fiber, beam splitter, photovoltaic cell, and MEMS chip) is encapsulated in a Pyrex glass tube of 5 mm outer diameter. Drive voltage of 5 V was obtained by the optical modulation, and the MEMS scanner chip operated at 350 Hz resonance for optical scan angle of 8 degrees. In this paper, we present the MEMS device structure, optical system, and preliminary imaging of human skin tissue by the optical coherent tomography.

6376-07, Session 3

Exceptional photonic properties from molecular design and controlled self-assembly

A. K. Y. Jen, Univ. of Washington

No abstract available

6376-08, Session 4

An active vision system for microassembly

X. Tao, H. Cho, Korea Advanced Institute of Science and Technology (South Korea)

Active vision system had been already researched for over two decades in macro world. It can interact with the environment by changing camera parameters such as spatial position, orientation, focus and zoom states according to the different task. So it can achieve robust, real-time perception for a robot in a complex, dynamic world just like a human eye.

In recent years, miniaturization becomes a trend in the product development. More and more micro systems need consist of micro parts that are made of various materials and have complex geometrical shapes. The microassembly has become an important technology to meet this trend. However three-dimensional microassembly is still very difficult due to many reasons. One of the important reasons is insufficient vision information especially for the vision-guided microassembly. The active vision is vital solution for this problem. But due to the inherent problems of microscopy, such as small field of view and small depth of filed, most of microassembly systems with one fixed microscope limit system performance. In order to ease such limitation, some other types of systems have been proposed, such as multi microscope, active zooming and adaptive scanning optical microscope, which have some partial functions of active vision.

In this paper, we propose an active vision system for microassembly. The proposed system can change spatial position, orientation, focus and zoom states during microassembly process. This system can provide more visual information than conventional vision system. It can change the field of view by zooming, track the moving object in three-dimensional micro world, provide different view with different angle and keep the object in the focus plane.

In order to change the focus plane of the system, the deformable mirror was used to achieve high speed focusing. In order to control the shape of the mirror, instead of using wave front sensor, we proposed a new method to determine the optimal shape of the mirror based on particle filter. Each particle represents one shape state of mirror. After several iteration of computation, we can get optimal shape of mirror. In order to adjust orientation, we use wedge prisms to change the view angle. The scanning system is designed to change spatial position of the field of view. The scanning system and prisms system operate accordingly to get a different view angle on the target. In proposed system, we used a zooming objective lens as the image lens of the camera. So the field of view can be easily changed.

For the design verification and optimization, we use optical design software package (ZEMAX) to simulate the system. In this paper, we show the simulated performance of our design. After verification and optimization, we built the prototype system to test our design. A series of the experiments were performed on micro peg and hole assembly to investigate the feasibility of the proposed system.

The active vision system for microassembly proposed in this paper can improve the microassembly process especially for the three-dimensional microassembly. It can change spatial position, orientation, focus and zoom states. So it can achieve sufficient visual information for microassembly. This system can also be used in biological observation, surface inspection, circuit board inspection and many other applications.

6376-09, Session 4

Assembly of micro-optical systems with mechanical positioning

A. Stockham, J. G. Smith, J. A. Hammer, MEMS Optical, Inc.

Aligning of multiple micro-optical components is required for many systems composed of arrays of multiple lens elements, apertures, and filters. Methods of aligning two such wafers using mechanical features are discussed here. Alignment features include binary holes and posts, or grooves and ridges. With the circular holes or rectangular grooves etched into the two wafers, the mating pins or ridges are formed on both sides of a separate element to set both the lateral and vertical positioning. Grayscale technology allows for the printing of V-grooves and V-cones onto any substrate material over a wide range of aspect ratios. When integrated with cylindrical (fiber) or spherical (ball lens) mechanical features, this allows for accurate positioning. Some techniques allow for repositioning as well as disassembly and reassembly. The designs are kinematic or nearly kinematic. The paper discusses tolerances on mating components, and the associated precision of the overall alignment.

6376-10, Session 4

Intelligent force control of a microchip packaging system

J. H. Shim, Korea Polytechnic Univ. (South Korea)

In this paper, we have developed a new mounting head system for packaging of a micro electronic chip. The proposed head system consists of a macro/micro positioning actuator for stable force control. The macro actuator provides the system with a gross motion while the micro device yields fine tuned motion to reduce the harmful impact force that occurs between very small sized electronic parts and the surface of a PCB(printed circuit board). In order to show the effectiveness of the proposed macro/micro chip mounting system, we compared the proposed system with the conventional chip mounting head equipped with a macro actuator only. A series of experiments were executed under the mounting conditions such as various access velocities and PCB stiffness. As a result of this study, a satisfactory voice coil actuator as the micro actuator has been developed , and its performance meet well the specifications desired for the design of the chip mounting head system and show good correspondence between theoretical analysis and experimental results.

6376-11, Session 5

Vision feedback in an automatic nanohandling station inside an SEM

T. Sievers, M. Jähnisch, C. Schrader, S. Fatikow, Univ. of Oldenburg (Germany)

In micro- and nanotechnology, handling and manipulation processes are important. Because of the size of the structures, Scanning Electron Microscopes (SEM) are employed. One important task is the handling of nanowires, (e.g. silicon nanowires) especially the accomplishment of pick and place operations. To support these operations, two important visual measurement approaches are presented. The first one is vision-based force measurement. Standard force measurement with AFM probes is costly and hard to realize inside a SEM. Furthermore, AFM probes are not applicable for every handling task and, e.g. microgrippers more suitable tools. Therefore, a force sensor is needed, which is independent of the handling tool. In this paper, the application of an active contours tracking algorithm for real-time measurement of the bending line of micro- and nanoobjects is proposed. If the bended object is very thin in comparison to its length, the bending line is approximately the contour of the object. By tracking the contour, the bending line can be estimated continuously. This tracking algorithm works directly on SEM images and can calculate the applied force in real-time with respect to the image acquisition time.

The second presented approach deals with the calculations of depth information inside an SEM by means of stereoscopic images. For precise handling, there is a need to know the position of the objects and the tools in all three dimensions of space. For solving this problem, the 2D information of SEM images is not sufficient. There is a need for 3D information.

For object tracking an active contours algorithm with shape space and key-frames is applied. The target contour is modelled by B-splines. The distance between B-splines and target contour is minimized by a recursive fitting algorithm in each SEM frame. From this, the active contour is used to collect the bending line of deformable micro- and nanoobjects to measure applied forces. The algorithm is used to measure the force on a silicon nanowire, by taking into account the mechanical model of a single sided fixed beam. This model demands knowledge of E-modulus, axial moment of inertia and of the geometry of the target object, which are known for the silicon nanowire. The tracking algorithm works directly on SEM images and can calculate the

applied force in real-time with respect to the image acquisition time.

A stereoscopic SEM image pair is generated by tilting the electron beam with a special lens system. The advantage of this concept for handling processes is the fast image acquisition without any impact on the process. The proposed stereo algorithm based on a biologically motivated energy model utilizing a coherence detection analysis algorithm is suitable to process such images. In addition, a filter is presented which detects low-texture regions and removes the noise in the disparity map on these positions.

6376-13, Session 5

Microassembly of 3D micromirrors as building elements for optical MEMS switching

N. Dechev, Univ. of Victoria (Canada); M. A. Basha, S. K. Chaudhuri, S. Safavi-Naeini, Univ. of Waterloo (Canada)

A robotic-based microassembly process has been successfully applied to the construction of a novel micro-mirror design for optical switching. The microassembly process used is derived from the PMKIL (Passive Micrograpper, Key and Inter-Lock) assembly system [1,2,3]. The micro-mirror consists of a novel electro-static rotary motor, onto which a 3D mirror structure is assembled. The 3D micro-mirror is used as a building element for 1xN optical switching systems and for NxM optical cross-connects.

This paper describes how robotic-based microassembly can be used to construct the 3D micro-mirror, so that the device can meet its design and performance requirements. Details of the assembly system include, the process to construct the device, the microgripper design, and the micro-part assembly features. A working prototype of the 3D micro-mirror is also presented.

In order to realize a high performance optical MEMS switch, precise alignment of the system components such as optical fibers, collimating lenses, and mirrors, is critical. A small angular misalignment can cause significant power loss, and cause a high coupling loss between the input and output fibers. Also, angular misalignment loss will increase with longer optical path length. For the micro-mirror design of this work, the mirror must be placed at a precise 45 degree angle, and at an elevated height above the micro-motor located on the substrate. Furthermore, the structure must be rigidly constructed, to minimize vibration and settling time between moves. In order to construct this micro-mirror, the PMKIL microassembly system has been used. It has previously been used to assemble surface micromachined micro-parts, into 3D microstructures [2]. Other research into the construction of micro-mirrors located on top of micro-motors includes [4]. Additionally, other fabrication processes and assembly methods were considered for constructing micro-mirrors tilted at 45 degrees to the substrate, but none could meet the design requirements for this system. Monolithic surface micromachining processes are not suitable, since they cannot create 3D microstructures with smooth surfaces oriented at oblique angles to the substrate. Self-assembly processes were considered for use, including polyimide joint technology [5], and plastic deformation magnetic assembly (PDMA) [6]. However, there are three primary concerns with self-assembly methods. Firstly, to create the device, a fabrication process with the required types of micromachined layers for creating the underlying micro-motor, plus the fold-out micro-mirror, plus the required self-assembly layers, is not commercially available, and would be difficult for custom fabrication. Secondly, the final angle of the micro-mirror cannot be guaranteed with a self-assembly system due to process variations. Thirdly, if the micro-mirror was simply folded-out of plane, without side supports, it would be more prone to vibration and significant mirror curvature may occur because of the large mirror dimensions used in the optical switching.

The robotic-based microassembly system is able to avoid the concerns of other methods. It is able to assemble together multiple micro-parts, originating from various current micromachining processes. Further, the accuracy micro-mirror angle, and the rigidity of the assembled micro-mirror is designed into the micro-parts geometrically, and is not a function of the assembly process or its variations. This guarantees the desired micro-mirror structure. Further more, it makes use of available commercial fabrication processes and does not require a custom fabrication process. The micro-mirror presented here is constructed from a set of surface micromachined parts fabricated using the MUMPs [7] process. The construction of a 3D micro-mirror requires the assembly of three or four micro-parts, depending on the design. Vertical structures called ‘posts’ are assembled first. The posts connect vertically to the micro-motor and are designed to carry the micro-mirror. Finally, the micro-mirror plate is inserted into the posts to complete the device. The assembly of a micro-part (post or micro-mirror) is a 5-step process that consists of: (a) grasping a micro-part with a microgripper, (b) removing the micro-part from the chip substrate on which it was fabricated, (c) manipulating the micro-part by translation and rotation to the target assembly location, (d) joining the micro-part to another micro-part, and (e) releasing the micro-part from the microgripper. In this way, the described 3D micro-mirror has been successfully constructed.

The micro-mirror is able to achieve precise optical alignment through the combination of the 45 degree micro-mirror assembly, and the novel electro-static micro-motor design. The micromotor has a resolution from 480 to 720 steps per full revolution, which provides excellent step resolution for aligning purposes. The assembled mirror combines the simplicity of a 2D cross-connect plus the versatility of a 3D switch.

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6376-14, Session 6

Segmented MEMS deformable mirror for wavefront correction

M. A. Helmbrecht, Iris AO, Inc.

For adaptive optics to take hold in commercial applications, high-performance low-cost deformable mirrors (DM) must be made available. Conventional piezoelectric DMs cost over $1000 per actuator, precluding the use of these except for high-budget research efforts. Furthermore, many commercial applications such as free space optical communications and medical imaging require DMs with a small form factor. Portable applications dictate the need for low-power DMs. Microelectromechanical Systems (MEMS) technologies are well suited for fabricating DMs with these attributes.This presentation will present recent characterization results of the Iris AO 37-segment deformable mirror. In addition to stroke and optical quality, we will present frequency response data and results from cyclic testing. The paper will also discuss wavefront correction using a position controller Iris AO has developed and is currently testing.

6376-15, Session 6

Fabrication of concentric light guiding plate with SiO_2 reflective film

Z. Chen, C. Chien, Tatung Univ. (Taiwan)

A Traditional LCD backlight system is consist of light sources, a light guiding plate (LGP) and prism sheets, diffusion sheets and reflection

sheet. Following the development of the thin LCD, many researchers modify the backlight system which has already become the trend. The LGP is very important element in backlight unit which is usually made of Polymethyl methacrylate (PMMA). Generally, the traditional LGP is fabricated by injection molding. MEMS and hot embossing techniques are applied to fabricate the concentric LGP in this research. The v-cut micro structures, the micro pyramids and SiO2 reflective thin film are constructed on the concentric LGP which is guiding the light to the LCD panel evenly. A new backlight system will be simplified to use only one integrated LGP without using any optical sheets. The concentric integrated LGP can reduce three types of the optical sheets in backlight module, so it can save the space and the fabrication process cost. In future, the concentric integrated is applied in thin-LCD system.

6376-16, Session 6

Two-photon photopolymeric micro-nano fabrication for polymer device application

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We have demonstrated the technology to fabricate a polymer sub-micrometer structure by two-photon-induced photopolymerization. Since photopolymerization resin contained conventional laser-dye and polymer host, we could obtain optically active polymer structures such as laser microcavities and photonic crystals. We have been investigating the polymer material for use it as an optical high gain medium, and found that a spherical macromolecule, called as dendrimer, could be especially useful for our applications. Observed optical response attributes to the site-isolation effect of dendrimer, which limits cluster formation and intermolecular energy transfer, promising a high level of optical gain. We utilized these effects for two-photon induced laser lithography, which is often sensitive to the energetically quenching problems. From the viewpoint of the extension of the polymer material to the optical device application, it is important to consider the device dimensions with a scale of sub-micromeres. We investigate both the material functions in the molecular scale and controlling the device structure for desired applications such as a polymer DFB and photonic crystal.

6376-17, Session 7

Monolithic wavelength-selective switches and cross connects with integrated MEMS mirror array

C. Chi, Univ. of California/Berkeley and Univ. of California/Los Angeles; M. C. Wu, Univ. of California/Berkeley

Wavelength-selective switches (WSS's) and wavelength-selective cross connects (WSXC's) enable flexible, intelligent wavelength-division-multiplexed (WDM) networks as well as reduce the operating cost. In a 1xN WSS, the wavelengths from the input port can be independently switched to any of the N output ports. WSXC allows switching of optical signals at wavelength level between N input ports and N output ports. Most of the WSS's and WSXC's reported to date are realized by free-space optical systems with either micro-electro-mechanical-systems (MEMS) or liquid crystal (LC) beamsteering array, or by silica-based planar lightwave circuits with cascaded 2x2 thermal optical switches.

In this paper, we present a new approach to monolithically integrate WSS and WSXC on a single chip. Using silicon-on-insulator (SOI) planar lightwave circuits (PLC), optical waveguides, micrograting, planar micro-optical elements such as collimating and focusing reflectors, as well as MEMS active switching micromirrors are monolithically fabricated on the same substrate using a one-step etching process. The micromirror array is integrated at the focal plane of the focusing mirror for independent switching of the wavelength channels to the desired output waveguides. We have successfully fabricated a 1x4 WSS with CWDM (20 nm) channel spacing on a 1x2-cm^2 chip, and achieved a fiber-to-fiber insertion loss of 11.7 dB, and a switching time of 0.5 msec.

The monolithic 4x4 WSXC is realized by integrating four 4x1 WSS's and four 1x4 multi-mode interference (MMI) splitters on the same wafer. No fiber connections or external splitter are required. The 90° waveguide bend and 90° waveguide crossing are employed to minimize insertion loss and crosstalk. The fabricated 4x4 WSXC has a chip area of 3.2x4.6 cm^2 and an insertion loss of 24 dB, including a 6-dB splitting loss. The WSXC supports unicast, multicast, and broadcast functions.

6376-18, Session 7

Generation-free platform architecture with a reconfigurable and scalable optical interconnection system

S. Yanagimachi, T. Yoshikawa, S. Araki, A. Iwata, NEC Corp. (Japan)

Recently, the demand for service-oriented systems has been increasing. "Scale out" is an important function for such systems. For example, the service capability of a GRID computing system is enhanced by distributing tasks to more than one server for load balancing. A blade server is suitable for the GRID system because it has many server blades in a pool, and users can select some of them for scale-out use. However, one problem is the system's initial high cost, because a big chassis and interconnections between server blades must be prepared for maximum system capacity from the first deployment. Another problem is that the scalability is limited within a single chassis designed for a particular service. Users cannot enlarge the system beyond the number of server cards. The switch that interconnects server cards is a key component for scalability of the system because its port number and capacity limits the number of server cards.

In this paper we propose a highly scalable switch that consists of a three-stage Clos switch with optical interconnections that connect its elemental switches. The three-stage Clos switch is known for its highly scalable and non-blocking switch architecture. The elemental switches of the first stage distribute input data to the middle stage elemental switches. The middle stage supplies many paths between the first and the final stage. The final stage concentrates the paths to a certain desired port. Generally, the first stage and the final stage switches are implemented in the same switch chip in order to reduce the mounting area of the switch card. Then, if the first stage switch and final stage switch chip are mounted on a service card, the middle stage switch can be separated to a different card as a switch card itself. Using this implementation, it is easy to increase the switching capacity by increasing the middle stage switches and reconfiguring the interconnections. Employing our proposed new switch architecture comprised of a modular scalable switch with optical interconnection, the switch capacity is able to flexibly increase up to 1.92Tbps. We will also discuss the future requirements for an optical switch in the generation-free platform.

6376-20, Session 7

Reconfigurable optical add-drop multiplexer (R-OADM) based on silicon photonic crystal slab waveguides

T. Chu, H. Yamada, A. Gomyo, J. Ushida, NEC Corp. (Japan); S. Ishida, Y. Arakawa, The Univ. of Tokyo (Japan)

Reconfigurable optical add/drop multiplexers (R-OADMs) are fundamental devices in wavelength division multiplexing (WDM) optical networks, since they can be used for dynamically wavelength routing and for replacing any failed OADM unit. There is a growing demand for R-OADMs in future photonic network nodes that are much more compact, consume less power and based on silicon-on-insulator (SOI) substrates, due to the integration leverage from well-developed silicon processing technologies and the monolithic integration of both optic and electronic devices. Therefore, we propose a R-OADM based on silicon photonic crystal (PhC) slab waveguides, which is controlled through thermo-optic effect, for wider and flexible applications. The R-OADM was composed using a tunable channel drop filter (CDF) and a 2x2 optical switch, which were both formed with Mach-Zehnder interferometers (MZIs). The device was compact with a net device footprint of 500 x 140 micrometer, excluding the electrode pads. The dropping wavelength of the R-OADM was tuned through thermo-optic effect by heating the CDF, and the output of optical signal at the dropping wavelength was alternately changed between the ports THROUGH and DROP with the 2x2 optical switch. A 8-nm of dropping wavelength shift was obtained at a 0.85 W of heating power. The 3-dB channel-dropping bandwidth was 7 nm and the extinction ratio at the dropping wavelength for port THROUGH was better than 16 dB. The tuning speed was about 100 microseconds. At the conference, we will report in detail the device structure, the fabrication processes, and the latest optical characterization.

6376-21, Session 8

Optical add-drop multiplexer with hexagonal-hole lattice PC slab waveguides

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In-plane channel-drop optical filters (CDFs), which are based on photonic crystals (PCs), are effective in wavelength division multiplexing (WDM) in a photonic network, but they need to be more compact. In particular, 2-D PC slabs with a hexagonal lattice air-hole processed in silicon-on-insulator (SOI) substrates are very promising because of their common use of nano-scale silicon for LSI device processes.

Two types of channel-drop filters (CDFs) with photonic crystal slabs—connected between silicon channel waveguides and fabricated on an SOI wafer—were designed and fabricated and these demonstrated wavelength division demultiplexing.

One type of CDF is using a single defect cavity and a high reflection interface structure with PC slabs. CDF is Simulated results by 2D FDTD and the plane wave method demonstrated that considering the impedance profile which is directly correlated with the reflective coefficient at the highly reflective interface, is essential to design a highly drop efficient CDF structure. The fabricated filters attained a drop efficiency above 95% at around a wavelength of 1.6 * m and a dropping bandwidth of 1.5 nm.

Another type of CDF using mode-gap of photonic crystal slab propagating mode was proposed. The results simulated with the 2-dimensional finite-difference time-domain and plane-wave methods demonstrated that index-guiding mode for a line defect waveguide of photonic crystal slab has a band gap at wave vector k = 0.5 for TM-like light-wave. The mode gap works as a distributed Bragg grating reflector for the propagating light-wave through the line defect waveguide, and can be used as an optical filter. The filter bandwidth was varied from 1 nm ~ 8 nm with r/a (r; hole radius, a; lattice constant) variation around the wavelength range of 1550 nm ~ 1600 nm. We have fabricated a CDF with a Mach-Zehnder interfereoeter with the photonic crystal waveguide and two 3-dB couplers with Si-channel waveguides. And we attained flat- band spectrum with high efficiency of ~100% from drop ports of CDFs.

6376-22, Session 8

Preparation and properties of novel silicone-based flexible optical waveguide

K. Hara, Asahi Denka Co., Ltd.

UV curable novel silicone polymers, Nano-Hybrid Silicone (NHS), having high thermal stability, low-shrinkage and high transparency were developed. The optical waveguide could be fabricated by direct UV exposed patterning method, since photo lithograph using NHS could be available. Two kinds of NHS for optical waveguide were developed, one is for optical waveguide on Si substrate and the other is for film optical waveguide. The optical losses of these waveguides measured by cut-back method at 850 nm were significantly low, and indicated 0.05 dB/cm (Si substrate waveguide) and less than 0.1dB/cm (film waveguide) respectively. Heat durable tests of these waveguides were carried out for surface packaging technologies under lead free solder melting temperature, and no significant changes of optical loss were observed. Especially with the waveguide on Si substrate, the optical loss increase was only less than 0.02 dB/cm without shape change after the heat resistance test at 270 degrees Celsius for 10 minutes. UV durable tests of these waveguide were also carried out for the adhesion using UV curable resin on electric board. No change was observed with optical waveguide capability after UV exposure (10 J/cm2 at 365 nm). Furthermore, value movement of optical loss was small at preliminary tests of heat-cycling and reliability under the high temperature and humidity condition according to telcordia specification. Due to their various processes durability, the waveguides made with novel silicone-based material are expected to be suitable for practical uses.

6376-23, Session 8

Plasmonic waveguides and micro/nano couplers for nanophotonics devices

J. Takahara, Osaka Univ. (Japan)

A plasmonic waveguide is a key component of nanophotonics devices beyond diffraction limit of light. We have proposed cylindrical (one-dimensional) or planar (two-dimensional) types of plasmonic waveguides from the point of view of low-dimensional optical waves. We have pointed out that a negative dielectric (ND) gap waveguide can be used as a nano-optical waveguide for integrated nano-optical circuits. Nevertheless, there are two drawbacks in a plasmonic waveguide: (1) connection between microphotonic and nanophotonic circuits and (2) large propagation loss of the waveguide.

In this paper, we propose a plasmonic micro/nano coupler for efficient connection between microphotonic and nanophotonic circuits. Structure of the coupler is a tapered ND gap waveguide and this coupler is suitable for I/O port of integrated nano-optical circuits. We report adiabatic propagation of coupled surface plasmon polariton (SPP) mode in tapered ND gap waveguides by using FDTD method. We show that wavelength of coupled SPP mode gradually changes from the order of 100nm to 10nm. In addition, we report the experimental results of coupled SPP mode in an ND gap waveguide fabricated on a high refractive index prism. We study coupled SPP mode experimentally by attenuated total reflection (ATR) method.

6376-12, Poster Session

Reference pattern-based 2D measurement with nanoresolution

Z. Wang, S. Su, Cardiff Univ. (United Kingdom); Y. Verevkin, Institute of Applied Physics (Russia); S. Fatikow, Univ. of Oldenburg (Germany)

Abstract:

This paper presents a reference pattern-based two-dimensional (2D) measurement method. In the method, surface structure patterns obtained from a multi-beam laser interference lithography process were used as reference patterns for 2D measurement. The nano resolution of the measurement was achieved by image processing and pattern matching techniques. The method is potentially useful for micro and nano manipulation in the processes of assembly, packaging and manufacturing of nano and micro-systems when relative nano positioning accuracy is required.

Introduction:

One of the challenging problems in micro and nano manipulation for assembly, packaging and manufacturing of nano and micro-systems is to ensure high relative positioning accuracy between the end-effector and the object to be manipulated. This topic is currently still under investigation. 'Object-oriented' manipulation could provide a solution to this problem [1, 2]. Object-oriented micro and nano manipulation has been proposed for accurate positioning of the end-effector relative to the object in an SPM or SEM. The method uses object pattern recognition to deal with the precise interactions between the end-effector of the robot and the object to be manipulated to remove the errors caused by environmental variations and instrument inaccuracy. With this method, a reference pattern scale is used as a 'ruler'. Nano imaging and pattern recognition techniques are key to this method.

In this paper, two surface structure patterns obtained from a multi-beam laser interference lithography process were used as reference patterns for 2D measurement by image processing and pattern matching techniques[3, 4]. One reference pattern had an area of 2700Å~2700 nm and the other had an area of 8500Å~8500 nm. In the experiment, measurement was made using direct counting method based on the contour plots for the regular reference patterns. Pattern matching was used to achieve sub-pixel resolution. A statistical analysis indicated that the measurement made by pattern matching has the feature of averaging noise [5, 6, 7].

The experimental results have shown that the reference pattern-based 2D measurement method has the advantage of using simple reference patterns in a process available to achieve nano positioning accuracy. The method is potentially useful for micro and nano manipulation in the processes of assembly, packaging and manufacturing of nano and micro-systems when relative nano positioning accuracy is required.

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6376-25, Poster Session

Time shared bidirectional repeatered system for scalable sensor network with time synchronization

K. Aida, Shizuoka Univ. (Japan); Y. Katagiri, Nippon Telegraph and Telephone Corp. (Japan)

Bidirectional transmission over a single fiber is not only expected to realize economical fiber networks, but also enables to acquire sensing data with time stamps from every remote node by time synchronization or propagation delay compensation. By connecting bidirectional repeaters and fibers to an existing network in tree topology, the network size can be enlarged adaptively.

Most of the bidirectional repeaters are based on WDM technology and composed of plural erbium doped fiber amplifiers (EDFAs) for upward and downward channels with WDM multiplexers and de-multiplexers. Complete propagation delay compensation is difficult in these WDM based bidirectional systems, because of wavelength dispersion of the fibers and path differences in the repeaters.

We report here a new approach to realize a bidirectional repeater suitable for sensor networks. A quasi-bidirectional linear repeater, that enables to reconfigure directionality of signal flow periodically, is realized using a unidirectional EDFA and a non-mechanical optical router module composed of magneto-optic components. In this configuration, path length of each direction is identical.

Directionality reconfiguration has been accomplished as fast as 0.05ms. The experiment of periodical directionality switching of 2.5ms over 100 hours have confirmed that the bidirectional linear repeater works very stably.

We have reported a new approach to realize a bidirectional linear repeater for sensor networks. Experimental data and uncertainty discussion of the time synchronization by the bidirectional repeatered line will be presented at the conference.

6376-26, Poster Session

Fabrication of a novel integrated light guiding plate for backlight system by MEMS technique

Z. Chen, Tatung Univ. (Taiwan); C. Chien, Tatung univ. (Taiwan)

A Traditional LCD backlight system is consist of light sources, a light guiding plate (LGP) and prism sheets, diffusion sheets and reflection sheet. Following the development of the thin LCD, many researchers modify the backlight system which has already become the trend. The LGP is very important element in backlight unit which is usually made of Polymethyl methacrylate (PMMA). Generally, the traditional LGP is fabricated by injection molding. MEMS and hot embossing techniques are applied to fabricate the novel integrated LGP in this research. The v-cut micro structures, the micro pyramids and SiO2 reflective thin film are constructed on the novel integrated LGP which is guiding the light to the LCD panel evenly. A new backlight system will be simplified to use only one integrated LGP without using any optical sheets. The novel integrated LGP can reduce three types of the optical sheets in backlight module, so it can save the space and the fabrication process cost. In future, the novel integrated is applied in thin-LCD system.

Sunday-Monday 1-2 October 2006

Part of Proceedings of SPIE Vol. 6377 Advanced Environmental, Chemical, and Biological Sensing Technologies IV

6377-01, Session 1

Use of LIBS technology in biological media

A. Kumar, P. C. Sharma, Tuskegee Univ.

No abstract available

6377-03, Session 1

Optical superposition in fiber double loop ringdown

C. Wang, A. E. Mbi, Mississippi State Univ.

No abstract available

6377-04, Session 1

Surface-enhanced Raman for environmental sensing

T. Vo-Dinh, Duke Univ.

No abstract available

6377-05, Session 1

Kinetic investigations of proton transfer and complex formation reactions by laser-based ion mobility spectrometry

H. Loehmannsroeben, T. Beitz, Univ. Potsdam (Germany); R. Laudien, Optimare GmbH (Germany)

Ion mobility (IM) spectrometry is based on the drift movement of molecular ions in a bath gas under the influence of an external electrical field. The mobilities of gas phase ions depend on the interaction potentials and the geometries of the colliding partners, e. g. molecular cations and drift gas atoms. Hence, IM spectrometry allows experimental determination of diffusion cross sections (DCS) and structural evaluation of gas phase ions. Combined with quantum chemical calculation methods, providing structure proposals, and with improved models for DCS calculations, a powerful tool for structure determination of gas phase ions has been established. An additional application of IM spectrometry is the investigation of ion/molecule reactions (IMR) at atmospheric pressure.

As examples for IMR, complex formation reactions (CFR) and proton transfer reactions (PTR) are considered. The CFR of aniline radical cations and PTR of toluene radical cations, formed by multiphoton ionization with different neutral polar molecules were investigated in a laser IM spectrometer at atmospheric pressure between 283 and 333 K.

The kinetic studies include the investigation of the temperature dependence of the PTR and CFR bimolecular rate constants. In both IMR the difference of the proton affinities (PA) of [toluene-H] and [aniline-H] radicals and the polar molecules was varied. The rate constants of the IMR were calculated according to the Langevin and the Average Dipole Orientation (ADO) theory. The mechanism of the CFR will be discussed regarding the PA difference and the comparison of ADO and experimental rate constants. A further aspect is the determination of unimolecular decay rate constants of ionic aniline-molecule complexes as a function of temperature. The stability of the complexes is discussed in dependence on the relative PA difference of the reactants and the steric properties of the complex formers.

6377-06, Session 2

Diagnostics of single-base mismatch DNA hybridization on gold nanoparticles using hyper-Rayleigh scattering technique

P. C. Ray, Jackson State Univ.

We present for the first time the HRS assay for ss-DNA sequence recognition based on the difference in electrostatic properties between ss-DNA and ds-DNA. Here we demonstrated that the hyper-Rayleigh scattering (HRS) technique could be used for ultra-sensitive detection of single base-pair mismatch oligonucleotide strands on gold nanoparticle without any tagging. The mechanism of HRS signal enhancement after hybridization have been discussed. This method will have several advantages and these are i) one can avoid covalent tagging of any dyes to probe protein and DNA in solution by HRS technique, ii) it can be 1-2 orders of magnitude more sensitive than the usual colorimetric technique, iii) single base-pair mismatches are easily detected.

6377-07, Session 2

Development of nano-bio optical fiber sensor using laser-induced fluorescence

J. P. Singh, C. K. Kim, R. R. Kalluru, F. Yueh, S. T. Willard, A. N. Musselwhite, Mississippi State Univ.; P. C. Ray, Jackson State Univ.

A nano-bio optical fiber sensor is being developed to study human breast cancer cell lines (e.g., MCF-7). This sensor exploits laser-induced fluorescence (LIF) technique with fiber optics. In this work, firstly, raw LIF spectra of cultured MCF-7 breast cancer cells were normalized with the reference signal obtained from the peak intensity of dye solution. The normalized LIF spectra of MCF-7 human breast cancer cells obtained from different cultured passages (i.e., growth over time) were then studied. Secondly, the LIF spectra of the MCF-7 cells treated continuously with 4-hydroxytamoxifen (a chemotherapeutic anti-estrogen) were compared with the LIF spectra of untreated MCF-7 cells. Two different excitation wavelengths (pulsed Nd: YAG laser operating at 355nm and laser diode operating at 410nm) were employed for this study. By comparing the LIF spectra of the breast cancer cells treated with 4-hydroxytamoxifen with the standard spectra the selective differentiation of cancer cells was studied using two different excitation light sources. A unique data processing technique has been developed to analyze the recorded data for cell line identification and differentiation. The design of a compact, inexpensive, miniature nano-bio sensor for possible DNA sequencing application will also be described.

6377-08, Session 2

Optical nanobiosenor for environmental health studies

T. Vo-Dinh, Duke Univ.

No abstract available

6377-09, Session 2

A fluorescent bio-aerosol point detector incorporating excitation, emission, and lifetime data

P. C. Trepagnier, SPARTA, Inc; P. D. Henshaw, SPARTA, Inc.; R. F. Dillon, Lumen Labs., Inc.; D. McCampbell, Midwest Research Institute

This paper describes work performed under the DARPA Spectral-Sensing of Bio-Aerosols (SSBA) program. A goal of the program is to decrease false alarm rate relative to current bio-aerosol trigger sensors, and our approach was to extract as much information as possible from fluorescence by using as much of the full excitation-emission-lifetime (XML) fluorescence space as could be conveniently gathered. Our XML approach of collecting a broad range of data requires collecting a bulk aerosol sample and immobilizing it during analysis. Most conventional aerosol trigger sensors interrogate each aerosol particle separately, and implicit in our choice is the conviction that the higher-dimensional data that we gather allows the increased background clutter that attends bulk collection to be suppressed. We have shown this to be the case, thus opening the door to sensors that exhibit higher sensitivity with less elaborate optics than is the case with single-particle sensors.

The present paper has two parts. In the first part, we present initial XML spectral data gathered under the SSBA program using a commercial laboratory spectrofluorometer and illustrate its analysis in a multi-dimensional Principal Components Analysis (PCA) data space. We

demonstrate classification using the spectral angle (SA) methodology developed for hyperspectral imaging in this PCA hyperspace. In the second part, we present a design for a custom trigger sensor motivated by the initial results and built to exploit them by gathering XML data in a rapid time line. We compare data gathered with this sensor to that gathered with the initial laboratory spectrofluorometer.

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6377-10, Session 2

Study of bacteria using Raman spectroscopy

V. S. Tiwari, F. Yueh, J. P. Singh, M. Cunningham, Jr., L. Pulakat, N. Gavini, Mississippi State Univ.; P. C. Ray, Jackson State Univ.

The Surface -Enhanced Raman Scattering (SERS) of Azotobacters, a genus of free-living diazotrophic soil bacteria, incubated with gold nanoparticles is examined with 532-nm as an excitation laser wavelength. The basic instrumentation for characterizing the bacteria employed a frequency doubled 532 nm continuous wave (CW) Nd: YAG laser and a modified In-Photonics fiber optic state-of-art miniaturized Raman Probe. Azotobacter has generated a great deal of interest owing to their unique mode of metabolism. It is a large, obligately aerobic soil bacterium, which has one of the highest respiratory rates known among living organisms and is able to grow on a wide variety of carbohydrates, alcohols and organic acids. Azotobacter has been intensely studied for many years because of its ability to synthesize three different nitrogenase enzymes and to fix nitrogen in air. The surface enhancement effects allowed the observation of Raman spectra of such bacterial cells, and were excited in the visible region of wavelength at low incident power for minimum sample degradation. Spectral contrast observed in gold particles conjugated bacteria from nitrogen fixing and non-nitrogen fixing condition is analyzed for the identification of cell components, and details will be presented in the paper.

6377-11, Session 3

Fiberoptic diisocyanate personal monitoring device

S. A. Lis, LightLine Technologies, Inc.

Isocyanates and diisocyanates are produced by the millions of tons per year and are used for the large scale production of polyurethane products that range from coatings, to solid castings, and to industrial foam products. Occupational exposure has been linked to asthma-like symptoms and is a significant environmental concern requiring personal monitoring devices for employees that are sensitive and accurate in the parts per billion range.

A novel design fiber optic chemical sensor has been developed which has demonstrated sensitivity of 0.2 ppb (parts per billion) for a 20 minute exposure in air for multiple isocyanate species. Sensor response is very linear over the range of 0 to 25 ppb. The sensor is based on a novel, long fiber, evanescent wave design that provides high sensitivity while maintaining low materials cost.

Experimental performance results are presented, as well as a novel measurement approach that provides excellent linearity. Sensitivity to interference by humidity is modest.

Sensor packaging is directly compatible for passive use in personal monitoring and the sensor us reusable. The sensor is simple and inexpensive to fabricate, and easy to process by the user in an inexpensive automated instrument. Sensor processing is simple and is a nearly all dry process. The solid-state sensor can be packaged in a convenient size for personal monitoring. Highly quantitative sensor response is provided by a unique data analysis process that can be readily automated and provides high linearity over a sensitivity range that is of direct applicability to sensing needs.

6377-12, Session 3

NiCl2/SiO2 sol-gel material for ammonia sensing

A. Tsigara, N. Madamopoulos, G. Manasis, L. Athanasekos, A. Meristoudi, G. Mousdis, National Hellenic Research Foundation (Greece); N. A. Vainos, National Hellenic Research Foundation (Greece) and Univ. of Patras (Greece)

NiCl2/SiO2 sol gel materials are proposed for the first time for ammonia sensing. Thin films are prepared by spin coating or casting the solution on appropriate substrates and tested for sensitivity in ammonia environment. We report a uniform optical response over the visible spectrum reaching at variation as high as 20% in optical transmission. The main mechanism of operation is based on reversible chemical complexation effects which enhance the optical scattering of the unprocessed material. Interface tailoring and interrogation methodologies based on diffractive approaches are discussed. Fiber-optic based photonic sensors based on the NiCl2/SiO2 sol gel materials are proposed and built offering remote interrogation of the sensitive material an information processing and transport. Such ammonia sensor can find applications in industrial chemical sensor applications including "on-line" process monitoring and quality control.

6377-13, Session 3

Fiber optic sensor coatings with enhanced sensitivity and longevity

S. R. Cordero, R. A. Lieberman, H. Mukamal, Intelligent Optical Systems, Inc.

Fiber optic sensors that utilize evanescent field interactions as a sensing mechanism have proven to be quite sensitive. Recently we have reported this type of distributed sensor for HCN, H2S, and Cl2. The optical fibers are multimode and consist of a fused-silica core and a chemically sensitive cladding. Upon exposure to the analyte the cladding changes color resulting in an alteration of the light intensity throughput. These fibers are mass produced using a conventional fiber optic draw tower. Failure mechanisms such as indicator migration, crystallization, and degradation are known to decrease the lifetime of thin film optical sensors. We will report recent progress regarding the optimization of our sensors as it relates to these failure mechanisms. These optimizations include bonding of indicators with the fiber optic cladding during the fiber drawing process, detouring crystallization, and using anti-oxidants to minimize degradation.

6377-14, Session 3

Fabrication of silica-silver core-shell microspheres with designed surface charge for SERS-based sensing

Y. Han, S. Tan, S. A. Sukhishvili, H. H. Du, Stevens Institute of Technology

We report an approach towards synthesizing SERS active silica-silver core-shell microspheres with designed surface charge for sensing of cationic and anionic species in aqueous solutions. Two routes, both of which involve a polyelectrolyte and silver nanoparticles, are explored by self-assembly. In the first route, core-shell microspheres with negative surface charge were fabricated by immobilizing citrated-reduced silver nanoparticles (20-60nm in diameter) on 4μm silica spheres mediated with branched polyethyleneimine (BPEI). The coverage density and thickness of the silver shell can be controlled by adjusting the amount of polyelectrolyte adsorbed on the core surface, solution pH, as well as through the application of the nanoparticles/BPEI layer-by-layer technique. In the second route, positively charged silver nanoparticles (30nm in diameter) were first produced in the solution using BPEI and N-(2-hydroxyethyl)piperazine-N'-2-ethanesulfonic acid (HEPES), and then allowed to adsorb on the surface of 4μm bare silica spheres. In both cases, the coverage density of silver shell was well controlled. The resultant core-shell microspheres were used for surface-enhanced Raman scattering of positively charged Rhodamine 6G and negatively charged perchlorate and cyanide in water. Detection sensitivity down to the ppb level was achieved, indicating the potential robust nature of the core-shell microspheres for chemical sensing.

6377-15, Session 4

Analysis of jet fuel properties on the tarmac by Raman spectroscopy

W. W. Smith, S. R. Farquharson, Real-Time Analyzers, Inc.

The quality of jet fuel is a concern when refueling in developing countries, because below standard fuel effects flying range and routes. For example, pilots add 10% extra fuel due to sub-standard heat of combustion and avoid polar routes due to sub-standard freezing

points. The cost of these “safety factors” is as much as $5000 per flight. A portable fuel analyzer that could measure these and other critical parameters would allow cutting this expensive precaution in half. Towards this goal we have been developing a portable Raman analyzer that allows measuring the Raman spectrum of a fuel in 1 minute with no sample preparation. The challenge, however, is that as distilled fractions of crude oil, all fuels are composed of hundreds of hydrocarbon components that boil at similar temperatures, and performance properties can not be simply correlated to a single component, and certainly not to specific Raman peaks. To meet this challenge, we have measured the spectra of several hundred jet fuels from around the world and have used chemometrics to correlate the entire Raman spectrum to fuel properties. Critical to the success of this approach is laser excitation at 1064 nm to avoid fluorescence interference (almost all fuels fluoresce) and a rugged interferometer that provides 0.1 cm-1 wavenumber (x-axis) accuracy to guarantee accurate correlations. Here we present chemometric models used to determine the following chemical and physical properties: acid, aromatic, olefin, and sulfur content, cloud, distillation, flash, freeze and pour points, density, cetane index, heat of combustion, and viscosity.

6377-16, Session 4

Class identification of biomolecules based on multicolor native fluorescence spectroscopy

M. Bassler, P. Kiesel, O. Schmidt, N. M. Johnson, Palo Alto Research Ctr. Inc.

All biological molecules are composed of only a few basic building blocks and, therefore, exhibit similar physical properties. In particular, aromatic amino acids can be found in biological molecules and exhibit native fluorescence. Tryptophan, phenylalanine and tyrosine are some of the most common fluorescent molecules. In addition, many enzymes or cofactors, NADH (reduced b-nicotinamide adenine dinucleotide) and Riboflavin being the most prominent examples, exhibit pronounced native fluorescence.

Laser induced fluorescence (LIF) is a promising tool for differentiating fluorescing molecules. As the variety of biological molecules is huge compared to the number of basic building blocks, the fluorescence spectra of different analytes are often quite similar. A high spectral resolution is required to reveal differences in the emission spectra. In addition, multi-wavelength excitation has to be used to obtain complementary spectra information to aid the bio-agent class identification.

Native fluorescence from various proteins, bacteria and fungi was excited by 266 nm and 355 nm laser sources. Emission spectra were collected between 280 and 560 nm with a conventional fluorescence setup from different analytes (bovine serum albumin, horse heart cytochrome C, bacillus thuringiensis, yeast, NADH, tryptophan). To extract the distinguishing features for each analyte the detailed spectral information was evaluated by principal component analysis (PCA). The PCA enabled a clear separation among the simulants, and thus class identification was successfully demonstrated.

Future issues to be addressed include randomized testing on unknown analytes in order to explore the identification probability, recording fluorescence spectra for analyte mixtures, evaluating the class identification probability for mixtures of analytes, and examining class identification for simulants in different solutions (e.g., di-ionized and tap water).

6377-18, Session 4

Development of dual-LED fiber optic surface plasmon sensor for liquid refractive index detection

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A surface plasmon wave (SPW) is a charge-density wave that propagates along interface between a metal and a dielectric medium. As the SPW is influenced by the refractive index of the dielectric medium, the SP has been applied to chemical and biochemical sensors. In this paper, we present a novel fiber optic SP sensor for measuring liquid refractive index. The proposed system consists of a pulse circuit for alternatively flashing dual light emitting diodes (LEDs) at 1kHz, the sensor with two optical couplers, and a detection circuit with a photo diode (PD). The wavelengths of dual LEDs are 612nm and 680nm. The used optical fiber is multimode and its core diameter is 400 micrometer. The optical fiber is cut and the cladding of 1cm from the end surface is removed. Thick silver layer is evaporated onto the end surface as a mirror and then gold film of 60nm is evaporated around the core surface to generate SPW. The used wavelengths and thickness are determined by considering the optimum condition. The reflected light is detected by the PD. Compared the developed system with a conventional optical fiber SP sensor, which needs a white light and a spectrograph, the system is compact and low cost. Moreover, high sensitive detection system is achieved by monitoring the differential signal between signals corresponding to the wavelengths of 612nm and 680nm. Ethanol or glucose solutions and water at different temperature are measured. The results indicate that the sensor responses only depend on the refractive indices and measurable refractive index range is from 1.3293 to 1.3616.

6377-20, Session 5

LED-based tetracycline analyzer for field analysis

G. Chen, U.S. Dept of Agriculture

Tetracycline (TC) is a significant class of antibiotic drugs widely used in human and veterinary medicine. Sensitive and selective instruments and methods are in demand for its analyses in clinical, food, biological, and environmental matrices. Many of these tasks must ideally be performed in the field. To serve such needs, we developed a portable tetracycline analyzer capable of time-resolved luminescence measurements. A 385 nm UV LED is used to selectively excite the TC analytes. Its narrow bandwidth and low residual radiation allow improvements in background performance over a xenon flashlamp. TC forms a complex with Eu in the reagent solution; and its long-lasting luminescence is detected by a photomultiplier tube (PMT) and digitized at a 4-μs time resolution and a 12-bit amplitude resolution. Both instrument operation and data processing are controlled by a laptop computer running a custom LabVIEW program. The analyzer can be configured for two operation modes: (A) liquid-phase measurement using a sample cuvette, and (B) solid-matrix measurement on a sorbent surface after TC extraction and enrichment. The performance of this analyzer is evaluated using oxytetracycline as a model analyte. In configuration A, a 0-3 ppm linear dynamic range (LDR) ($r^2 = 0.997$) and a 0.25-ppb limit of detection (LOD) were achieved with a typical 10% relative standard deviation (RSD). In configuration B, a 0-100 ppb LDR ($r^2 = 0.999$) and a 0.13-ppb LOD were achieved after 1-hour extraction with a typical 5% RSD.

6377-21, Session 5

Optimization of the anthropogenic vadose zone monitoring at the sulfidic mining waste dumps or engineering constructions

I. Twardowska, S. Stefaniak, K. Janta-Koszuta, J. Kyziol, Polska Akademia Nauk (Poland)

Acidic Rock Drainage (ARD) that causes severe ground water deterioration and mobilization of potentially toxic elements is one of the persistent environmental problems in countries with a developed extractive industries. In brief, it results from exothermic process of sulfide minerals decomposition in mining waste deposited at the surface in the presence of atmospheric oxygen and moisture/infiltration water from precipitation. To attenuate the environmental impact of extractive wastes, the European Commission issued adequate legislative documents: proposal for a Directive on the management of waste from the extractive industries and a Reference document on Best Available Techniques for Management of Tailings and Waste-Rock in Mining Activities (BREF, 2004). These documents oblige the extractive industry to intercept the generation of ARD. Simultaneously, mining waste is an attractive material widely used in civil engineering as a common fill. This results in the need of early-warning monitoring of a potential of disposed/reused mining waste to generate acidic and/or highly mineralized leachate, and of the efficiency of interceptive/insulation protection measures. The performance-based techniques comprise sampling waste material along the waste layer profile by drilling, with subsequent off-site pore solution extraction and analysis by ICP-MS. Though detailed and precise, these techniques are time-consuming and expensive, and thus being limited to few randomly selected profiles. Large area of the sites and heterogeneity of a material

causes problems with proper selection of representative profiles and therefore with evaluation of the environmental behavior of a reused or disposed material. For better characterization of a problematic site, its screening with cone penetrometer integrated with real-time, downhole sensing devices equipped with sensors for measurements of temperature, pH, rock moisture content and conductivity seems to be the best solution that would provide the most important information concerning reactivity of a material in the waste layer and efficiency of protective measures.

6377-22, Session 5

Determination of concentration of ratio of nitrogen and oxygen in a liquid mixture

A. Moitra, R. R. Kalluru, F. Yueh, J. P. Singh, Mississippi State Univ.

An innovative technology pertaining to optical fiber sensor by Laser Raman Spectroscopy has been designed, to provide potential users (e.g. NASA), to quickly determine the percentage adulteration of Nitrogen in a Liquid Oxygen fuel tank during the ground testing of their Rocket System. This paper reports the conceptual design and development of a real time in-situ fiber optic sensor, which can be broadly used for various Raman sensitive sample compositions for their quantitative as well as qualitative determination. Efforts have been made to provide a detailed description of the instrumentation and its comparative performance. Fibre-optic monitoring systems offer special advantages for remote measurements in hazardous and rugged environment or in a situation where there is a large amount of electromagnetic noise and possibility of data corruption.

6377-23, Session 5

Assessment of chemical status of ground waters based on aggregated data from a monitoring network exemplified in a river drainage basin

E. Kmiecik, M. Stach-Kalarus, J. Szczepanska, Univ. of Science and Technology (Poland); I. Twardowska, S. Stefaniak, Polska Akademia Nauk (Poland)

According to the EU Water Framework Directive 2000/60/EU (WFD, 2000), water quality should be compulsory assessed for uniform parts of usable ground water basins (GWB). The assessment has to be accomplished in two stages: (i) preliminary identification of GWB of poor or unsatisfactorily elucidated water quality; (ii) detailed assessment for GWBs that do not fulfill the good chemical status criteria. If this analysis confirms poor quality of ground waters, they should be covered by a monitoring to found out the cause of a threat and ways of its interception. Both FWD and the draft EU Directive on the protection of ground water against pollution (GWD, 2004) distinguish only poor or good chemical state of water, while GWD comprises a list of chemical constituents, for which the EU Member States should develop uniform maximum concentration levels (MCL) by the end of 2006. The chemical status of ground waters in the selected Koprywianka river basin was evaluated within the 6FP BRIDGE project aimed to realization of this task on the basis of 37-point monitoring network with use of both national (RMS, 2004) and European (GWD, 2004) chemical parameter lists. These data were used for point and spatial evaluation of groundwater chemical status. For spatial evaluation (drainage basin and particular GWBs), the data aggregated by mean and median methods were used. The results show the better precision of ground water status evaluation both by point and spatial methods, and a need of a careful selection of monitoring points separately for shallow and deep circulation. It has been proved that the spatial evaluation should be carried out on the basis of median, and not mean concentrations recommended by GWD (2004), as chemical constituents in ground waters usually display a log-normal distribution that is not being deformed to such extent as mean values.

6377-24, Session 5

Continuous in situ bacteria detection in fluid lines

I. F. Saxena, Intelligent Optical Systems, Inc.; J. W. Costerton, Univ. of Southern California

Bacterial fouling can be persistent, and is highly undesirable, particularly in medical practice. The quantification of bacteria by standard plating techniques typically requires a lengthy (48 hour) culturing process, and therefore is not amenable to in situ system monitoring. In situ bacteria detection and quantification would be extremely useful in numerous applications, such as in the validation of sterile water and fluids used in pharmaceuticals, and in the prevention of a host of infections caused by contaminated water lines. In situ detection could also be used in studies of the microbiological resistance of biomedical implant materials, which need to be qualified for their ability to prevent the adherence of virulent bacterial strains.

The real-time, bacteria-detecting, prototype instrument described here offers the potential for utility in these applications. The results obtained when using the prototype to monitor bacteria in a flowing water line are presented herein.

6377-25, Session 6

Hyperspectral imaging based techniques in fluff characterization

G. Bonifazi, S. Serranti, Univ. degli Studi di Roma/La Sapienza (Italy)

Light fractions produced after vehicles dismantling are conventionally defined as “fluff”. They represents about the 25% of the weight of a car and are usually constituted by materials characterized by intrinsic low specific gravity (i.e. plastics, rubber, synthetic foams, etc.). When processed to perform their recovery, they result polluted by materials presenting higher specific gravity (i.e. copper, aluminium, brass, iron, etc.), constituting parts of the electrical devices of the vehicle that, for their shape, size (i.e. wires, metal straps, slip rings, wipers, etc.) and utilization remain concentrated in the lighter products. Such “polluting agents”, for their intrinsic characteristics, are not well removed by classical separation techniques. The possibility to utilize finer fluff fractions, the most complex to process, to produce energy could dramatically contribute to increase the full recovery of such a kind of products. To reach this goal the quantity and the quality of the metal contaminants have to be strongly controlled in order to not prejudicate the quality of the final fluff based fuel. In this paper, innovative selection-control architectures, based on the detection of the spectral signature, in the VIS-NIR (400-1000 nm), have been investigated to evaluate the possibility to apply “real time spectrometry” techniques to perform fast and reliable analysis to identify and quantify specific fluff characteristics in order to define innovative contaminants detection strategies.

6377-26, Session 6

Chemometrics and recognition technologies for spectral classification

K. J. Siddiqui, SUNY Fredonia

The broader definition of chemometrics includes pattern recognition (PR) and signal processing methods. PR and chemometrics are among the most powerful tools currently available for noninvasively examining spectroscopic and other chemical data. Using spectral data, these systems have found a variety of applications employing analytical techniques for computational chemistry such as gas chromatography, fluorescence spectroscopy, etc. PR approaches make no a priori assumption pertaining to the structure of patterns. However, a majority of these systems rely on human judgment for parameter selection and classification.

Generally a spectral pattern recognition (SPR) problem is considered as a group of several subproblems. We considered a SPR problem as a group of five subproblems: spectra acquisition, feature extraction, feature selection, spectra organization, and classification. One of the basic issues in PR approaches is to determine and measure the discriminatory features useful for successful classification. A spectral pattern classification system combining spectral feature extraction and selection, and decision-theoretic approaches is developed. It is shown how such a system can be used for analysis of large data analysis and interpretation.

In a preliminary test, the classifier was used to classify synchronous UV-vis fluorescence spectra of relatively similar petroleum oils with reasonable success.

6377-27, Session 6

Thermodynamics of information loss in spectroscopic measurements

K. D. Mohan, M. A. Khan, A. N. Dharamsi, Old Dominion Univ.

Absorption and emission spectroscopy measurements have been extensively and effectively utilized in the probing and monitoring of gases. The lineshape profile of a particular species contains all the information about that species, such as the concentration, temperature, Doppler velocity, Energy band structure etc. However, as in any real experimental situation, the measurement of absorption or emission profiles results in a loss of information due to practical limitations, such as a finite frequency bandwidth of the detectors. In addition, the relationship between information loss and thermodynamics is well known. For example, it has been shown by Bennet et al that at the fundamental level, a minimum amount of heat equivalent to kTln2 is generated when erasing 1 bit of information. Hence, the question “How much information, in bits, is lost when making a practical spectroscopic measurement and how much heat is generated in the process?” arises. This is a fundamentally important question to answer in any experimental measurement that strives to achieve the highest precision possible, in terms of the amount of information extracted. We use information theoretical concepts developed by C. E. Shannon to quantify the information lost due to practical limitations such as averaging over a finite frequency bandwidth. The heat generated at such a photodetector is also studied, and the relationship between the heat generated and information lost as the result of the finite bandwidth of a practical detector with finite bandwidth is investigated.

6377-28, Session 6

SERS spectroscopy inside light-guiding capillary tubing

D. Pristinski, S. Tan, H. H. Du, Stevens Institute of Technology

We report on a new type of surface enhanced Raman spectroscopy (SERS) sensor resulting from immobilization of silver or gold nanoparticles on the inner surface of fused silica light-guiding capillary tubing (LGCT). Non-aggregated nanoparticles were immobilized at the surface covered with a self-assembled polyelectrolyte monolayer. LGCT was butt coupled with a mating step-index fused silica fiber and a small spacing allowed for solution to be pumped through the LGCT for flow-through sensing applications. The functionalized LGCTs were evaluated for their potential for SERS-based sensing and identification of air and water pollutants at ultra-low concentrations and in sampling volumes below 1 μl. The SERS characterization was performed with visible or NIR range excitation, which wavelength was selected based on the nanoparticle size and nature. LGCT light collection efficiency for evanescent field excited SERS signal is discussed. Signal accumulation along the LGCT is compared with light attenuation occurring due to secondary scattering, and the optimum tubing length is estimated.

6377-29, Session 6

Quantitative imaging characterization of aluminum pit corrosion in oak ridge research reactor pool

P. Jang, R. Arunkumar, Z. Long, M. Mott, W. Okhuysen, Y. Su, D. L. Monts, Mississippi State Univ.; P. G. Kirk, Oak Ridge National Lab.; J. Ettien, Bechtel Jacobs Company LLC

No abstract available

6377-31, Session 6

A conductivity measuring method driving by frequency self-adaptive current

W. Chen, Xiamen Univ. (China)

Under the driving of constant-source, the output voltage derivative of conductance pool can be estimated and the task frequency of signal measure source can be detected automatically, thereby the problem on how to choose a suitable task frequency of a signal measure source is solved. In this paper we not only analyse the method theoretically but also provide the circuit and experiment results.:Using the instrument we take an experiment as follow::By the adjustment liquid preparation method (GB11077-89) used in conductance instrument measurement, different KCL liquid is confected in the air. The conductance rates are measured under the temperatures of 18±0.2°C, 20±0.2°C and 25±0.2°C respectively. The measure results are demonstrated in this paper.

6377-32, Session 6

Fluorescence lifetime sensing of temperature

P. R. Kommidi, B. R. Reddy, Alabama A&M Univ.

Fluorescence lifetime sensing is useful to measure temperature in harsh environments. We implemented the technique using samarium doped materials. The sample was exposed to a pulsed laser beam and the resulting lifetime was measured. A plot of lifetime versus temperature exhibited a linear dependence. A small change in temperature produced a significant change in lifetime, which is important in measuring temperature accurately. This technique is an alternative when conventional techniques are not suitable.

6377-17, Poster Session

Studies of stability of petroleum emulsions by confocal microscopy

J. Hung Low, Instituto Venezolano de Investigaciones Científicas (Venezuela); J. A. Castillo, Univ. Central de Venezuela (Venezuela)

Recently, the developments of techniques such as confocal microscopy have been of great interest for the petroleum industry. Confocal microscopy is known for its non-contact and non-destructive features, and has been used extensively in the biomedical areas. Confocal microscopy excludes out-of-focus information by focusing through a small aperture (a confocal pinhole). Confocal images permits through of direct observation obtain the acquisition and interpretation of in situ information of the emulsions systems, without the requirement of sample pretreatments and can be applied to samples of high optical density as crude oils. This property of the confocal technique is of great utility in the case of the study of the colloidal structural evolution in very dark samples as water in crude oils emulsions, and asphaltenes. In this work, the applicability of a homemade confocal microscope is shown. Studies as stability of colloidal suspensions (asphaltenes and emulsions), aggregation kinetic, flocculation dynamic, and characterization of colloidal system are showed. High-resolution micrographic images of asphaltenes flocculation induced by n-heptane addition permit to demonstrate the early stage of the asphaltenes flocculation process, additional, the images of the dynamics in the drop size and drop size distributions during the initial stage of the separation of water drops from Furrial crude oils are also reported. In this communication, we show the versatility and precision of this equipment with respect to the conventional techniques. This technique directly permitted for example, visualization of the coalescence of small droplets to form large ones from water-in-crude oil emulsions and visualize the morphology of flocculated asphaltenes.

6377-30, Poster Session

An intensity modulation based high-speed and high-resolution long-period fiber grating sensor interrogating system

C. Chiang, C. Shin, National Taiwan Univ. (Taiwan); S. Liaw, National Taiwan Univ. of Science and Technology (Taiwan)

A fast responding interrogation system based on intensity modulation using fiber Bragg gratings (FBG) has been developed to interrogate long period fiber grating (LPFG) sensor. Temperature and dynamic strain monitoring using this system have been successfully demonstrated. This system is capable of resolving strain to 0.2 micro-strain at a loading frequency of 20 Hz, and temperature resolution to 0.02 degree-C. The performance of LPFG sensors in single and double cladding fibers are compared.

6377-33, Poster Session

Polychromatic detection of dissolved and particulate matter in fresh and seawater

M. Belz, World Precision Instruments, Inc.; K. Larsen, K. Klein, Fachhochschule Giessen-Friedberg (Germany)

The development of accurate, global, ocean color models for remote sensing imagery is an important goal for Earth Science Research. Estimates of the concentration of dissolved and particulate materials in water can be derived by inversion of remote sensing imagery, that is, remote sensing reflectance based on empirical or semi-analytical models of reflectance vs. water constituents. The efficacy of these models depends on accurate measurements of the spectral absorption of dissolved and particulate materials.

However, traditional methods of measuring the absorption of dissolved and particulate materials require special handling and storage prior to measurement using expensive laboratory spectrophotometers. Further, their detection limit is often insufficient to detect the typically low concentrations of dissolved and particulate matter in seawater.

Portable instrumentation to measure the absorption of dissolved organic matter and particulate matter is described. A multiple pathlength liquid core waveguide is used to measure dissolved organic matter in seawater. Traditionally, particulate matter is measured via the Quantitative Filtering Technique" (QFT), where particulate matter is concentrated on a Glass Fiber Filter (GFF) pad and its forward absorption measured with a laboratory based spectrophotometer and an integrating sphere. Performance and design of an inexpensive and portable fiber-optic-based GFF filter holder are discussed. Further, particulate absorption is measured in solution using liquid core waveguides (20cm) with different numerical apertures. Methods for scatter correction are evaluated.

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6378-01, Session 1

Leveling the playing field: why ROC curves?

K. O. Schafer, ChemImage Corp.

Receiver operator characteristic (ROC) curves were developed in the 1950's as a means to evaluate radio signals contaminated by noise. In the CB defense community ROC curves are the de facto standard for assessment of CB sensor performance. Motivations for adoption of this powerful technique will be described.

6378-02, Session 1

Test methodology development for biological agent detection systems

A. C. Samuels, J. L. Santarpia, J. R. Bottiger, U.S. Army Edgewood Chemical Biological Ctr.; S. A. Hunter, U.S. Army; E. W. Stuebing, U.S. Army Edgewood Chemical Biological Ctr.

Optical detection systems play a vital role in the early warning detection of airborne biological agents. Fluorescence and elastic scattering signals have been historically exploited in order to characterize and profile bioaerosols and yield information that can help suggest the occurrence of a biological attack. More recently, other optical methods, including Raman, infrared, and laser-induced breakdown spectroscopy, have shown promise as candidates to replace or augment the information obtained from fluorescence and scattering in bioaerosol detection systems. The selection of an optimal approach involves careful consideration of advantages and disadvantages among these various alternative optical methods. Key considerations are detection probability, false alarm rate, time to detect, and sensitivity. These four parameters are interrelated functions of the nature of the optical signal - characterized by absorption and/or emission cross-section, information content, and signal measurement system technology limitations.

In this paper, we describe a careful, deliberate process of developing a standardized aerosol challenge that mimics the properties of not only a biological agent release, but also the highly complex natural and anthropogenic aerosol background in order to evaluate prototype systems that exploit optical signatures to detect and warn of the presence of biological aerosols. The key to developing this test methodology involves 1) interpretation of the limited background aerosol data, 2) development of dynamic aerosol challenge capabilities, and 3) integration of experimental design principles in the development and execution of artificial challenge tests and in the reduction and interpretation of sensor system performance based on the test results.

6378-03, Session 1

Optically based bioaerosol detection

J. D. Eversole, Naval Research Lab.

For airborne threats or hazards, the development of point detection capability for materials that are inherently aerosols is principally an issue concerned with determining aerosol composition. The utility of receiver operating characteristic (ROC) curves to clarify tradeoffs between the probability of detection, and probability of false positive classification will be discussed, as well as the application of confusion matrix description of data feature separation. Examples will be taken from ongoing optical imaging and spectroscopy efforts to illustrate the connection between parameters such as discrimination, sensitivity, and response time made on an individual sample basis, to potential overall system performance.

6378-04, Session 1

Qualifying biomaterials for signature library construction

K. S. Kalasinsky, A. Shea, Armed Forces Institute of Pathology

Biological weapons have become a primary focus for detection techniques in defense. Knowing the presence or absence of biological threats is a key to safety of the military and security of the homeland. Numerous detection techniques have been explored, but the goal is for a rapid, sensitive, and specific method that can be readily transported to various sites. Raman spectroscopy has the desired specificity, and combining it with microscopic imaging has greatly increased the sensitivity. Since the fall of 2001, anthrax has been the center of attention for biothreat detection, but a technique must also be able to readily identify the other primary biological threats including bacteria such as those causing plague and tularemia, as well as viruses and toxins. Appropriate identification relies heavily on an accurate reference data set as well as the ability to separate the organism from a vast array of environmental background materials. Efforts to assure that the reference materials are accurate representation of the desired biological is as important as obtaining good quality data. Without a qualified signature library the analytical results lack reliability. Many diagnostic and proteomic steps are applied to each biological sample to maintain the integrity necessary for reference data. A significant Raman database of qualified reference materials has been created for biothreat analysis. Raman imaging has shown that molecular analysis of microbiological materials can be achieved and small amounts of biological material in complex backgrounds have been sampled and identified with the signature library.

6378-05, Session 1

Spectrometer correction and validation techniques for the development of Raman spectral databases for homeland security applications

S. J. Choquette, B. Benner, A. Kearsley, National Institute of Standards and Technology

Raman spectroscopy is a reagent-less analytical technique that is enjoying rapid growth because it can provide chemical sample identification in real-time and with a minimum of preparation. The development of inexpensive lasers, fiber optics, and detectors has reduced the size of the spectrometers from previously room-filling instruments to ones that are can literally be carried in a briefcase. Because a useable Raman spectrum can be acquired through many types of packaging, such as clear plastic containers and even colored glass bottles, a number of forensic laboratories are using the technique as a first-line analytical screening method for unknown compounds. Briefcase-sized Raman spectrometers are now being used at crime scenes, chemical spills, and other sites where remote or through-the-container analysis of an unknown may be important in protecting the safety of the investigative response team. Although the Raman method is not definitive, it can provide a rapid assessment of sample identity or sample class-often discerning the bad stuff from benign substances

Field deployable Raman instruments typically employ vendor-supplied Raman libraries.

Comparing results between systems or within the same instrument under field conditions requires considerable expertise and experience on the part of the user. If non-technical operators are to be used, then a software approach that is essentially user-independent is required. Our goal is to provide both the physical standards and the validated Raman spectral libraries necessary to impart confidence in these Raman measurements, to provide measurement traceablity to national standards, and to ensure evidentiary acceptance of these measurements.

This talk will discuss the generation of instrument-corrected Raman libraries and the transfer of this reference data to field-portable systems. The first step is a two-phase process that involves the qualification of the materials and the spectrometers used to generate the reference libraries. The second step is the evaluation of new algorithmic approaches to transfer this reference data to field portable systems. Examples of operator-independent methods for library searching, an important consideration for use of the technique by non-specialists, will be included.

6378-06, Session 1

Assessing threat sensor and signature performance

P. J. Treado, M. P. Nelson, J. H. Neiss, ChemImage Corp.; W. Beckenbaugh, Sceptor Industries, Inc.

Chemical imaging combines molecular spectroscopy and digital imaging, and is being demonstrated for rapid, reagentless molecular analysis of chemical, biological and explosives (CBE) threats in complex matrices. Because of the reliance on solid state photonics technologies, chemical imaging sensors are fieldable in cost-effective configurations. Chemical imaging provides molecular compositional information suitable for threat agent identification by comparing sensor response to a threat signature library. However, agent identification performance is limited inherently by signature variability. Sources of variability include sensor uncertainty, background variability and target signature variability. Target variability is most significant in biological threat agents. In this presentation, ongoing efforts to validate chemical imaging technology, signatures and analysis methods will be described.

6378-07, Session 1

Application of the adaptive subspace detector to Raman spectra for biological threat detection

T. A. Russell, S. Borchardt, R. Anderson, Applied Signal Technology, Inc.; P. J. Treado, J. H. Neiss, ChemImage Corp.

Effective application of point detectors in the field to monitor the air for biological attack imposes a challenging set of requirements on threat detection algorithms. Raman spectra exhibit features that discriminate between threats and non-threats, and such spectra can be collected quickly, offering a potential solution given the appropriate algorithm. The algorithm must attempt to match to known threat signatures, while suppressing the background clutter in order to produce acceptable Receiver Operating Characteristic (ROC) curves. The radar space-time adaptive processing (STAP) community offers a set of tools appropriate to this problem, and these have recently crossed over into hyperspectral imaging (HSI) applications. The Adaptive Subspace Detector (ASD) is the Generalized Likelihood Ratio Test (GLRT) detector for structured backgrounds (which we expect for Raman background spectra) and mixed pixels, and supports the necessary adaptation to varying background environments. The structured background model reduces the training required for that adaptation, and the number of statistical assumptions required. We applied the ASD to large Raman spectral databases collected by ChemImage, developed spectral libraries of threat signatures and several backgrounds, and tested the algorithm against individual and mixture spectra, including in blind tests. The algorithm was successful in detecting threats, however, in order to maintain the desired false alarm rate, it was necessary to shift the decision threshold so as to give up some detection sensitivity. This was due to excess spread of the detector histograms, apparently related to variability in the signatures not captured by the subspaces, and evidenced by non-Gaussian residuals. We present here performance modeling, test data, algorithm and sensor performance results, and model validation conclusions.

6378-08, Session 1

Evaluation of a high-throughput liquid crystal tunable filter for Raman chemical imaging of threat materials

X. Wang, Kent State Univ.; T. C. Voigt, ChemImage Corp.; P. J. Bos, Kent State Univ.; M. P. Nelson, P. J. Treado, ChemImage Corp.

Liquid crystal tunable filters (LCTF) have been used in systems developed for fluorescence and Raman chemical imaging spectroscopy of chemical, biological and explosives threat materials. However, an ongoing challenge in detecting trace levels of materials is the limited throughput provided by previous generation LCTFs. In this presentation, we will focus on a new class of birefringent LCTFs for Raman Chemical Imaging. Such LCFTs are based on a multi-conjugate filter design that provides high throughput over an extended wavelength range (450 nm-750 nm). The spectral resolution, tuning accuracy, out of passband rejection efficiency and imaging quality have been evaluated and are demonstrated on a Raman chemical imaging microscope platform. Detection of trace threat particulate matter in the presence of complex background will be described.

6378-09, Session 1

Performance characterization of material identification systems

C. D. Brown, L. Zhu, J. D. Santillan, Ahura Corp.

In recent years a number of analytical devices have been proposed and marketed specifically to enable field-based material identification. Technologies reliant on mass, near- and mid-infrared, and Raman spectroscopies are available today, and other platforms are imminent. These systems tend to perform material recognition based on an on-board library of material signatures. While figures of merit for traditional quantitative analytical sensors are broadly established (e.g., SNR, selectivity, sensitivity, limit of detection/decision), measures of performance for material identification systems have not been systematically discussed. In this paper we present an approach to performance characterization similar in spirit to ROC/DET curves, but specialized for the material identification objective. Important experimental considerations are discussed, including study design, sources of bias, and uncertainty estimation, and the approach as a whole is illustrated using a handheld Raman material identification system.

6378-10, Session 1

Relative infrared (IR) and terahertz (THz) signatures of common explosives

S. W. Sharpe, T. J. Johnson, D. M. Sheen, D. A. Atkinson, Pacific Northwest National Lab.

Pacific Northwest National Laboratory (PNNL) has recently recorded the infrared and far-infrared (sometimes called the terahertz, THz) signatures of four common explosives in the condensed phase. The signatures of RDX, PETN, TNT and Tetryl were recorded both in the infrared and the THz domains, using Fourier transform infrared (FTIR) spectroscopy. Samples were thin films deposited from acetone. The complete spectrum spanned the range from 4,000 to ~8 cm-1 at 2 cm-1 spectral resolution. Preliminary results in the infrared agree with those of previous workers, while the far-IR (THz) signatures, while unique, are clearly at least one order of magnitude weaker than the strongest IR bands.

6378-11, Session 2

Tunable diode laser and difference frequency generation absorption spectrometers for highly sensitive airborne measurements of trace atmospheric constituents

A. Fried, P. K. A. Weibring, D. A. Richter, J. G. Walega, National Ctr. for Atmospheric Research

Enhancing our understanding of atmospheric processes and transformations require a suite of ever more sensitive, selective, versatile, and fast instruments that can measure trace atmospheric constituents at and below mixing ratios of 100-parts-per-trillion on airborne platforms. Instruments that can carry out such measurements are very challenging, as airborne platforms vibrate, experience accelerations, and undergo large swings in cabin temperatures and pressures. These challenges notwithstanding, scientists and engineers at the National Center for Atmospheric Research (NCAR) have long been employing mid-infrared absorption spectroscopy to acquire atmospheric measurements of important trace gases like formaldehyde on a variety of airborne platforms. The present talk will discuss two very recent airborne formaldehyde instruments employing tunable diode laser and difference frequency generation mid-IR laser sources. Both instruments employ second-harmonic absorption spectroscopy utilizing astigmatic multipass Herriott cells. This talk will discuss the performance of both instruments during recent airborne campaigns, focusing on the many steps necessary for minimizing the various aircraft perturbations. Prospects for the detection of other trace gases will also be presented.

6378-12, Session 2

Methane-in-air standards neasured using a 1.65-micron cavity ring-down spectrometer

P. M. Chu, J. T. Hodges, G. C. Rhoderick, National Institute of Standards and Technology; D. Lisak, Univ. Mikolaja Kopernika (Poland); J. C. Travis, National Institute of Standards and Technology

We have recently developed a frequency-stabilized cavity ring-down spectrometer (FS-CRDS) with single-mode excitation using a tunable external cavity diode laser to help support the development and delivery of reference gas concentration standards. In the initial effort to benchmark the system, high-resolution spectra of CH4-in-air standards ranging in concentration from 1 ppm to 100 ppm, the current range of NIST CH4-in-air Standard Reference Materials (SRMs), have been measured. CH4 transitions in the 2 * 3 band around 1.65 micron were monitored as a function of sample pressures to identify the best conditions to measure samples over this concentration range and to begin to assess the degree of pressure-dependent effects. For a given sample, numerical integration of the measured spectra yielded areas that scale linearly with pressure to within 1 %. Fitting four Voigt profiles to the observed absorption feature reduced this discrepancy to 0.4 %. However, linearity between the measured spectral areas and reference concentrations was 3 % and 1%, based on numerical integration and Voigt profile fits to the data, respectively. On going efforts to resolve these differences will also be discussed.

6378-13, Session 2

Detecting ammonia and methane with antimonide lasers

D. C. Hovde, D. S. Bomse, Southwest Sciences, Inc.

Type I antimonide diode lasers operate in the 2000 to 2800 nm spectral region. Compared to the 1300 to 1650 nm communications spectral band, the antimonide band can access stronger molecular transitions and thus potentially achieve higher sensitivity. Compared to quantum cascade or lead-salt lasers operating at longer infrared wavelengths, antimonide lasers have the advantage that both laser and detector technology support room temperature, cw operation. This paper describes experiments to measure ammonia and methane simultaneously, with high sensitivity and fast response, using a distributed feedback laser at 2200 nm. Our approach is based on scanning the laser over a small spectral region that encompasses several lines, either by varying the laser temperature or current, while simultaneously using wavelength modulation with harmonic detection to record the spectrum. Temperature scanning is slower but can cover a wider spectral interval. Digital signal processing methods, including classical least squares and singular value decomposition, extract the gas concentrations from the measured spectra. The accuracy and precision of these algorithms are compared in two limits: the limit when both gases are absent or present only at low levels, and the limit when the concentration of one gas is high.

6378-14, Session 2

Trace gas optical detection using a differential multiple-pass astigmatic Herriott-style cell

D. S. Bomse, M. A. Zondlo, J. A. Silver, Southwest Sciences, Inc.

We describe trace methane detection using a near-infrared diode laser combined with a novel, differential, multiple-pass, astigmatic Herriott-style cell. This approach eliminates near all common mode features of the laser (1/f noise, fiber-induced noise, etalons, and harmonic distortion) that can reduce the sensitivity of absorbance measurements. The cell consists of two cylindrical mirrors and has the novel property that after traversing half the number of passes, the beam always strikes the center of the far mirror. This feature allows designing a differential cell in which part of the beam travels through half the total number of optical passes and is then used as the reference leg of a noise canceler circuit (also known as a balanced ratiometric detector). The other part of the beam travels the full complement of passes and is used as the signal leg of the noise canceler. Thus, the two beam experience nearly identical environments except that the path length of the signal beam is double the length of the reference beam.

6378-15, Session 2

High-precision CO_2 sensor for meteorological balloons

J. A. Silver, M. A. Zondlo, Southwest Sciences, Inc.

Over the past decade, the importance of understanding the sources and sinks of carbon dioxide and other greenhouse gases has been recognized. A variety of research studies to measure the fluxes and fluctuations of CO2 from average conditions have been performed, including airborne measurements of CO2 profiles throughout the troposphere and lower stratosphere. While these studies have demonstrated a precision as low as 0.05 ppmv, they have been restricted to airplane or large stratospheric-type balloon gondola platforms, due to the size, weight and power requirements of the instrumentation involved. A more frequent measurement campaign using smaller, less expensive, conventional meteorological balloons has been limited by the lack of suitable instrumentation having sub-ppm precision. In this work, we discuss the development and flight testing of a compact, diode laser-based sensor for measurements of CO2, which achieves its precision using a novel pressure/temperature compensating reference cell. This device weighs about 1 kg and uses less than 4W of electrical power (batteries). It is fully controlled by a digital signal processor and uses a 2004 nm vertical cavity laser. A full description of the sensor and a discussion of its performance will be presented.

6378-16, Session 2

High-sensitivity cryogen-free ammonia monitor using a pulsed quantum cascade laser

D. D. Nelson, J. H. Shorter, J. B. McManus, S. C. Herndon, M. S. Zahniser, Aerodyne Research, Inc.

Emission of ammonia (NH3) to the atmosphere is a major environmental concern and a potential health hazard, but the accurate measurement of ammonia sources requires improved instrumentation. There is a need for a high sensitivity, fast response, autonomous, continuous ammonia instrument to monitor present emissions, quantify the effectiveness of control measures, and evaluate the effects of ammonia emissions on local and regional soils, groundwater, and atmospheric environments. We have addressed this problem by developing an ammonia monitor based on high resolution infrared absorption spectroscopy using a thermoelectrically cooled quantum cascade (QC) laser at 967 cm-1.

We detect the infrared radiation with an optically immersed, thermoelectrically cooled infrared detector rather than a liquid nitrogen cooled detector since we require that the instrument operate autonomously for long time periods (several weeks). We partially compensate for the increased detector thermal noise by maximizing optical intensity with careful collection and transport of the laser beam through a 76 meter astigmatic multiple pass absorption cell. Using this approach, we have demonstrated a measurement sensitivity for NH3 of 180 parts-per-trillion-by-volume (pptv) with a 1 second measurement time in an entirely non-cryogenic QC laser instrument. With signal averaging, the noise level is reduced to approximately 60 pptv in 40 seconds.

6378-17, Session 2

An adaptive robust computational method for removing unwanted etalon fringes from diode laser absorption spectra

D. S. Bomse, Southwest Sciences, Inc.

Theoretical detection limits for diode laser absorbance measurements are in the 10-8 to 10-7 Hz-1⁄2 range — defined by laser shot noise or detector thermal noise — yet practical diode laser spectrometers rarely perform better than 10-5 Hz-1⁄2 short term and 10-6 long term. Unwanted optical interference fringes (etalons) cause this difference between theoretical and actual performance. We describe an adaptive filtering method based on singular value decomposition (SVD) that can selectively subtract the unwanted optical interference fringes without perturbing signals due to genuine optical absorption in wavelength modulation spectra. The SVD approach was tested using a fiber-coupled, near-infrared, telecommunications laser operating at 1530 nm

to measure acetylene concentrations. Long term drift (~1 week) was reduced by a factor of five; short term noise (several seconds) increased slightly. The SVD routine is computationally fast and can operate in real time for a system with a 1 Hz update rate. It is relatively robust, showing relative lack of sensitivity to key parameters such as the number of basis functions used and the number of eigenfunctions retained. SVD is compatible with post-filtering methods such as Kalman filtering.

6378-18, Session 2

Gas-cell measurements for evaluating LWIR passive sensor performance

A. S. Cummings, Tetra Tech; R. J. Combs, Research and Technology Consultants; T. Curry, M. J. Thomas, U.S. Environmental Protection Agency; R. T. Kroutil, Los Alamos National Lab.

Long-wave infrared (LWIR) passive spectrometer performance is evaluated. The evaluation is performed with a gas cell accurately positioned between the sensor and a NIST-traceable blackbody radiance source. The gas cell contents are varied over the Beer's Law absorbance range from the limit of spectral detection to near saturation. In addition, the effects of absorbance saturation are documented. The gas cell contents for all concentration-pathlengths are verified with a traditional laboratory Fourier transform infrared (FTIR) spectrometer. Blackbody source temperatures for the LWIR passive sensor range from 5 to 50 degrees Celcius. These blackbody temperatures and target gas absorbances simulate those often encountered in open-air scenarios which are important to both industrial and environmental monitoring applications.

6378-19, Session 3

FTIR spectroscopy for bacterial spore identification and classification

N. B. Valentine, T. J. Johnson, J. Forrester, Pacific Northwest National Lab.

The ability to distinguish endospores from each other, from vegetative cells, and from background particles has been demonstrated by PNNL and several other laboratories using sundry analytical techniques. Recent studies at PNNL using Fourier transform Infrared (FTIR) spectroscopy combined with statistical analysis have shown the ability to characterize and discriminate bacterial spores and vegetative bacteria from each other, as well as from interferents. In some cases it is even possible to determine the taxonomical identity of the species using FTIR. This effort has now grown to include multiple species of bacterial spores, vegetative cells, and background materials analyzed by FTIR. The project is moving toward the ultimate goal of being able to use FTIR, or FTIR in combination with other techniques, for rapid and reliable discrimination and analysis under a myriad of conditions.

6378-20, Session 3

The evolution of fluorescent portable digital lidar: from laboratory to low-rate production and beyond

C. R. Prasad, Science & Engineering Services, Inc.

Low-power and eye-safe Fluorescent Portable Digital Lidar systems using commercial IR and UV lasers, photon counting PMTs, and customized software for detection and discrimination of bio-aerosols have been developed in the past several years at Science & Engineering Services, Inc. (SESI). Examples include SESI's long range (\>10km) Joint Biological Standoff Detection System (JBSDS) for JPEO-CBD and short range (~500m) Ultraviolet Biological Trigger Lidar (UBTL) for DARPA, both successfully demonstrated on multiple occasions at Dugway Proving Ground since 2003. The current JBSDS uses low power 10 kHz solid state near-IR and UV laser sources with common integrated transmitter-receiver geometry for standoff detection of aerosol clouds at ranges from 500m to 10,000m, and more importantly good and reliable discrimination of bio-warfare-agents (BWA) at ranges up to 3,000m in field (cluttered) environments under nighttime conditions. The UBTL is designed to use low power semiconductor continuous wave UV laser diodes and a range capability of up to 500m

Standoff sensors offer distinct attributes when compared to point bio-warfare agent sensors for military and civilian users. The standoff bio-sensor has the unique ability to provide the "unblinking eye" for warning against bio-warfare agent threats (capable of providing several minutes of warning), and at the same time afford a relatively small and lower-cost "logistics tail." Moreover, standoff sensors can provide precious minutes for preliminary indication, warning, and responsive action.

JBSDS is now sufficiently mature to enable hands-on operation by Soldiers and Airmen in less than one week of training. Further, multiple users are now seeking system enhancements to objective requirements such as day-light operation, higher sensitivity, and reduced false positive rate. Recent findings in the course of SESI's Internal R&D indicate that these objectives can be fulfilled. We will review recent scientific results and outline how Fluorescent Portable Digital Lidar can now be taken to the next level of capabilities.

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6378-21, Session 3

Detection of invisible bacillus spores on surfaces using a portable SERS-based analyzer

S. R. Farquharson, F. E. Inscore, Real-Time Analyzers, Inc.

Since the distribution of anthrax causing spores through the U.S. Postal System in the autumn of 2001, numerous methods have been developed to detect spores, largely focusing on the analysis of air, with the goal of minimizing casualties. Although possibly less critical, it is also important to detect spores on surfaces, to assess extent of an attack, to quantify risk of infection by contact, as well as to evaluate post-attack clean-up. To perform useful measurements, analyzers and/or methods must be capable of detecting as few as 10 spores/cm2, in under 5-minutes, with little or no sample preparation or false-positive responses, using a portable device. In an effort to develop such a device, we have been investigating the ability of surface-enhanced Raman spectroscopy (SERS) to detect dipicolinic acid as a chemical signature of bacilli spores. In general, SERS is capable of detecting mg/L concentrations and lower, unequivocal identification of chemicals based on each one's unique spectrum, and rapid analysis with minimal sample preparation.

In 2003 we employed SERS to measure 10,000 spores in a 1 microliter sample in two minutes. This was accomplished by causing the release of dipicolinic acid using hot dodecylamine. Other researchers, employed nitric acid in combination with ultrasound to accomplish the same goal, and reported detection of 187,000 spores per microliter. Since that time we have explored numerous chemicals and combinations to cause the release of spores without the need of heat or ultrasound. Here we report our success and the measurement of 220 Bacillus cereus spores collected from a surface in a 1 microliter sample. The entire analytical process was performed in 2 minutes. Details of these measurements and the portable Raman analyzer used to perform them will be presented.

6378-22, Session 3

Water and surface contamination monitoring using deep UV laser induced native fluorescence and Raman spectroscopy

W. F. Hug, Photon Systems, Inc.; R. Bhartia, A. Tsapin, A. L. Lane, Jet Propulsion Lab.

Reagentless water and surface sensors employing laser induced native fluorescence (LINF) and resonance Raman spectroscopy (RRS) in the deep UV are making significant progress in detecting chemical and biological targets and differentiating them against a wide range of background materials. Methods for optimizing sensor performance for specific target and backgrounds materials will be discussed in relationship to closed industrial environments and open environmental environments. Limits of detection and chemical specificity will be discussed for high and low spectral resolution systems for a wide range of compounds and composite particles such as spores and cells.

A range of sensors will be described along with their physical and

performance specifications including sample, sipper and immersion sensors for water and fixed point and scanner systems for surfaces. In addition, the use of UV LINF and RRS for detection in capillary electrophoresis and liquid chromatography will be described.

6378-23, Session 4

Miniature FT-IR spectrometer for passive and active sensing

C. J. Manning, M. Gross, Manning Applied Technologies, Inc.; A. Samuels, U.S. Army Edgewood Chemical Biological Ctr.

A novel handheld FT-IR spectrometer system is described. While the first version will employ photoacoustic detection and selectively absorbing resin for preconcentration of airborne chemical agents, a range of applications, including active and passive remote sensing, are possible. The extremely small size and resistance to vibration make it suitable for use on miniature aircraft. Application of selectively absorbing materials will provide detection in the part per billion range. Models indicate that the sensitivity may extend to the part per trillion range. Recent advances in electronics, particularly in computing engines, have made practical a range of miniature sensor systems. Other innovations, such as lithium-ion batteries, MEMs microphones, and new source materials, enable a pocket-sized FT-IR spectrometer. However, FT-IR spectrometers have not yet been miniaturized, probably because of throughput limitations. The use of field-widening has been known for many years, but applied infrequently. While there are a number of approaches to field widening, the simplest is to construct an interferometer body from a high index material. The useful range of solid angles (i.e., field of view) can be expanded by approximately the square of the refractive index, allowing the aperture area to be reduced by a similar factor. Thus, a 1-cm aperture, in a solid germanium interferometer, can provide roughly same throughput as a large benchtop research spectrometer with a 4-cm aperture.

6378-24, Session 4

A fiber optic sensor for nerve agent

S. R. Cordero, R. A. Lieberman, Intelligent Optical Systems, Inc.

We report advances made on the development of a fiber optic nerve agent sensor having its entire length as the sensing element. The optical fiber is multimode and consists of a fused-silica core and a nerve agent sensitive cladding. Upon exposure to Sarin gas the cladding changes color resulting in an alteration of the light intensity throughput. The fiber is mass produced using a conventional fiber optic draw tower. This technology could replace, or be used with, a collection of point-detectors to protect personnel, buildings and perimeters from dangerous chemical attacks.

6378-25, Session 4

Design and calibration of low-cost fiber optic sensors for refractive index measurement of turbid liquids

P. Gupta Bhaya, A. K. Ghosh, V. Saxena, J. John, Indian Institute of Technology Kanpur (India)

Refraction of light by turbid colloidal suspensions has been of interest to physical chemists for more than fifty years. In light scattering and turbidity spectroscopic studies of polymeric or particulate suspension it is important to know the refractive index of the suspended particles so that experimental results can be analyzed. Traditional bulk refractometers are not appropriate for measurements in turbid suspensions especially with small quantities of biological turbid liquids. A set of low-cost fiber-optic refractive index sensors is designed and fabricated in our laboratory for accurate and precise measurement of refractive indices of turbid liquids. The sensors are made by stripping out a portion of the plastic cladding of large-core multimode plastic and silica fibers. The liquid being tested is put on to the measuring fiber probe so that the evanescent field in the stripped cladding portion comes in contact with the turbid liquid. The loss of optical power in the sensing fiber is thus made a function of the complex refractive index of the liquid as well as that of the suspended particles.

In this paper we discuss the experimental results on the calibration and reliability studies of these sensors. We found that our sensors are sensitive measurement devices in the refractive index range 1.33 to 1.56. The precision achieved is in the range of 0.001 to 0.000001 depending on the method of fabrication. We experimented with various techniques of cladding removal and the plastic cladding of fibers has been stripped to different values of cladding thickness. The variation of cladding thickness brings to fore the role of cladding mode in such evanescent wave based refractive index sensing. We find that an optimal amount of cladding remaining on the core of the fibers enhances the sensitivity of refractive index measurements. The effects of surface quality of the etched-cladding and liquid interface and the influence of absorption are also reported in the paper.

6378-26, Session 4

Analysis of oxytetracycline in surface water using a portable analyzer

G. Chen, U.S. Dept of Agriculture; F. Qin, Shanghai Institute of Drug Control (China)

A huge amount of oxytetracycline (OTC) is used in aquaculture worldwide. Since it is poorly absorbed by the gastrointestinal (GI) system and has a long lifetime, it is an important task to monitor its distribution and fate in the marine environment and its impact on human and the biosphere. A portable LED-based analyzer was prototyped employing europium-sensitized luminescence to perform field analysis of OTC in water, sediment, and other marine environmental matrices. In this study a simple and sensitive method for OTC analysis in surface water is developed using this instrument. OTC is first extracted and enriched from water onto 17Å~15 mm C18 sorbent strips under 1-hr constant stirring. The strips are then dipped into a Eu-containing reagent solution for 2 min. Next the dried strips are desiccated and exposed to a pulsed 385-nm UV beam. The time-resolved luminescence is directly measured on the sorbent surface. A 0-100 ppb linear dynamic range (LDR) (r2 = 0.999) and a 0.13-ppb limit of detection (LOD) are achieved with a typical 5% relative standard deviation (RSD). Based on the experimental results, this portable instrument and the assay method can be applied to aquacultural system monitoring, and to environmental analysis in general.

6378-27, Session 4

Continuous water monitoring of chemical agents and their hydrolysis products by SERS

S. Farquharson, F. E. Inscore, Real-Time Analyzers, Inc.

Protection of military personnel and civilians from water supplies poisoned by chemical warfare agents (CWAs) requires an analyzer that has sufficient sensitivity (μg/L), selectivity (differentiate the CWA from its hydrolysis products), and speed (less than 10 minutes) to be of value. In an effort to meet these requirements, we have been investigating the ability of surface-enhanced Raman spectroscopy (SERS) to detect these chemicals in water. The expected success of SERS is based on reported detection of single molecules, the one-to-one relationship between a chemical and its Raman spectrum, and the minimal sample preparation requirements. It has been shown that the Raman scattering efficiency of a molecule can be increased by a many as 14-orders of magnitude, when that molecule interacts with surface plasmon modes of metal nanoparticles.

Recently, we have developing a simple sampling device designed to optimize the interaction of the target molecules with the metal surface plasmon modes with the goal of increasing sensitivity and decreasing sampling times. This sampling device employs a syringe to draw the water sample containing the analyte into a capillary filled with the SERS-active material. Recently we used such SERS-active capillaries to measure 1 μg/L cyanide in water. Here we will describe these measurements as well as those for blister and nerve agent hydrolysis products, and portable analyzers suitable for point and continuous water monitoring.

6378-28, Session 4

Differential fluorescence from molecularly imprinted polymers containing europium ions as a transducer element

D. Pestov, Virginia Commonwealth Univ.; J. E. Anderson, U.S. Army Corps of Engineers; G. C. Tepper, Virginia Commonwealth Univ. and Sentor Technologies Inc.

Molecularly imprinted polymers (MIPs) have the potential to provide a unique combination of high chemical selectivity and environmental stability and are, therefore, being widely studied in chemical sensor applications. Optical interrogation of the MIP-chemical interaction is very convenient for the detection of fluorescent compounds, but is problematic for the detection of non-fluorescent species. Doping MIPs with Eu3+ is one approach that can facilitate the optical detection of non-fluorescent species. Eu3+ has absorption in the near UV and the doped MIP can, therefore, be excited with a commercially available laser diode at 375nm. In the present paper MIPs doped with Eu3+ and imprinted to methyl salicylate (MES), a chemical warfare agent simulant, were prepared in the form of a thin film on a quartz substrate. Non-imprinted (Blank) polymer films were also was prepared using the same imprinting procedure, but without introducing the MES template. Both polymers were tested to MES and the structurally similar compound methyl 3,5-dimethylbenzoate in hexane. For MES, the fluorescence intensity of the MIP was significantly stronger than for the Blank, while for the methyl 3,5-dimethylbenzoate, the Blank polymer exhibited the stronger fluorescence signal. A portable chemical sensor employing differential fluorescence from MIP/Blank polymer pairs is under development and allows target discrimination without the need for spectroscopic analysis of the emission spectra. Advantages and disadvantages of this new optical chemical sensor are discussed.

6378-29, Session 4

Portable natural gas leak detector

M. E. Paige, J. A. Silver, D. S. Bomse, Southwest Sciences, Inc.; D. Petroski, Southern Cross Corp.

A diode laser based natural gas leak detector has been developed that can measure methane concentrations over six orders of magnitude, from ambient (1.7 ppm) to pure gas levels. The detection method utilizes wavelength modulation absorption spectroscopy and a small multipass optical cell. At high methane concentration, various forms of unmodulated absorption spectroscopy are used. The instrument is a handheld unit that operates on less than 2 W of power and weighs under 5 lbs. A small pump on the unit pulls outside gas into the enclosed optical cell through a handheld wand. The response time of the instrument is 1 sec.

6378-30, Session 4

Water assessment using beam diameter measurement

E. Jonathan, Harare Institute of Technology (Zimbabwe)

A simple optical technique primarily for assessing water samples from different sources is discussed. The technique relies on measurement of the diameter of the transmitted beam after multiple passes through the water sample in a holding cuvvette. The preliminary experimental data reveal a relationship between the ‘nature’ of the water sample and the transmitted beam diameter taken to be the Full-Width at Half-Maximum (FWHM). We envisage the technique will find use in low-cost simple-to-use insrumentation for rapid assessment of water samples.

6378-31, Session 5

Bioaerosols laser-induced fluorescence provides robust signature for standoff detection

S. Buteau, J. Simard, J. E. McFee, J. Ho, P. Lahaie, G. Roy, P. Mathieu, B. Déry, Defence Research and Development Canada (Canada)

One of today’s primary security challenges is the emerging biological threat due to the increased accessibility to biological warfare technology and the limited efficiency of detection against such menace. By the end of the 90s, DRDC developed a standoff bioaerosol sensor, SINBAHD, based on intensified range-gated spectrometric detection of Laser Induced Fluorescence (LIF) with an excitation at 351 nm. The LIDAR system, that monitors atmospheric cells from a standoff position, generates specific spectrally wide fluorescence signals originating from inelastic interactions with complex molecules forming the building blocks of most bioaerosols. This LIF signal is spectrally collected by a combination of a dispersive element and a range-gated ICCD that limits the spectral information within the single atmospheric cell of interest. This work has showed an important potential of detecting and classifying bioaerosols in real-time. This data exploitation process is based on fitting in a least-square sense the acquired fluorescence signal by a linear combination of spectral basis. The detection and classification processes are hence directly depending on the accuracy of the basis to represents the intrinsic fluorescence of bioaerosols. The comparison of spectral signatures acquired at Suffield in 2001 and at Dugway in 2005 of bioaerosol simulants, Bacillius subtilis var globiggi (BG) and Erwinia herbicola (EH), having different origin, preparation protocol and/or dissemination modes, have demonstrated the robustness of these spectral basis. Other results showing minimum detectable concentrations for different stimulants/interferents obtained at the Joint Biological Standoff Detection System (JBSDS) increment II field demonstration trial, Dugway Proving Ground (DPG) in June 2005, will also be presented.

6378-32, Session 5

Real-time determination and suppression of bioaerosol constituents

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Standoff detection of bio-aerosols using an active UV-induced fluorescence lidar probes a column of air, which contains interferents such as pollen, fungal spores, diesel particulates or paper dust, and which may contain a bio-agent such as bacteria, bacterial spores, toxin, or virus. These interferent concentrations will have unpredictable spikes with at least an order of magnitude dynamic range. Mixtures of interferents may mimic the signatures of bio-agents. In general, a small number of interferents will be present in significant concentrations in any test location, but these constituents may change with both season and time of day.

Previous work by the authors and others has shown how the signatures of known constituents can be suppressed if multi-dimensional data are available. Determining what constituents are actually present thus becomes a key enabling capability to lower the false alarm rate of remote sensors.

This paper will summarize previous work in background suppression and bio-agent detection, and will present several candidate stand-off applications. A radiometric modeling approach based on UV fluorescence measurements will be outlined. An unsupervised method for extracting constituents (equivalent to identifying endmembers of the mixture) will be presented, and a visualization of the results of this approach for typical fluorescence signatures will be shown.

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6378-33, Session 6

Remote detection of gases and liquids by imaging Fourier transform spectrometry using a focal plane array detector

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Remote sensing by Fourier-transform infrared spectrometry allows detection and identification of hazardous clouds in the atmosphere from long distances as well as identification of solids and liquids. A conventional remote sensing Fourier transform infrared spectrometer is based on an interferometer with a single detector element. By combination of an interferometer with a synchronized scanning mirror system, an imaging system may be constructed. Such an imaging system yields high spectral quality but the temporal resolution and as a consequence also the spatial resolution are limited by the sequential measurement of all fields of view within the field of regard. Moreover, the spatial resolution of remote sensing systems optimized for high throughput is generally low. In order to increase the spatial resolution and the temporal resolution, an imaging Fourier-transform spectrometer

(IFTS) with a detector array instead of a single detector element is currently being developed at TUHH. In this work, the method and first measurements are presented.

6378-34, Session 6

Design of CATSI EDM: a passive standoff chemical warfare agent detector

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With the constant menace of terrorist attacks with warfare agents, the community needs reliable detection systems. The CATSI EDM system, designed for the Canadian Forces, offers unmatched performances for standoff chemical detection and identification. This sensor is based on high resolution Fourier Transform Spectrometer technology and has a unique feature that performs automatic background rejection. Its large field of regard combined with its high sensitivity and large étendue makes of it a very powerful tool for homeland security services.

This paper presents the conceptual approach for the optics, mechanics, thermal management and the main functionalities. Performance results obtained with the sensor during its integration are also presented.

6378-35, Session 6

Vibrational overtone stretching transitions in sarin

M. W. P. Petryk, Defence Research and Development Canada (Canada)

The CH stretching overtone transitions of the nerve agent Sarin (isopropyl methylphosphonofluoridate) are of interest to the standoff detection of chemical warfare agents, as many of these transitions occur near regions where small, efficient, portable diode lasers (originally developed for use in the telecommunications industry) operate. However, the interpretation of experimental vibrational overtone spectra is often difficult, and the computational simulation of overtone transitions in a molecule is challenging. Presented herein are the simulated CH overtone stretching transitions in Sarin. Spectral regions are simulated from overtone transition energies and intensities, both of which are calculated within the harmonically coupled anharmonic oscillator (HCAO) model. Data for HCAO calculations are obtained from ab initio calculations, without any recourse to experimental data. The possibility of computationally predicting the vibrational overtone spectrum of any molecule is addressed.

6378-36, Session 6

Detection of explosive materials by differential reflection spectroscopy

A. M. Fuller, R. E. Hummel, C. Schoellhorn, P. H. Holloway, Univ. of Florida

It is shown that traces of 2, 4, 6-Trinitrotoluene (TNT) display strong and distinct structures in differential reflectograms, near 420 nm and 250 nm. These characteristic peaks are not observed from moth balls, nail polish, PVC, starch, soap, paper, epoxy, aspirin, polycarbonate, aspartame, polystyrene, polyester, fertilizer, or sugar, to mention a few substances which may be in or on a suitcase. This exclusivity implies an ideal technique for explosives detection in mass transit and similar locations. The described technique for detection of TNT is fast, inexpensive, reliable, portable, and does not require contact with the surveyed substance. Moreover, we have developed a curve recognition program for field applications of the technique. Other explosives such as RDX, HMX, nitroglycerin, and PETN have also been investigated and demonstrate similar, but unique, characteristic spectra. The technique utilizes UV light reflected from two spots on the sample surface yielding a differential reflectogram of the sample corresponding to the absorption of the sample. The origin of the spectra is attributed to the HOMO-LUMO transitions within the respective explosive molecule. Experiments using UV-Visible spectrometry have been performed to define the specific transitions. These results are supported by computer modeling of the molecular orbitals and subsequent UV and visible transitions.

6378-37, Session 6

Remote detection of chemicals with passive millimeter waves

N. Gopalsami, S. Bakhtiari, T. Elmer, A. C. Raptis, Argonne National Lab.

Active and passive spectroscopic sensors operating in the optical range have been employed for environmental monitoring and remote sensing applications. Optical systems, which provide superb sensitivity as a direct consequence of the high-energy vibrational transitions of molecules, are limited in their range for remote sensing because of their extreme sensitivity to atmospheric effects. Although a passive millimeter-wave system has been used to remotely map solid targets and to measure low-pressure spectral lines of stratospheric and interstellar gases, its application to pressure-broadened spectral detection of terrestrial gases is new. This paper will describe the design, development, and testing of a novel multispectral radiometer in the 146-154 GHz range for remote detection of rotational spectral lines of chemicals. With Dicke-switched integration of radiometric signals, on-line calibration, and novel signal processing to minimize atmospheric fluctuation, molecular spectral line detection has been made possible from chemical plumes hundreds of meters away. Application of spectroscopic techniques for passive terrestrial detection of hazardous molecules in a chemical plume at millimeter wave frequencies is a new frontier in science, and the offshoots of this technology are expected to have industrial, scientific, and medical applications.

6378-38, Session 7

Variable-size variable-band selection for spectral feature characterization in hyperspectral data

S. Wang, C. Chang, Univ. of Maryland/Baltimore County

This paper presents a band selection technique for spectral feature characterization in hyperspectral data, referred to as band selection for hyperspectral signature feature characterization (BSHSFC). Since a hyperspectral signature is characterized by its spectral profile, the number of bands to be selected is totally determined by spectral features that uniquely characterize the signature. As a result, two hyperspectral signatures may require different sets of bands for spectral characterization. The proposed BSHSFC is a variable-size variable-band selection (VSVBS) where the number of selected bands varies with a hyperspectral signature to be processed. In order for BSHSFC to select an appropriate set of bands for a hyperspectral signature, a new band prioritization criterion, referred to as orthogonal subspace projector-based band prioritization criterion (OSP-BPC) is derived for this purpose. It assigns a different priority score to each spectral band of a hypserpctral signature such that various features can be captured by the BSHSFC from the original set of bands. Accordingly, the BSHSFC can be interpreted as a spectral feature extraction technique for signature characterization. Finally, experiments using two sets of data are conducted to demonstrate that the BSHSFC-based BS can improve the performance of hyperspectral signature characterization.

6378-39, Session 7

Exploration of methods for estimation of number of endmembers in hyperspectral imagery

C. Wu, C. Chang, Univ. of Maryland/Baltimore County

An endmmeber is an idealized, pure signature for a class and provides crucial information for hyperspectral image analysis. Recently, endmember extraction has received considerable attention in hyperspectral imaging due to significantly improved spectral resolution where the likelihood of a hyperspectral image pixel uncovered by a hyperspectral image sensor as an endmember is substantially increased. Many algorithms have been proposed for this purpose. One great challenge in endmember extraction is the determination of number of endmembers, p required for an endmember extraction algorithm (EEA) to generate. Unfortunately, this issue has been overlooked and avoided by making an empirical assumption without justification. However, it has been shown that an appropriate selection

of p is critical to success in extracting desired endmembers from image data. This paper explores methods available in the literature that can be used to estimate the value, p. These include the commonly used eigen-analysis method, principal components analysis (PCA), an information criterion (AIC), minimum description length (MDL) information theory, Gerschgorin radius arising in array processing and Neyman-Pearson detection method in detection theory. In order to evaluate the effectiveness of these methods, two sets of experiments are conducted for performance analysis. The first set consists of synthetic image-based simulations which allow us to evaluate their performance with a priori knowledge, while the second set comprising of real hyperspectral image experiments which demonstrate utility of these methods in real applications.

6378-40, Session 7

Modified Fisher's linear discriminant analysis for hyperspectral image compression and classification

Q. Du, Mississippi State Univ.

In this paper, we present a modified Fisher's linear discriminant analysis (FLDA) to hyperspectral image exploitation. The basic idea of FLDA is to design an optimal transform which can maximize the ratio of between-class scatter matrix to within-class scatter matrix. The practical difficulty of applying the FLDA to hyperspectral remote sensing imagery includes the unavailability of enough samples of different classes. So the original FLDA is modified to avoid the requirement of class samples. Then, in the following data classification using the FLDA-transformed data, a more powerful classifier is required. Fortunately, we find this is not difficult to achieve. Since the major purpose of FLDA is dimension reduction, we also investigate its performance in image compression. In conjunction with sophisticated wavelet based spatial coding techniques, such as JPEG 2000, the FLDA based compression can yield very high compression ratio. The experiments using AVIRIS, HYDICE, and Hyperion data demonstrate the modified version of FCDA is very useful in hyperspectral image compression and classification, when the class spectral signatures are known a priori.

6378-41, Session 7

Signature reduction methods for target detection in multispectral remote sensing imagery

H. Ren, National Central Univ. (Taiwan); J. P. Fang, Y. Chang, National Taipei Univ. of Technology (Taiwan)

Multispectral sensors are still widely used in satellite remote sensing. They usually have spectral bands less than ten channels. The problem for so few channels is that it can not directly solve linear mixture model by least square unmixing for subpixel target detection. In order for least square approach to be effective, the number of bands must be greater than or equal to that of signatures to be classified, i.e., the number of equations should be no less than the number of unknowns. This ensures that there are sufficient dimensions to accommodate orthogonal projections resulting from the individual signatures. It is known as band number constraint (BNC). Such constraint is not an issue for hyperspectral images since they generally have hundreds of bands, however, this may not be true for multispectral images where the number of signatures to be classified might be greater than the number of bands. In order to relax this constraint, we present two signature reduction methods to reduce the number of unknowns, based on signature selection and signature fusion. A SPOT image scene will be used for experiment to demonstrate the performance.

6378-42, Session 7

Relative radiometric calibration for multispectral and hyperspectral remote sensing imagery

H. Ren, National Central Univ. (Taiwan)

Our environment has been changed continuously by nature causes or human activities. In order to find out what has been changed during certain time period, we need to spend enormous resources to record all kinds of data and compare them. With remote sensing images, change detection has become one efficient and inexpensive technique. It has wide applications including disaster management, agriculture analysis, environmental monitoring and military reconnaissance. To detect the changes between two remote sensing images collected at different time, radiometric calibration is one of the most important processes. Under the different weather and atmosphere conditions, even the same material might be resulting distinct radiance spectrum in two images. In this case, they will be misclassified as changes and false alarm rate will also increase. To achieve absolutely calibration, i.e., to convert the radiance to reflectance spectrum, the information about the atmosphere condition or ground reference materials with known reflectance spectrum is needed but rarely available. In this paper, we present relative radiometric calibration methods which transform image pair into similar atmospheric effect instead of remove it in absolutely calibration, so that the information of atmosphere condition is not required. A SPOT image pair will be used for experiment to demonstrate the performance.

6378-43, Session 7

A simulated annealing band selection approach for hyperspectral imagery

J. P. Fang, Y. Chang, National Taipei Univ. of Technology (Taiwan); H. Ren, National Central Univ. (Taiwan); W. Liang, National Taipei Univ. of Technology (Taiwan); J. Fang, National TaiChung Univ. (Taiwan)

For hyperspectral imagery, greedy modular eigenspaces (GME) has been developed by clustering highly correlated hyperspectral bands into a smaller subset of band modular based on greedy algorithm. Instead of greedy paradigm as adopted in GME approach, this paper introduces a simulated annealing band selection (SABS) approach for hyperspectral imagery. SABS selects sets of non-correlated hyperspectral bands for hyperspectral images based on simulated annealing (SA) algorithm while utilizing the inherent separability of different classes in hyperspectral images to reduce dimensionality and further to effectively generate a unique GME feature. The proposed SABS features: (1) avoiding the bias problems of transforming the information into linear combinations of bands as does the traditional principal components analysis (PCA); (2) selecting each band by a simple logical operation, call SA feature scale uniformity transformation (SA/FSUT), to include different classes into the most common feature modular subset of bands.; (3) providing a fast procedure to simultaneously select the most significant features according to a scheme of simulated annealing. The experimental results show that this SABS approach is effective and can be used as an alternative to the existing band selection algorithms.

6378-44, Poster Session

Optical bar code recognition of methyl salicylate-surface imprinted InGaP EviTags for environmental monitoring using fluorescence resonance energy transfer on thin films

C. B. Smith, J. E. Anderson, U.S. Army Corps of Engineers; B. Tatineni, D. Pestov, R. Kesik, G. C. Tepper, Virginia Commonwealth Univ.

Fluorescence resonance energy transfer (FRET) is a process in which energy is transferred non-radiatively (via long-range dipole-dipole coupling) from one fluorophore (the donor) in an excited electron state to another, the chromophore (the acceptor). FRET is distinctive in its ability to reveal the presence of specific recognition of select targets such as the nerve agent stimulant Methyl Salicylate (MES) upon spectroscopic excitation using a xenon arc lamp source or active laser induced fluorescence imaging system. MES was investigated as a donor to various acceptor fluorophores and quantum dots. The quantum dot(s) selected were newly developed non-organometallic Indium Gallium Phosphide (InGaP) cores that are less toxic to the environment and are coated with a unique outer shell that makes it water stable. This allowed for surface imprinting of the MES to the outer shell of the quantum dots for functionalization of the quantum dots. We introduce a surface imprinted non-organometallic InGaP quantum dot matrixed thin film for MES that underwent AC-Electrospray ionization for donor-acceptor pair(s) via polymeric solvent/fluorophore ratios and displayed FRET when collected on to plasma cleaned quartz based medium. The carrier polymer solvents selected

were polyvinyl alcohol (PVA) and polypyrrole (PPy), which consisted of various concentrations of the donor-acceptor pair(s): 9, 10 diphenyl-anthracene (donor), rhodamine 123 (acceptor), and MES-InGaP (donor-acceptor).

6378-45, Poster Session

Fabrication of a monolithically integrated multiple wavelength Fabry-Perot filter array using transparent etch stop layers for accurate wavelength determination

D. Convey, N. V. Le, S. M. Smith, P. Holm, J. H. Baker, Motorola, Inc.

The original Fabry-Perot filters were developed by Charles Fabry and Albert Perot in 1897. Since then, designs based on their original construction of bulk lenses, mirrors, and beam optics have provided both high tuning ranges and extremely high optical wavelength resolution. Many variations of Fabry-Perot type filters exist, however the basic filter consists of two highly reflective mirrors separated by a dielectric spacer layer. It is the thickness of this dielectric layer which dictates the central wavelength and bandwidth of the resulting filter.

For many sensor applications, multiple wavelength filters provide increased spectral sampling and more flexibility. In order to fabricate a multiple wavelength filter one would simply increase the number of cavity/etalon layer iterations in the device design. However, the greater the numbers of wavelengths, the tighter are the requirements for the oxide thickness control. Thus, using timed etch for fabrication in a manufacturing environment would be difficult.

In this paper we describe a method of fabricating a Fabry-Perot filter array consisting of four distinct wavelengths which in turn is discriminately measured. Precise control of the oxide thickness is demonstrated using reflectance to measure center wavelengths, (CWL), and full width half maximum, (FWHM), values to confirm good narrow band filter characteristics. The filter array is fabricated directly on top of silicon photo diodes, forming a complete multi-wavelength sensor system. Fabricating a multi-wavelength filter array using etch-stop layers can provide better thickness control and across wafer uniformity compared to a timed-etch approach.

6378-46, Poster Session

Photodynamics of Ag and Au thin metal film surface-enhanced Raman spectroscopy substrates

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Surface enhanced Raman spectroscopy (SERS) has been widely demonstrated to be capable of single molecule detection. In addition to enhancement of Raman scattering, the substrates used for SERS also display other unique optical properties such as photoluminescence and blinking. In this work, the photoactivation of Ag thin metal films as it relates to the mechanism of SERS enhancement and the production of Ag cluster SERS active sites was explored. Specifically, the photodynamics of SERS-active thin Ag films were quantitatively studied using a combination of optical imaging and high and low resolution spectroscopy. A key hypothesis tested in this work addressed the role of oxygen in thin metal film photodynamics. Based on spectroscopic and kinetic differences observed from thin Ag films under both ambient and nitrogen atmospheres, a simple photochemical mechanism for blinking in optical phenomena was developed and tested. The proposed mechanism relies on the photoreduction of silver oxide to produce an active species, which was postulated to be silver clusters. Similar experiments were also performed on Au thin metal films under ambient and nitrogen atmospheres in order to evaluate the broader applicability of a metal cluster facilitated SER mechanism to additional SERS substrates.

6378-47, Poster Session

Novel pathlength saturation effects in modulation spectroscopic techniques

M. A. Khan, K. D. Mohan, A. N. Dharamsi, Old Dominion Univ.

Wavelength Modulation Spectroscopy (WMS) has been extensively used as a tool for sensitive detection through precise measurements of the absorption lineshape function of gaseous species. In this paper pathlength saturation in wavelength modulation spectroscopy is studied. New effects are found when one takes advantage of demodulation at higher harmonics of the modulation frequency. We show here that modulation spectroscopy is a much more sensitive probe of these effects. In particular, when synchronous detection is performed at higher harmonics of the modulation frequency, even very small pathlength saturation effects become clearly visible. The method discussed allows one to probe lineshape profiles by observing how the signal profile varies with absorption pathlength. In particular, the signal around line center displays effects of saturation that are characteristic of the lineshape. This method is powerful because, ultimately, all the information about any measurement is contained in the lineshape profile. Since different lineshape profiles exhibit different saturation behavior, higher harmonic detection provides a new method to perform sensitive detection. We have shown effects of saturation on the central lobes of harmonic signals. We also show that there are definite relationships between the variation of the individual side lobes as well as their relative magnitudes that yield further information about the lineshape function.

6378-48, Poster Session

Development of a variable pressure infrared spectrometer for field measurement of gaseous pollutants in indoor and outdoor environments

B. Hanoune, B. Lemoine, Univ. des Sciences et Technologies de Lille (France)

Pollutants detection by tunable diode laser spectroscopy is conventionally achieved by scanning the emission frequency of the laser around an isolated absorption line of the species under investigation. Absolute quantification relies on the comparison of the measured absorption signal with the absorption signal of a calibrated sample at the same pressure, or with a calculated line profile when the spectroscopic parameters are available and accurate. We developed an alternative procedure : with the laser emission frequency actively stabilized on top of the absorption line, both the pressure inside the cell and the absorption signal are measured while the cell is progressively filled with the sample up to about 12 Torr. The slope at origin of the signal vs. pressure curve is proportional to the concentration in the sample and absolute concentration is obtained with a calibrated mixture injected into the cell at regular intervals.

This procedure proved as efficient as the conventional one, is less demanding in terms of gas consumption, does not, by principle, require a precise pressure stabilization, and can be applied to species with unresolved infrared absorption spectrum, such as 1,3-butadiene.

A mobile instrument based on this protocol has been constructed and applied so far to the continuous quantification of formaldehyde in outdoor and indoor (buildings and cars) environments. A description of the instrument, analytical procedure and results will be given at the conference.

6378-50, Poster Session

Trace acetylene sensing by means of quartz-enhanced photoacoustic spectroscopy

A. A. Kosterev, T. S. Mosely, F. K. Tittel, Rice Univ.; J. D. Tate, L. D. Le, The Dow Chemical Co.

Quantification of trace acetylene by means of quartz-enhanced photoacoustic spectroscopy (QEPAS) was performed both in nitrogen and in gas mixtures containing other hydrocarbons. The QEPAS approach is based on the use of a high Q-factor quartz crystal as a sharply resonant acoustic transducer [1, 2]. A fiber-coupled telecommunication DFB diode laser was used as an excitation source, delivering 55 mW of optical power to the QEPAS absorption detection module. An absorption line at 6529.1721 cm-1 was used for acetylene monitoring. A noise-equivalent acetylene concentration of 70 ppbv was achieved in this configuration with a 1 s time constant at an optimum pressure of 75 Torr. A multivariate linear regression analysis of the spectral data allowed us to quantify trace acetylene in mixtures with ethylene and methylacetylene that create a strong absorption background.

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6378-51, Poster Session

Measurement of water quality using optical methods

I. O. Niskanen, H. Huttunen, P. Koponen, Univ. of Oulu (Finland)

Optical techniques have a long history of use for liquid analysis and monitoring various processes in industry. The advantages of optical techniques lie in their rapidity, simplicity, relatively low running costs and versatility. In addition, several quantities can be measured simultaneously. These techniques are based on the interaction of light (UV-Vis-NIR) with the sample. The characteristic transmission, absorption, fluorescence spectrum or vibration properties of chemical compounds are measured in order to determine its concentration or identity or dissolved solid in liquid.

UV-Visible Spectroscopy is a powerful technique that can measure many variables important in the analysis of wastewater. The spectrum of any wastewater sample is actually a composite of the spectra of its constituent parts including total organic carbon (TOC), biological oxygen demand (BOD), chemical oxygen demand (COD), Total Suspended Solids (TSS), nitrates, color and turbidity. NIR spectroscopy can be used when molecular bonding is of interest. Also, properties of water such as alkalinity and salt contents can be resolved from water spectrum using multivariate analysis. Methods to analyses solid matter content, total carbon, BOD and phosphorus are under investigation. NIR-spectra of water can be obtained using either transmittance of transflectance methods.

The fluorescence technique has also found its way into environment monitoring, where it is used to measure the most important and global water quality parameters like BOD, COD, Total Organic Carbon (TOC) and Dissolved Organic Matter (DOM). Fluorescence methods are widely used in biomedical studies to measure for instance enzymes and bacteria. These measurements are also adaptable to environmental water quality evaluation.

Calibration of spectrophotometer was based on the PLS-1model correlating the concentration of the required determinants to UV/Vis spectra. The COD and nitrate/nitrite analyzer was operating according to the standard methods. The calibration correlation was 0.98 for COD and 0.92 for nitrate/nitrite from natural water. With NIR-spectroscopy promising results were achieved for TOC, alkalinity, sodium, phosphate, ammonium, and solid contents. With waste water samples phosphorus also shows some promise.

6378-52, Poster Session

Detection of nerve gas agent by microplasma emission spectroscopy

W. Cao, Q. Jia, Y. Duan, Los Alamos National Lab.

A DC microplasma based, portable apparatus for detection of nerve gas agent is described in this paper. A micro discharge chamber with volume of 150 nL was constructed for molecular fragmentation and excitation at atmospheric pressure. The emission was couple to a palm-size spectrometer through an optical fiber. The intensity of an emission peak of phosphorus element at 253.6 nm was employed to determine the concentration of a simulant of nerve gas agent, Triethyl Phosphate. The effects of operational parameters such as voltage, plasma gas flow rate were investigated. The detectable level of Triethyl Phosphate is lower than 100 ppb. Meanwhile, Triethyl Phosphate vapor was tested by a microwave plasma source for purpose of comparison with our DC microplasma source. The results demonstrate that our low power DC microplasma source is more suitable for the detection of nerve gas agent. The detector we developed was very stable and did not experience electrode fouling. It is very promising for field and real-time detection of nerve gas agent.

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6379A-01, Session 1

Nonlinearity enhanced fiber ring laser

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Multiwavelength erbium-doped fiber lasers (MW-EDFLs) have attracted considerable interest for their potential applications in optical test and measurement, optical wavelength-division-multiplexing communication and sensing systems. Compared with the compact, inhomogeneously gain broadened semiconductor-based multiwavelength laser source, EDFLs are competitive for the all-fiber structure and high power capability. The requirements for the multiple wavelength sources include small, equal wavelength spacing, a large number of peaks within broadband, high output uniformity over the channels, which implies a very challenging task for building a cost-effective multiwavelength EDFL sources, both continuous-wave (CW) and pulse operations. Due to the homogeneously broadened gain property, many 2- or 4-wavelength EDFLs are developed with wavelength spacing larger than homogenous linewidth (~3.5 nm) to overcome gain competitions. Although a MW-EDFL with 16 wavelengths has been presented by cooling an EDF to 77 K using liquid nitrogen, the increased complexity and cost make it impractical to many applications. Many different approaches of the multiple wavelength EDFLs such as polarization or spatial hole burning, independent gain media, frequency shift, and phase modulator have also been reported.

In this paper, we propose and demonstrate a novel room temperature multiwavelength erbium-doped fiber laser (EDFL) scheme with the wavelength spacing less than homogeneous broadening linewidth based on the inter-channel four-wave mixing (FWM). The gain clamping effect in EDF are compensated by the parametric FWM between multiwavelength channels in a highly nonlinear fiber section that is inserted into the fiber ring cavity. In our demonstration, a stable CW MW-EDFL is firstly implemented based on a length of high nonlinear photonic crystal fiber (HNL-PCF) and sampled-fiber Bragg grating (SFBG). The multiple wavelength operation is initiated by adjusting the polarization controller and a specific SFBG with 0.8nm wavelength spacing. And then it is stabilized by an FWM induced dynamic gain flattening mechanism. The FWM processes suppress the homogenous line broadening of the EDFL and stabilize the multiple wavelength oscillation. By tuning the intra-cavity polarization controller and then the FWM efficiency, the number of the concurrent lasing wavelengths can be changed from two to five, and the peak power differences for the main oscillation wavelengths are less than 2.0dB.

We further extend the idea of FWM induced self-stable operation of MW-EDFL to the multiwavelength mode-locking fiber ring laser to generate ultra-short, ultra-fast, multiwavelength and synchronized pulse sources. By using 1 km conventional highly nonlinear fiber (HNLF), 2 and 4 wavelengths anchored on ITU-T standards with 100 GHz channel spacing are successfully mode-locked at 10-GHz simultaneously, without gain competition. The amplitude fluctuation and timing jitter are measured to be less than 1% and 100fs, respectively. The supermode suppression ratio is higher than 60 dB. The time-bandwidth products vary between 0.39 ~ 0.41 hence our laser generates nearly transform-limited pulses. Moreover, we implement a much more compact cavity structure with 60 m HNL-PCF to achieve the extremely small channel spacing of 0.5 nm operation of 10 GHz dual-wavelength mode locking with the help of fiber birefringence. This is the most dense 10 GHz mode locked fiber lasers reported to our best knowledge and the system is easy scalable for more wavelength operations. The channel spacing can be designed according to the repetition rate and the fiber birefringence evolution. Therefore, with proper combination of pump power, fiber nonlinearity and intracavity mode selector, our scheme is promising for the development of either CW or high-speed, dense channel spacing, multiwavelength fiber laser systems with superior performance.

6379A-02, Session 1

Photopolymer microtips for efficient light coupling between single-mode fibers and small-core photonic crystal fibers

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A novel method for light coupling between single mode fibers and small-core photonic crystal fibers is demonstrated. The method is based on growing photopolymer micro-tips directly on the end face of single mode fibers. The advantages of this micro-tip fabrication method are its simplicity, controllability, reproducibility and being inexpensive. The shape and the size of the tips can be controlled, by adjusting the laser power, the exposure time and the oxygen diffusion concentration for polymerization, to match its mode field to the small-core photonic crystal fibers. A photopolymer micro-tip integrated on the end face of a single mode fiber is used to reduce the mode field diameter and increase the numerical aperture of the light beam coming out from the single mode fiber, so that there is a better match to the small mode field diameter and the large numerical aperture of small-core photonic crystal fibers. A 5 dB improvement in coupling efficiency between a single mode fiber and a commercial small-core, highly nonlinear photonic crystal fiber is experimentally demonstrated. This compact and efficient butt-coupling method is particularly suitable for photonic crystal fiber gas sensor applications where holes in the photonic crystal fiber need to be kept open at the joint for easier access to the evanescent field, This method also may be suitable for the connecting a single mode fiber to a hollow-core photonic crystal fiber with the central hole filled with a liquid sample for liquid sensor applications.

6379A-04, Session 1

Four point photo-conductance (FPPC) monitoring array for speckle and fringe motion sensing

J. Bessette, A. Gogo, P. Heinz, E. M. Garmire, Dartmouth College

We report on the increase in frequency response of a semi-insulating GaAs Four Point Photo-Conductance (FPPC) monitoring array. This simple, rugged device has been demonstrated to work for remote, non-contact vibration sensing applications in the kilohertz regime at a distance over five meters. The FPPC sensor only requires a line-of-sight path to the object being probed, although later models are expected to work also with multimode fiber optics feed. Due to its construction, the sensor can also be enclosed in a high temperature environment without the adverse effects exhibited in other interferometric systems. This paper reports techniques for increasing the frequency response in these sensors. Experimental results will be given on sensors that have an approximate -3db rolloff of 10 kHz, with a useable signal up to 150 kHz. The performance improvements were achieved by replacing the opaque AuGe electrical contacts with transparent Indium Tin Oxide (ITO) contacts. These 80 nm thick films were deposited by RF sputtering at 3mTorr Argon back pressure. Further frequency response improvements were obtained by increasing the array conductivity with background illumination from red, white and infrared LEDs. These improvements are attributed to the reduction in lateral space charge distribution across the active areas. The FPPC devices exhibited rise times of 1.5 microseconds and an effective fall time of 100 microseconds. The pulse tails exhibit an underdamped oscillatory behavior, whose damping increased with increasing background illumination. A mathematical analysis of the asymmetric rise and fall times using the harmonic oscillator model is presented, from which we will make predictions for future devices.

6379A-05, Session 1

Bragg wavelength detection in fiber Bragg grating sensor by combining nonlinear least squares with Kalman smoothing

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In fiber Bragg grating (FBG) sensors, detecting the Bragg wavelength accurately could be difficult due to a low signal-to-noise ratio (SNR) in

the FBG spectrum. Two common sources of noise are the general Gaussian white noise from the broadband sources and the interferometric noise caused by the residual reflections in the sensor system. Conventional filtering techniques could be quite effective in removing the general Gaussian white noise, but not so for the interferometric noise, which is very structured. On the other hand, parameter estimation techniques such as nonlinear least squares can be used to identify the parameters in the interferometric noise and remove it accordingly. However, since the parameter estimation problem is nonlinear, the larger the number of parameters, the higher the chance that the algorithm will get trapped into a local minimum and fail to identify the correct parameters. In this paper, it is proposed to combine the nonlinear least squares method with a Kalman smoother. Hence, the number of parameters to be estimated by the nonlinear least squares algorithm will be greatly reduced. To do this, a continuous-time linear time-varying state-space model is derived for the FBG spectrum and then the model is discretized so that the Kalman smoother can be applied. A very interesting point to note is that, at the cost of a slight redundancy in the state, the model can be written as linear time-varying instead of nonlinear, thus avoiding the use of an extended Kalman filter. Computer simulations are also provided in the paper to demonstrate the effectiveness of the proposed method and its improvement in the accuracy of Bragg wavelength detection.

6379A-03, Poster Session

Trace-gas detection based on temperature-tuning periodically poled MgO: $LiNbO_3$ optical parametric oscillator

J. Kong, C. Chan, D. Tang, N. Ni, B. Zhao, Nanyang Technological Univ. (Singapore)

Optical parametric oscillator (OPO) working in the near and mid-infrared wavelength range are particularly promising for the detection of trace gases. In this paper, we demonstrated an efficient singly resonant optical parametric oscillator based on periodically poled MgO-doped LiNbO3. Through temperature tuning, the OPO can generate signal and idler output in the range of 1.41-1.78 õÌm and 2.7-4.3 õÌm respectively. The maximum signal power was measured to be 35.4 mW with a 120 mW absorbed pump power. Considering the instability of the OPO system in the output power and output wavelength, a synchronization measuring system was designed, in which the measuring errors caused by the instability of the OPO could be greatly reduced. Concretely, a computer was used to measure the signal wavelength, reference power, and absorbed signal power at the same moment. By changing the crystal temperature through the temperature controller, the OPO could produce wavelength-tunable signal output. At the same time point, the computer measured the signal wavelength, the power of the signal wave after passing the gas cell, and the power of the reference wave which was used to calculate the value of the signal power before passing through the gas cell. By using this type of configuration, the effect caused the fluctuation of the signal output power was eliminated. And the instability caused by the mode hoping of the OPO signal wavelength was greatly reduced. The usefulness of the OPO for trace gas detection was demonstrated by measuring the absorption spectra of methane and ethane.

6379A-19, Poster Session

Tunable photonic band gaps in a photonic crystal fiber

J. Sun, C. Chan, X. Y. Dong, P. Shum, Nanyang Technological Univ. (Singapore)

The transmission spectrum of a photonic band gap fiber filled with low index material is investigated. A simple analytical model is developed to predict the position and bandwidth of the band gap in the wavelength domain with respect to the refractive index. The wavelength of the band gap has a blue shift and the bandwidth of the band gap becomes narrow with the increasing of the refractive index of the filled material. The degree of shifting of the band gap increases with the reduction of air-filling fraction of the photonic band gap fiber.

6379A-20, Poster Session

Application of digital signal processing technique on mid-infrared gas detection by using optical parametric oscillator

N. Ni, C. Chan, J. Kong, D. Tang, Nanyang Technological Univ. (Singapore)

With the development of the global industrialization, gas sensing systems have become increasingly important for safety and environmental monitoring. Among numerous trace gas detection techniques, direct absorption spectroscopy operating in the mid infrared (MIR) region is paid particular attention not only due to its simplicity, high selectivity and sensitivity but also because the molecular absorptions of most interesting gases typically are the strongest in that region. Therefore, wide tunable and high power laser source radiated in the mid infrared region is highly demanded for gas detecting absorption in the MIR period. In this paper, a temperature-tuning optical parametric oscillator (OPO) based on periodically poled MgO: LiNbO3 is set up to detect methane, carbon monoxide and ethyne, these three kinds of gases absorptions. By changing the crystal temperature and grating periods, the OPO is able to emit the light in the ranges of 1.41-1.78* m and 2.7-4.3* m respectively. Although the specific properties of the OPO are fully employed, the line-width of the OPO source and the interferometric noises in the experimental system will contribute significant errors in the detection. In order to improve the measurement accuracy of gas detection system, the use of digital signal processing (DSP) technique is proposed to remove those defects in such a system. Compared to its real optical counterparts, the attraction of DSP technique comes from key advantages such as no drift in performance with the ambient environment and great flexibility without the need to modify the hardware. After digital processing, the accuracy of the sensing system improves up to 10dB, which verifies the feasibility of applications of DSP technique on the OPO sensing system.

6379A-21, Poster Session

Guided-wave optical pressure sensor with semi-closed space under the diaphragm: step response in relation to the area of a small hole of a semi-closed space

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An original guided-wave optical pressure sensor, which has a semi-closed space with a small hole under a diaphragm, could be used even under high static pressure with no sacrifice of sensitivity, unlike conventional pressure sensors. Also, the sensor demonstrates characteristics of a high-pass filter, so that it responds to high-frequency components of pressure change.

Regarding static pressure, since the small hole balances the pressures in the surroundings and in the semi-closed space, no pressure difference appears on the diaphragm even in high ambient pressure. In a step-like change in ambient pressure, pressure in the semi-closed space cannot quickly adjust due to the small hole that restricts fluid flow. So, a pressure difference is induced on the diaphragm for a short while (called 'the duration of the induced pressure difference'). The duration of the induced pressure difference is very significant because the reciprocal of the duration determines a cutoff frequency of the high-pass filter of the sensor property. According to our theoretical consideration, the duration is inversely proportional to a cross-sectional area of the small hole. This study reports our experimental examination of this relationship. The diaphragm dimensions of the fabricated sensors are 14mm X 14mm X 0.22mm, and the volume of the semi-closed space is 14mm X 14mm X 1.8mm. The diameter of the small hole varies, ranging from 0.1mm to 1mm. For a small hole of 0.1mm in diameter, the measured duration was approximately 80sec when ambient pressure was rapidly increased by 1.3kPa.

This sensor would be useful to detect malfunctions in static-high-pressure pipelines of industrial plants, and to detect tidal waves caused by hydraulic pressure changes on the bottom of the sea, etc.

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6379B-06, Session 2

Ormosil coating-based oxygen sensor for aircraft ullage

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Significant emphasis has been placed on fuel tank safety since the TWA flight 800 accident in July 1996. Upon investigation the National Transportation Safety Board (NTSB) determined that the probable cause of the accident was an explosion of the center wing tank (CWT), resulting from ignition of the flammable fuel/air mixture in the tank. The Federal Aviation Administration (FAA) has focused research to support two primary methods of fuel tank protection — ground-based and on-board — both involving fuel tank inerting. Ground-based fuel tank inerting involves some combination of fuel scrubbing and ullage washing with Nitrogen Enriched Air (NEA) while the airplane is on the ground (applicable to all or most operating transport airplanes). On-board fuel tank inerting involves ullage washing with OBIGGS (on-board inert gas generating system), a system that generates NEA during aircraft operations. An OBIGGS generally encompasses an air separation module (ASM) to generate NEA, a compressor, storage tanks, and a distribution system. Essential to the utilization of OBIGGS is an oxygen sensor that can operate inside the aircraft's ullage and assess the effectiveness of the inerting systems. OBIGGS can function economically by precisely knowing when to start and when to stop. Toward achieving these goals, InnoSense LLC is developing an all-optical fuel tank ullage sensor (FTUS) prototype for detecting oxygen in the ullage of an aircraft fuel tank in flight conditions. Data would be presented to show response time and wide dynamic range of the sensor in simulated flight conditions and fuel tank environment.

6379B-07, Session 2

Optical device of non-contact temperature measurement and hot box detecting

S. D. Milic, Institut Nikola Tesla (Serbia and Montenegro)

This paper presents an optical device for uninterrupted non-contact temperature measurements and detection of overheated bearing of train. The pair of propose optical devices is suitable to be mounted along the same axis as wheel axle on both railway sides. The optimum position of optical devices mounted is 0.5m above rail tracks level. The proposed method is based on remote infrared measurement of lid surface of axle bearing. The device consists of three parts: optical part, infrared detector and processing unit.

This paper presents characteristics of used lenses and optical filter. The output signal waveforms depending on train speeds. Propose optical devices are shown to have a vital role in: keeping railroad operations safe, preventive maintenance and avoiding of damaging of axle wheel bearing in railway.

6379B-08, Session 2

A novel optical fiber with applications in sensing and communications

R. Albandakji, A. Safaai-Jazi, R. H. Stolen, Virginia Polytechnic Institute and State Univ.

A novel optical fiber, referred to as Fresnel fiber, is introduced. These fibers have equal area rings and are fabricated using two materials only. Transmission properties of Fresnel fivers, including effective area, bending loss, and dispersion are investigated. Design of these fibers for large or small effective area and prescribed dispersion characteristics, required for sensing or communication applications, are addressed.

6379B-09, Session 2

Detection of carbon dioxide emissions from a land transport vehicle using a mid-infrared optical fiber sensor

J. F. Mulrooney, J. Clifford, C. Fitzpatrick, P. Chambers, E. Lewis, Univ. of Limerick (Ireland)

An optical fibre sensor has been developed from low-cost mid-infrared components which is capable of detecting carbon dioxide emissions from both diesel and petrol engines. The optical fibre sensor is not cross sensitive to other gaseous species in the exhaust such as water vapour (H2O), carbon monoxide (CO), oxides of nitrogen (NOx) or oxides of sulphur (SOx).

Pulsed (at 2Hz with 85% duty cycle) broadband infrared radiation (1-10μm approx.) from a nichrome filament emitter is launched into a 120mm long stainless steel gas cell using a 710/820μm core/clad chalcogenide fibre and calcium fluoride (CaF2) collimating lens. A second CaF2 lens refocuses the radiation into a one to four 500/550μm core/clad chalcogenide fibre bundle that guides the radiation to four pyroelectric detectors. Each detector is a fitted with a narrow band filter corresponding to the absorption line of a particular gas. For the detection of CO2 gas, the output voltages of two of these pyroelectric detectors are monitored. One pyroelectric detector is fitted with a narrow band pass filter centred at 4.23μm (the fundamental absorption line of CO2) while the second detector is fitted with a narrow band pass filter centred at 3.9μm (a reference wavelength).

This sensor is capable of quantifying the presence of CO2 from a cylinder down to 350ppm. Initial tests carried out using a diesel engine have shown that it is capable of determining the presence of CO2 in the engine exhaust.

6379B-10, Session 3

Fiber optic hydrogen sensor leak detection system for launch vehicle applications

A. A. Kazemi, The Boeing Co.; K. Goswami, InnoSense LLC; E. A. Mendoza, Redondo Optics; L. U. Kempen, R. A. Lieberman, Intelligent Optical Systems, Inc.

This paper describes the successful test of a multi-point fiber optic hydrogen sensor system during the static firing of an Evolved Expandable Launch Vehicle (EELV)/Delta IV common booster core (CBC) rocket engine at NASA's Stennis Flight Center. The system consisted of microsensors (optrodes) using a hydrogen gas sensitive indicator incorporated onto an optically transparent porous substrate. The modular optoelectronics and multiplexing network system was designed and assembled utilizing a multi-channel opto-electronic sensor readout unit that monitored the hydrogen and temperature response of the individual optrodes in real-time and communicated this information via a serial communication port to a remote laptop computer. The sensor packaging for hydrogen consisted of two optrodes — one doped with an indicator sensitive to hydrogen, and the other doped with an indicator sensitive to temperature. The multi-channel hydrogen sensor system is fully reversible. It has demonstrated a dynamic response to hydrogen gas in the range of 0% to 4% with 0.1% resolution and a response time of ≤15 seconds. The sensor package was attached to a custom fiber optic ribbon cable, which was then connected to a fiber optic trunk communications cable (standard telecommunications-grade fiber) that connected to the optoelectronics module. Each board in the expandable module included light sources, photo-detectors, and associated electronics required for detecting hydrogen and temperature. The presentation would discuss the sensor design and performance data under field deployment conditions.

6379B-11, Session 3

Differential strain sensitivity of higher order cladding modes in weakly tilted fiber Bragg gratings

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Fiber Bragg gratings (FBG) are widely used as sensors of pressure-strain, temperature, microbending and external refractive index. These optical sensors are inherently immune from electromagnetic interference, chemically inert, and they are compatible with structures made of composite materials. The Bragg wavelength shift of FBG in a standard SMF-28 is determined by strain and temperature. With a single wavelength shift measurement it is impossible to distinguish these two factors in one FBG. To simultaneously measure the strain and temperature, it is necessary to use two FBGs, hybrid FBG with long period gratings (LPG), superimposed FBGs and high birefringence fiber gratings, which increase the complexity of the sensors.

Weakly tilted fiber Bragg gratings (TFBG) with grating planes tilted at small angles (<5°) relative to the fiber axis couple light both to backward propagating core modes and cladding modes. The resonant wavelengths for these mode couplings depend differentially on external perturbations.

In this paper, we present the differential strain sensitivity characteristics of core and cladding modes in weakly TFBG. Both experiment and analysis results will be presented, and they are well matched. The results show that there are three different strain sensitivity regions for cladding mode resonances: the short wavelength region, the ghost mode region and the nearly linear sensitivity change region between them. By monitoring the cladding modes with different strain sensitivities, and noting that the different cladding modes have similar temperature sensitivities, weakly TFBG are attractive candidates for more accurate temperature-independent strain sensors.

6379B-12, Session 3

Versatile fiber Bragg grating arrays for strain mapping and ultrasound Lamb wave detection

G. J. Thursby, Univ. of Strathclyde (United Kingdom); D. C. Betz, DaimlerChrysler AG (Germany); B. Culshaw, Univ. of Strathclyde (United Kingdom); W. J. Staszewski, The Univ. of Sheffield (United Kingdom)

The possibility of combining load history with ultrasound signal information offers, potentially, an extremely powerful method for determining the structural health of a structure. Here we describe how suitably configured fibre Bragg grating arrays can be used to both monitor strain fields and to detect the magnitude and direction of ultrasound waves. The directional responses of fibre Bragg gratings to both static and ultrasonic strain fields have been investigated and the results used to enable the FBGs to be configured into rosettes. These can be interrogated to give both the magnitude and direction of either the principle static strain or an incident ultrasound Lamb wave. Measurement of the static strains enables us to perform strain mapping and hence determine load history, whilst ultrasound detection allows us to monitor a structure for defects such as cracks. If Lamb waves are generated by, for instance, PZTs bonded to the structure, comparing signals from the rosette with data previously obtained for the healthy structure allows possible defects to be identified and located. Location is carried out by calculating the intersection point of ultrasound direction from 2 or more rosettes. The geometry of the rosette configuration is described, together with the parameters affecting efficient strain transfer and the optimisation of FBG interrogation techniques.

6379B-13, Session 3

Absolute low-cost diffractive angular encoder for steer by wire in automotive

M. Ndao, B. Kress, P. P. Meyrueis, Univ. Louis Pasteur (France); L. Tupinier, O. Marroux, Delphi Mechatronic Systems, Inc. (France)

We are proposing a novel technique to implement absolute position sensors via diffractive optics technology.

Grating diffractive incremental encoders (both linear and rotation) are very common now, and include a read-out grating and a ruling grating.

We are implementing in our encoders a more complex diffractive optical functionality which generates directly and without any interpolation a Gray code for high resolution absolute position encoding, both for linear, rotational or even more complex 2D position encoding (like X/Y or polar motion).

Due to the fact that the resulting optical signal is directly a Gray code, there is no need for complex electronics to decode the signal.

Furthermore, due to the nature of these diffractive optical elements (surface relief elements), they are very cheaply replicated in mass by either polymers embossing or injection moulding .

6379B-14, Session 3

Photonic components and networks for automotive applications

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Fiber optic networks have been implemented for the infotainment system of many automobiles. We have developed fiber optic transceivers (FOT) for automotive optical networks. The transmitter contains a vertical-cavity laser (VCSEL) light source operating in the infrared wavelength regime at 850nm. The package is leadframe style and low cost for through-hole or SMT mounting. The output power of the transceiver is limited 0.7mW to meet eye-safety class I requirements. An internal control circuit stabilizes the optical output power over the entire operating temperature range from -40C to +105C to within 1dB. The precise adjustment of threshold and modulation current over temperature results in a high 10dB extinction ratio and very low jitter of <150ps. Due to an integrated lens we achieve a wide coupling tolerance of the VCSEL into the PCS fiber of +/-80um over a long working distance of 0.5mm. The large alignment tolerance ensures a stable coupling over temperature and time and enables the usage of very low cost plastic molded connector ferrules. The receiver module contains a high speed MSM photodetector. The special design of the MSM photodetector enables high speed operation up to 3.2Gb/s in combination with a large active area for easy alignment.

We demonstrate a high speed 1Gb/s video transmission over up to 15m of polymer cladded silica (PCS) optical fiber using high speed FOTs. The video link consists of a camera with an electrical S800 LVDS interface and a high resolution monitor. A pair of fiber optic cable connects the two ports replacing and extending the regular electrical cable. In contrast to the electrical cable the optical fiber is thin, light weight, and highly flexible. The high power budget margin of the link allows 3 in-line connectors for the 10-15m link length. For other applications a longer link length is feasible using higher bandwidth optical fiber.

The fiber optic transceiver modules have passed extensive reliability testing including 1200 cycles of temperature cycling from -40C to +125C, 1000 hours of THB (85C temperature, 85% humidity, under bias), and 3000 hours of high temperature (105C), high bias operation.

In conclusion, we have developed high performance, highly reliable fiber optic transceivers for infotainment networks, information displays, and high speed video and camera links in automotive and other transportation system related applications.

6379B-15, Session 4

Particulate detection in turbine exhaust using laser-induced breakdown spectroscopy

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This paper discusses research efforts in the development of a prototype exhaust monitoring system based on LIBS technology. This prototype system has proven successful in two trials with turbine engines. The inherent flexibility of the spectroscopic technique allows the system to be configured to detect a wide array of elements within the exhaust stream. An overview of LIBS technology will provided along with descriptions of the two trials and test results. The goal of this work is to demonstrate the ability of LIBS technology to monitor the exhaust stream for particulate material and provide an early warning indication of engine failure.

6379B-16, Session 4

Gas detection using an integrating sphere as a multipass absorption cell

E. P. Hawe, E. Lewis, C. Fitzpatrick, P. Chambers, Univ. of Limerick (Ireland)

This paper describes a multipass absorption cell used to detect and monitor the presence of several gases in the ultra violet, visible and near infrared regions. An integrating sphere with a highly reflective

internal coating (over 99%) was adapted in order to input and output various gases. Carbon dioxide was detected in the near infrared region at 1.6nm using a C and L band ASE source as the emitter and an NIR spectrometer as the detector. Each of these was connected to the integrating sphere using appropriate NIR optical fibre with a 1mm core. Ozone was detected in the visible range at 604nm using a deuterium/ halogen light source as the emitter and an UV/VIS spectrometer as the detector. These were linked to the sphere using UV/VIS fibre with a 400 nm core. Nitrogen Dioxide concentration was measured in the range 5 ppm to 150 ppm in the ultra violet range using a UV LED centred at 370nm and a suitable UV photodiode. Both the LED and the photodiode were mounted directly onto the sphere to minimise emitted losses and to ensure higher optical power would be incident to the photodiode. A two-inch diameter integrating sphere was used as the multipass absorption cell. The optical path length is wavelength dependant and this has been calculated for each of the three wavelength regions where testing occurred. Results to date have shown that Nitrogen Dioxide levels as low as 4 parts per million are detectable. It is also reported that the detection limit for Ozone in the visible range is approximately 1000 ppm while the limit for Carbon Dioxide in the near infrared is 5%.

6379B-17, Session 4

Onboard monitoring of exhaust emissions using a UV optical fiber based sensor

G. L. Dooly, E. Lewis, C. Fitzpatrick, Univ. of Limerick (Ireland)

In cities across the globe, the personal automobile has become the greatest polluter in our world today. At the end of 1995, there was an estimated 490 million vehicles in use, today that figure is thought to be almost 800 million.

The level of pollution caused by this expanse may have suffering effects for the environment and human health if left unregulated. Therefore the European Union as part of a world wide campaign introduced the EURO directives in which all new vehicles must comply with a set of emission regulations. As part of the EURO 3 directives vehicles must be equipped with an onboard diagnostic system for emission control, drivers must be notified when emissions exceed mandatory thresholds.

The use of optical fibres for the monitoring of hazardous exhaust gases based on the optical absorption of ultraviolet light has been investigated and tested. The unique ultraviolet absorption spectra for each of the hazardous gases emitted from an exhaust are utilised to determine the concentration of each of the gases present in the exhaust. A non absorbing wavelength for the gases was also examined to ensure absorption has occurred. Calculations based on the Beer-Lambert law are utilised to plot graphs showing the expected light absorbed for each concentration level. Results were obtained and compared to theoretical results.

To date absorption has been observed for Nitrogen Dioxide, Sulphur Dioxide and Nitric Oxide. The sensor has shown to have a wide range of detection and have low sensitivity in the order of less than 5ppm for both NO2 and SO2 and 20ppms for NO. Further tests were carried out in-line with a Kubota diesel engine and absorption was observed in expected concentrations. Future work will see the sensors working with a wider range of gases including Benzene, Toluene and Xylene.

6379B-18, Session 4

Stabilization of the output signal of thermopile sensors in the thermal environment of automotive applications

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Thermal radiation sensors are of increasing importance in automotive applications. Future applications will include blind spot monitoring, pedestrian safety, break and tire temperature monitoring and passenger position control for intelligent airbag deployment. However, currently air conditioning control by thermopile sensors in the passenger cabin is the fastest growing market for automotive contact less temperature monitoring (Appendix). Mayor problem are the large and fast ambient temperature changes that are prominent at the possible mounting positions of such sensors. While ambient temperatures between -20 and 80°C are common within the cabin, depending on outside weather conditions and usage of the car, strong thermal gradients (spatial and temporal) are to be expected as soon as the car is in use and a comfort temperature is being generated. Further temperature gradients result from dashboard illumination and air flows.

Generally, the accuracy of thermopile sensors is compromised by thermal gradients in space and time “thermal shock”. However, for comfort purpose, high accuracies in the order of 1°C and better are desirable. Therefore, thermal shock management of thermopile sensors is of paramount importance in automotive applications.

We developed three independent methods to cope with such conditions that separately improve the stability and in conjunction lead to a significant improvement of the signal accuracy and stability under thermal shock conditions. These methods are:

- A sensor element design robust against thermal flows

- A isothermal housing that significantly reduces thermal gradients (in space and time) at the sensor element

- An intelligent signal processing scheme that allows predicting the effect of thermal gradients on the signal and linearly compensated for it.

Sensor Element:

The sensor element is a MEMS thermopile that measures the temperature difference between its centre (“hot contacts”) that is located on a thin membrane and its periphery (“cold contacts”) that is located above thermally conducting bulk silicon. Heat radiation will therefore increase the temperature of the thermally isolated centre while leaving the periphery of the sensor at the same temperature. The temperature difference between centre and periphery will be detected by the thermopile and in is thus the measured thermal radiation signal. Thermal flows into such a sensor will however disturb that balance and lead to erroneous signals. A special sensor design allows obtaining the same thermal conductivity between the hot contacts and the ambient as between the cold contacts and the ambient while maintaining a higher sensitivity for the hot contacts towards heat radiation. This results is a thermal shock stable sensor design.

Isothermal Housing:

Next to the radiation received from the target of the sensor, the housing itself can exchange heat radiation with the sensor element. If due to thermal gradients the housing is on a different temperature than the sensor, heat radiation between both parts is exchanged and an erroneous signal results. An isothermal housing must therefore have a high heat capacity combined with small dimensions in order to only slowly change its own temperature and be well heat conducting to communicate heat changes to the sensor element. This way the housing is always in quasi-equilibrium with the sensor element. It must also be of low emissivity for thermal radiation. We present such an isothermal housing, manufactured by machining of solid aluminium rods and hermetically welded to the stainless steel base plates with the sensor element.

Intelligent signal processing:

By determining the state of thermal equilibrium, one can predict the error which is induced by the thermal shock. Continuous monitoring of the ambient temperature in conjunction with an application specific calibration of thermal flows allows for an accurate measure of the effect of thermal shock on the sensor. The factory calibration has to be performed for each application only once, accounting for heat sources, and thermal contact of the sensor in its specific mounting. Parameters obtained are stored in the integrated ASIC of the sensor and are used for digital compensation of thermal shock.

The three methods discussed can be combined for mutual synergetic improvement of each others signal stabilizing properties. While in medical applications isothermal caps combined with a thermal shock resistant sensor design and software measures are used in conjunction, automotive sensors now in development at PerkinElmer combine an isothermal housing and intelligent signal processing. The latter allows for maximum stability without compromising sensitivity.

Appendix: Air conditioning control: This field can be devised into three applications [1,2]:

Heat load measurement:

One major function is the use of thermopile sensors in air conditioning applications where the measurement of the heat load in the room is used as a feed-forward input to the climate control system. When the weather conditions (e.g. cloudy) are changing, the different amount of sunlight absorbed changes the heat load of the room. However, regular feed back systems cannot react until the air temperature has already

increased. Therefore, modern air conditioners measure the temperature changes of absorbing surfaces directly with IR detectors, and use that information for feed-forward control in a combination with feed back regulation. Besides this, since glass is not transparent in the IR spectral range, but a good emitter in this range, the heat load (or sink, respectively) of the windows can be detected as part of the surface area that is subject of the averaging heat load measurement. [3] Another area of interest is that the driver's (passenger's) clothing directly exposed to intense sunlight, generates heat where it directly affects the persons' comfort.

Occupant surface temperature measurement:

Body temperature or "comfort level sensing" is based on the fact that the human body uses its surfaces to dissipate excessive heat or to reduce the heat loss, depending if the person is feeling warm or cold. [4]. Inside a car cabin, the position and direction of the driver's (passenger's) face are well defined. Such fix conditions ensures that the thermopile output is only influenced by the energy radiated by the cabin occupants and results in a reliable signal to feedback to the climate control system.

Windshield fogging control:

At low outside temperatures, condensation of moisture on the windshield can be more than just a nuisance but a significant safety issue. Immediately after the engine is started, the amount of available warm air to be either directed to the windshield (to avoid fogging) or the cabin (for comfort) is very low. An efficient use of the warm air implies the knowledge of the exact amount of air necessary for windshield defogging, so the rest can be used for comfort purposes. This implies the use of a moisture sensor for dew point monitoring and a thermopile sensor for monitoring the windshield temperature.

[1] M. Liess, A. Charlebois, J. Schilz, H. Ernst, H. Karagözoglu, G. Lauck, M. Hausner, Integration and miniaturization of thermopile basesed pyrometric module constuction sets, SPIE International Symposium Photonics West, San Jose, USA January 22 - 27, 2005

[2] M. Liess, M. Hausner, H. Karagoezoglu, H. Ernst, Temperature Radiation Sensors for Automotive Climate Control, IEEE Sensors 2004, The 3rd IEEE conference on Sensors, Vienna, October 24-27, 2004

6379B-23, Session 4

Rotation sensing with a low-cost simple FOG

A. Morshed, Ain Shams Univ. (Egypt)

The Fiber Optic Gyroscope (FOG) is a single axis rotation sensor, which is currently employed in many advanced navigation systems. A major contribution to the cost of an FOG is the price of components such as the polarizer, phase modulator and associated detection electronics. As a lower cost realization of the device is of great importance for its wide deployment in many applications, the possibility of rotation rate measurement with moderate accuracy without the use of such components, in a simplified FOG configuration, is a very interesting issue.

A low-cost simplified implementation of the open loop FOG was carried out to investigate its performance in the absence of a polarizer and a phase modulator and observe the extent to which it can usefully detect the rotation rate in the presence of polarization and phase fading. This paper reports on the realization of the simplified FOG configuration and discusses the association of polarization and phase effects to the measurement errors incurred. Our results indicate that the error due to the absence of the polarizer and phase modulator can be of the range of only few hundredth of the actual rotation rate. This is explained by noting that the phase changes in the path affect both perpendicular polarizations approximately similarly leading to Fx being almost equal to Fy and hence the polarizer importance appears when using a phase modulator which affects each polarization differently.

Possible practical uses of such a simplified gyroscope configuration are suggested for low accuracy automobile guidance applications. The signal processing electronics available in a modern vehicle can also be used to process the FOG data in combination with data obtained form other location determination facilities such as a GPS receiver to aid in vehicle navigation and control.

Tuesday-Wednesday 3-4 October 2006

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6380-01, Session 1

Monitoring intracellular signaling networks: DARPA's goals

D. K. Shenoy, DARPA

Intracellular signaling networks dictate cellular responses to virtually all stimuli. Optical technologies that permit real time quantitative monitoring of the signaling events in living cells would greatly enhance our understanding of cellular activities and may allow prediction of cellular activities. Current methods of tracking the time-sequential activation of signaling components in a pathway generally involve disruptive methods that capture the cell at a moment in time. Non-disruptive methods as with genetically encoded probes are limited in number and application. To develop a platform capable of extracting quantitative, real time information from living cells about all types of signaling events will require integrating advanced probe technologies with the latest methods of probe delivery and targeting. Sophisticated optical imaging and data processing techniques will permit multiplexed read out from multiple probes than can be non-disruptively introduced into a cell.

6380-02, Session 1

Advances in zinc ion sensing for studying zinc release events from pancreatic cells

Z. Rosenzweig, G. Crivat, Univ. of New Orleans

The presentation will describe the development of highly selective and sensitive zinc ion sensors for the analysis of zinc ion release from pancreatic cells. The sensors are based on the new zinc ion fluorescent indicator, ZnAF-2. The fluorescence intensity of ZnAF-2 increases sharply when binds to zinc ions. The presentation will describe the synthesis of the dye, its modification with a tether functional group to enable its conjugation to solid state supports to form a functioning sensor and the use of the sensors for real time monitoring of zinc release from chemically stimulated pancreatic cells.

6380-03, Session 1

Nanoparticle arrays for efficient detection of whole cells

T. A. Alexander, Army Research Lab.

Surface-Enhanced-Raman-Scattering (SERS) is potentially a very sensitive spectroscopic technique for the detection of biological agents (i.e., proteins, viruses or bacteria). However, since initial reports, its utility has not been realized. Its limited acceptance as a routine analysis technique for biological agents is largely due to the lack of reproducible SERS-active substrates. Most established SERS substrate fabrication schemes are based on self-assembly of the metallic (typically, Au, Ag, Pt, Pd or Cu) particles responsible for enhancement. Further, these protocols do not lend themselves to the stringent control over the enhancing feature shape, size, and placement on a nanometer scale. SERS can be made a more robust and attractive spectroscopic technique for biological agents by developing quantifiable, highly sensitive, and highly selective SERS-active substrates. Electron Beam Lithography (EBL), a semiconductor fabrication technique, can be utilized to address many of the obstacles which have limited the broad acceptance of SERS. Specifically, EBL can be employed to precisely control the shape, size and position (on a nanometer scale) of the SERS substrate enhancing features.

Novel Au SERS-active substrates fabricated using the EBL technique has been used for the spectral analysis of intact bacterial cells. This talk will focus on the substrate fabrication, characterization and application towards whole cells.

6380-04, Session 1

SERS probes for imaging individual biochemical species on the nanoscale

M. E. Hankus, B. M. Cullum, Univ. of Maryland/Baltimore County

We have developed novel surface enhanced Raman scattering (SERS)-based nanoimaging probes for dynamic chemical imaging in a non-scanning format. These probes have been developed for obtaining sub-diffraction limited chemical images of various biochemical species (e.g., lipids, proteins, etc.) as well as biological organisms (e.g., bacteria, etc.). They combine qualitative and quantitative information obtained from SERS with the imaging capabilities of coherent fiber optic bundles. Nanoimaging probes are fabricated from coherent fiber optic bundles composed of 30,000 individual 4 um diameter fiber elements. Using a CO2 laser based micropipette puller, bundles are tapered on one end resulting in the formation of equi-diameter individual elements tens of nanometers to hundreds of nanometers in dimension. Employing these probes, inherent image magnification and submicron spatial resolution is possible. Across these tapered probe tip, uniformly roughened surface features are creating by HF acid etching. These surface features consist of six cladding peaks that surround each individual fiber elements core and they are uniform in size, shape, structure, and spacing. SERS active surfaces are created on the tapered tips of the probes by selectively depositing silver onto these cladding peaks, creating an array of highly ordered uniform silver islands across these nanoimaging probes' surfaces. This fabrication process results in a high degree of uniformity in SERS enhancement across the image surface of the probes (< 3.0% RSD), which is key for reproducible quantitative imaging applications. Further SERS enhancement and specific excitation wavelength tuning can be achieved by controlling the spacing between silver islands and the overall size of the silver islands uniformly arrayed across these SERS probe tips. Characterization of these tunable SERS nanoimaging probes for chemical differentiation and imaging with nanometer scale spatial resolution in a non-scanning format of individual biochemical species will be discussed.

6380-05, Session 1

Intrinsic Fabry-Perot interferometer with a micrometric tip for biomedical applications

X. Wang, J. Xu, Z. Wang, K. L. Cooper, A. Wang, Virginia Polytechnic Institute and State Univ.

Abstract-This paper presents a novel intrinsic fiber optic Fabry-Perot (FP) structure with a micrometric diameter tip. With the FP cavity inside the fiber, the change in optical path length distance (OPD) caused by the environment can be demodulated. With such a tiny protrusion, the sensor can be inserted into micron size cells for intracellular measurements. This label-free detection method is very useful in biological areas such as DNA hybridization detection. It provides a valuable tool for intracellular studies that have applications ranging from medicine to national security. In addition, the fabrication is simple including only cleaving, splicing, and etching. The signal is stable with high visibility. Last but not the least, the structure shows great promise for reduction to nanometric size. Once this goal is achieved, the sensor can be inserted into most cells with minimal invasiveness.

6380-06, Session 2

Polarization imaging sensor for cell and tissue imaging and diagnostics

H. Zhao, Q. Chen, Y. K. Zou, Boston Applied Technologies Inc.; J. Xuan, The Catholic Univ. of America

In recent years there has been an increasing interest in the propagation of polarized light in randomly scattering media. The investigation of backscattered light is of particular interest since most medical applications aimed at the in-vivo characterization of biological tissue rely on backscattered light. By recording the spatially dependent response of a medium to a polarized light, the information about the scattering particles can be obtained, which are not accessible to mere intensity measurements. In this paper, an innovative NIR polarization maging solution based on high performance fast tunable phase retarder and novel algorithm is proposed. It has the ability to record both scattering images and Stokes polarization imaging. It allows very fast recording Stokes images at the speed limit of a CCD. It contains no moving parts and can accommodate to most of the existing CCD cameras. The unique measurement procedure allows efficient, accurate sensing of the polarization imaging. Diagnostics computer-aided

diagnosis software has been developed for the proposed polarization imaging system.

6380-07, Session 2

In silico cell electrophsiology for measuring transcellular calcium currents

D. M. Porterfield, A. ul Haque, M. Rokkam, A. R. De Carlo, S. Wereley, Purdue Univ.; H. W. Wells, Bionetics Corp.; W. T. McLamb, Dynamac Corp.; S. J. Roux, The Univ. of Texas at Austin; P. P. Irazoqui, Purdue Univ.

Challenges associated with automating cell handling, micro-positioning and signal/data acquisition integrity limit the throughput for doing basic cell electrophysiology research for biomedicine and pharmacology. To overcome these limitations we have designed and built an in-silico cell physiology biochip for measuring transcellular Ca2+ ion currents and extracellular concentrations from single cells. This device has been designed around specific science objectives of measuring real-time multidimensional calcium flux patterns around sixteen individually cultured cells in the lab-on-a-chip device. The sixteen microfluidic cell culture pores are 150 by 150 μm, and each have 4 Ag/AgCl electrodes leading into them. An SU-8 structural layer is used for insulation and packaging purposes. The in-silico cell physiology lab is wire bonded onto a custom PCB for easy interface with a state-of-the-art data acquisition (DAQ) system. The final packaging of the chip also includes basic fluidic controls and delivery systems. The DAQ uses a 512-crosspoint matrix in a dual 8 x 32 1-wire configuration to read the sensors sixteen at a time in differential mode where we measure the concentration differential between eight pairs of electrodes at once. This approach is referred to as the dual electrode differential coupling (DEDC) technique, and is unique in that each working electrode is referenced not to a ground but to another working electrode. This ultimately allows us to directly monitor trans-cellular flux by pairing electrodes at opposite poles of the cell.

The working electrodes in the fluidic pores are coated with a Ca2+ ion selective membrane based on ETH-5234 ionophore and during calibration phase are operated against an Ag/AgCl reference electrode. We have been through several iterations of prototyping for the lab-on-a-chip device and the supporting electronics and now have a reliable system. We currently get calibration yields of 58-64 electrodes on each chip, all with functional Nernst slopes of between 24-30mv/decade. We have found that electrode calibrations are stable over periods of days and have even continuously operated a single chip for over a month. While this technology was developed as a tool to enable basic research to study cell responses to microgravity, we anticipate that this basic platform for cell electrophysiology in a lab-on-a-chip system will be broadly applied in biomedical and pharmacological research by making minor modifications to the electrode material and the measurement technique. Future applications include detection of glucose, potassium, oxygen, pH, and nitric oxide as well as multiple analyte detection on the same chip. Towards this goal we have already begun fabricating new chips with Pt and Au electrodes and amperometric subsystems. We are also working towards integrating fiber optic based sensors and lifetime phase fluorometry into this format.

6380-08, Session 2

A fiber optic surface plasmon resonance (SPR) sensor applied to quantifying survival of motor neuron (SMN) protein in cell lysate

K. S. Booksh, M. Barnhart, M. R. Malone, B. Bert, R. Nieman, Arizona State Univ.

Spinal Muscular Atrophy (SMA) is a debilitating disease affecting nearly 1:6000 live births, and is the second most common genetic cause of infantile death. SMA is characterized by progressive degeneration of alpha-motor neurons, leading to paralysis and death. A high priority has been placed on development of tools for rapid measurement of survival of motor neuron protein (SMN) protein levels in patients with SMA, particularly for determining the efficacy of potential therapeutics for the treatment of the disease. We have developed a fiber-optic surface plasmon resonance (SPR) method that has the sensitivity to measure clinically meaningful levels of recombinant forms of SMN protein. We have also found that fiber-optic SPR can easily measure SMN protein levels in cultured cells. In addition, fiber-optic SPR can be deployed in a robust, real-time fashion, with minimal treatment of samples prior to analysis. These results suggest that fiber-optic SPR probes can be used to rapidly and flexibly measure SMN protein levels for evaluation of possible treatments for SMA. Our studies demonstrate that fiber-optic SPR can provide stable, reproducibile measurements of SMN protein levels in cultured HeLa cells.

6380-09, Session 2

Raman molecular imaging of tissue and cell samples using tunable multiconjugate filter

J. S. Maier, S. D. Stewart, J. Panza, A. Drauch, ChemImage Corp.

Raman spectroscopy is a powerful technique for rapid, non-invasive and reagentless analysis of materials, including biological cells and tissues. Raman Molecular Imaging (RMI) brings together high molecular information content Raman spectroscopy and digital full field imaging to enable the opportunity to investigate cells and tissues with optical spatial resolution and 8 wavenumber spectral resolution. This tool will be applied to the investigation of the correlation between disease states in tissue and cellular samples as Raman based approaches move toward validation in clinical settings. We will report Raman imaging data on fixed cells at different states in physiological transition including malignant transformation and apoptosis. These results demonstrate the sensitivity of Raman Molecular Imaging to physiological changes in biological systems which lays the foundation for the eventual use of this approach as a biological research and clinical diagnostic tool.

6380-10, Session 2

In vitro study of the spectrally selective UV-irradiation bacterial inhibition

A. E. Dudelzak, Darel Enterprises, Inc. (Canada); A. S. Koujelev, All-Optical Solutions (Canada); M. A. Miller, Jewish General Hospital (Canada)

Presented are the results of an in-vitro search for optimal parameters (wavelength, dose, intensity) of the spectrally selective UV bactericidal effect on several strains of common pathogenic flora. The UV bacterial inhibition efficiencies vs. irradiation wavelengths were measured at a fixed irradiation dose for seven bacterial strains to determine efficient bactericidal wavelengths. Then the bacterial sensitivity to UV irradiation was studied at optimal wavelengths as a function of exposure time, intensity and dose. Manifestations of bacterial “adaptation” or bactericidal “intensity threshold” were observed. Practical recommendations for therapeutic applications of the effect and instrumentation design have been made.

6380-11, Session 3

Evaluation of aptamers as molecular recognition elements for pathogens using capillary electrophoretic analysis

S. McMasters, D. N. Stratis-Cullum, Army Research Lab.

Molecular recognition ability of aptamers against Campylobacter jejuni was investigated to demonstrate the feasibility for developing a biosensor to permit rapid detection and identification. Three aptamers have been selected in-vitro via a systematic evolution of ligands using the exponential enrichment process. Biomolecular interactions between fluorescent-tagged aptamers and Campylobacter jejuni have been characterized using capillary electrophoresis with laser-induced fluorescence detection. From electrophoretic analysis, bound and unbound aptamers were resolved and identified. Binding affinities of the aptamers are being assessed based on the relative dissociation constants and binding stoichiometry. Such binding interactions were also compared with fluorescent-tagged polyclonal and monoclonal antibodies to ensure bacterial surface recognition. In addition, cross reactivity with other food-pathogens including Escherichia coli O157:H7 and Salmonella typhimurium were examined. Preliminary data suggest that one of the selected aptamers exhibits strong binding affinity towards Campylobacter jejuni with minimum cross reactivity toward other food pathogens. Such selectivity and recognition ability of the aptamer against Campylobacter jejuni shows the potential for integrating and selecting aptamers against other pathogens for use in variety of other applications.

6380-12, Session 3

Diazirine photochemistry as a means of functionalizing microcantilever biosensors

J. V. LaTour, F. A. Bourguet, T. V. Ratto, B. R. Hart, Lawrence Livermore National Lab.

A major hurdle in the development of a robust, workable microcantilever platform for biosensing is the surface chemistry involved in biofunctionalization, largely because the insulator of choice, silicon nitride, is so unreactive. We present diazirine photochemistry as a potential solution to this problem. Upon UV treatment, a diazirine releases nitrogen to form a carbene intermediate, which readily forms covalent bonds with silicon nitride. We show that diazirine photochemistry can be used to attach both biotin and DNA to silicon nitride wafers and that the resulting functionalized surfaces do indeed have the appropriate biological activities.

This work represents research efforts underway in the Forensic Science Center at LLNL and was performed under the auspices of the U.S. Department of Energy by University of California, Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

6380-13, Session 3

Novel gold SERS substrates with multilayer enhancements

H. Li, C. E. Baum, B. M. Cullum, Univ. of Maryland/Baltimore County

A novel class of multilayered gold film over nanosphere surface-enhanced Raman scattering (SERS) substrate providing significantly greater SERS enhancements, longer active lifetime, and better reproducibility than traditional silver SERS substrates has been developed. These multilayered metal film-based (SERS) substrates are capable of enhancing SERS signals over an order of magnitude relative to comparable conventional metal film over nanostructure substrates. These novel multilayer enhanced metal film over nanostructure substrates are fabricated by repeated vapor deposition of metal films over the nanostructures with dielectric layers deposited between metal layers. Different dielectric layers with various thicknesses have been studied to investigate their effect on the multilayer enhancements. Meanwhile, different sizes and concentrations of these nanostructures were evaluated in order to obtain the optimal SERS enhancements. In addition to the development and optimization of these substrates, this paper will also discuss the application of these novel gold multilayer substrates for trace chemical agents and chemical stimulant detection.

6380-15, Session 3

The investigation of liquid analysis method based on fiber microdrop sensor

W. Sun, X. Li, C. Zhang, X. Wang, Harbin Engineering Univ. (China)

A real-time practical fiber micro-drop sensor, with which can determine the physical and chemical parameters of the liquid, for example, the refractive index, the concentration, and absorption, has be designed and realized. The method combines simplicity of structure, facility of operation, wide range of measurement and low price.

Liquid drops are formed at the tip of a liquid sensing head passing thin tubing. The infrared light is injected into the drop through an optical fiber and is received by another fiber after reflection, scattering and absorption with the liquid drop. The curve of the light intensity vs. time is called as Fiber Drop Fingerprint (FDT), which depends on the character of the liquid to be tested.

The trend and distinguishing feature of the FDT is strongly relative to the shape-variation of the liquid drop. Sometime the FDT changes dramatically even the drop shape varies a little. Sometime the FDT drifts flatly under clearly growing of the drop. A series of experiments were done to find out the relationship of them. The theoretical fitting results were similar to the experimental FDT.

To distinguish two similar FDT, the correlation methods were induced to the signal analysis process. Some different liquid samples were chosen to taste this analysis method and gave the delighted results.

6380-16, Session 4

Liquid core optical ring resonator label-free biosensor array for lab-on-a-chip development

I. M. White, H. Zhu, J. D. Suter, H. Oveys, X. Fan, Univ. of Missouri/Columbia

Label-free optical biosensors offer advantages for many applications due to their simplicity and low cost compared to fluorescence detection. Thus, it is desirable to develop label-free sensors that can be integrated with advanced microfluidic systems into dense, multi-purpose biosensor arrays. One candidate technology is ring resonators, which utilize the resonating whispering gallery modes to create a strongly enhanced optical field in the sensing volume. Because of the high Q-factor of ring resonators, the optical field can be enhanced by 2-3 orders of magnitude. This leads to a much lower optical path length and sensing volume while still delivering a long effective interaction length. These are critical characteristics for dense integration into lab-on-a-chip systems.

We have developed a novel label-free ring resonator sensor based on a liquid core optical ring resonator (LCORR). This system uses a quartz capillary as both the fluidics and the ring resonator. With the LCORR, we have demonstrated a measurable whispering gallery mode spectral shift of 7 pm/refractive-index-unit (RIU), which leads to a detection limit of approximately 10-6 RIU. Additionally, we have achieved the detection of biomolecules adsorbing to the inner surface of the LCORR as the sample passes through. Furthermore, a 2-D multiplexed sensing array has been conceptually demonstrated by using multiple LCORRs and by patterning the inner surface through UV illumination of photoactive molecules. These experimental demonstrations of this novel sensing system will lead to the development of highly sensitive label-free sensors that are well-suited for dense integration with advanced microfluidics for lab-on-a-chip systems.

6380-17, Session 4

On-chip microfluidic PCR using monodisperse microdroplets

N. R. Beer, B. J. Hindson, J. C. Carter, K. A. Rose, Lawrence Livermore National Lab.; I. M. Kennedy, Univ. of California/Davis; J. P. Fitch, Battelle Memorial Institute; B. W. Colston, Jr., Lawrence Livermore National Lab.

Reducing the time required for pathogen characterization and detection is critically important due to the severe public health and economic effects of emerging infectious diseases, whether they be previously unknown (SARS, H5N1, etc.), endemic to the environment (Anthrax, smallpox, etc), or engineered for terrorist purposes. Microdroplet PCR has the potential to greatly reduce both the detection time and the amount of expensive reagents required, enabling a significant improvement in the efficacy of the public health response. Given the importance of quickly detecting and characterizing pathogens, a monodisperse droplet generator has been developed to create sub-nanoliter droplets in an oil sheath flow, and used to perform in-line PCR within the droplets.

This work was performed under the auspices of the U.S. Department of Energy by the University of California Lawrence Livermore National Laboratory under contract W-7405-Eng-48.

6380-18, Session 4

Compact optofluidic platform for detection of biomolecules

O. Schmidt, M. Bassler, P. Kiesel, N. M. Johnson, Palo Alto Research Ctr. Inc.

A concept is presented and demonstrated for analyzing fluorescence from bio-molecules by using a compact fluidic platform that integrates a fluidic channel with a chip-size spectrometer. Particles are continuously excited within a novel waveguide. Fluorescence spectra are recorded as the particles traverse the detection area. Unlike most other approaches for detecting and identifying an analyte, ours does not require immobilizing suspect particles for interrogation. Rather, it takes advantage of the general necessity to detect such particles in real time as they are moving.

A continuous excitation of the analytes is required while they are moving across the detection area. Conventionally, evanescent field

excitation is used to provide fluorescence excitation over an extended area. In order to improve the interaction between light and analyte we are using an anti-resonant waveguide, in which the light is guided within the target-containing medium, thereby enabling an extended interaction length. In this concept a low-refractive-index fluid is sandwiched between two transparent glass slides with higher refractive index. Dependent upon the coupling angle, light is either guided purely in the glass slides or is coupled into anti-resonant waveguide modes. These anti-resonant waveguide modes are inherently lossless and can have very high confinement factors within the liquid.

The compact spectrometer itself consists of a detector array integrated with a linear variable band-pass filter. The filter converts the spectral fluorescence information into a spatially dependent signal which is analyzed by the detector array. The photosensitive area of this spectrometer can be as large as the size of the detector array. This area is large compared to that for conventional spectrometers where the light has to be focused onto a small slit in order to achieve the requisite wavelength separation. Therefore, the chip-size spectrometer is especially well suited for large light emitting areas or moving particles.

6380-19, Session 4

Development of a MEMS 2D separations device

K. P. Bloschock, Georgetown Univ.; T. W. Schneider, ITT Industries; A. Hussam, George Mason Univ.; E. R. Van Keuren, Georgetown Univ.

A polymer based biochip for rapid 2-D separations of peptides, proteins, and other biomedically relevant molecules was designed and fabricated. Like traditional 2D polyacrylamide gel electrophoresis (2D-PAGE) methods, the device will allow molecules to separate based on isoelectric point (pI) and molecular weight (MW). The design, however, integrates both an initial capillary isoelectric focusing (cIEF) step followed by capillary electrophoresis (CE) in multiple parallel channels, all on a single microfluidic chip. Not only is the “lab-on-a-chip” design easier to use and less expensive, but the miniaturization of the device produces very rapid separations, on the order of several seconds. Compared to traditional 2D-PAGE, which can take hours to complete, we estimate separation times on the order of seconds. Fluorescence detection will be used in the preliminary stages of testing, but the device also is equipped with integrated electrodes in the electrophoresis channels to perform multiplexed electrochemical detection for quantitative analysis. Preliminary testing was done to demonstrate cIEF and CE with one analyte. Further experiments were done to demonstrate the separation of two analytes, as well as preliminary testing to implement a polyacrylamide gel in the electrophoresis channels. We will present the results of these experiments.

6380-20, Session 4

Surface mass sensitivity of a differential phase contrast BioCD at 0.2 pg/mm

D. D. Nolte, Purdue Univ.

The BioCD is a class of self-referencing interferometric optical biosensor that measures phase modulation from proteins on spinning disks. The optical detection of the patterns at high speed yields low noise floors far from 1/f noise. Periodic protein patterns on the disk provide a spatial carrier frequency that is demodulated to yield a slowly-varying protein envelope that can be differenced with high accuracy. Two consecutive differential scans of a disk are differenced without any disk dismount, yielding an rms surface height measurement error of only 20 pm corresponding to 5 femtograms of protein within a focal spot diameter of 20 microns. Simple area scaling realations are derived that predict the performance of immunoassays as a function of well size, and we demonstrate a surface mass sensitivity for a differential phase contrast BioCD down to 0.2 pg/mm. This BioCD sensitivity is comparable to the sensitivity of surface plasmon resonance sensors, but is achieved without resonant structures and hence is relatively easy to fabricate and operate.

6380-21, Session 4

Critical factors for nanoscale injection molding

S. Yoon, Univ. of Massachusetts/Lowell

Appropriate feature size and economically viable molding cycle are critical to meet the demand for biochemical analysis devices containing microfluidic channels. Since conventional mold tooling materials and techniques are not suitable for sub-micron scale molding, mature silicon processing technology was adopted.

Perfect replication has not been achieved so far via injection molding process. The objective of this research is to investigate the factors for the incomplete replication. feasibility of direct use of semiconducting materials as a mold insert for injection molding. Replication quality was evaluated in terms of depth ratio (depth of molded part/depth of tooling) and root-mean-square roughness. Simple pattern geometry of trench lines was employed to simplify the analysis.

Possible factors are : 1)Tooling damage, 2)Surface adhesion of polymer due to degradation of PC, 3)The effect of surface energy on adhesion, 4)Surface adhesion due to polymer melt fracture in ejection, and 5)Shrinkage of polymer. All of the factors may work synergistically, and the effects were even greater in case of small feature geometry, and resulted in poor replication.

6380-22, Session 4

UV LED exicted time-gated luminescence flow cytometry: concepts and experimental evaluation

D. Jin, R. E. Connally, J. A. Piper, Macquarie Univ. (Australia)

In fluorescence technique based bioinstrumentation, naturally occurring, intrinsically fluorescent substances (autofluorophores) can severely compromise the unique discriminative ability of fluorescent probes. The desired signal can be efficiently distinguished from the bulk autofluorescence when the fluorescence lifetime (t) of the probe is sufficiently different from that of the autofluorescent matrix. We present the concepts and experimental evaluation of a UV LED excited flow cytometer suitable for ultra-low background rapid counting of individual rare-event microorganisms previously labeled with lanthanide chelates. The prototype flow cytometer can positively identify long-lived luminescence tagged targets as efficient as 6,000 per second from autofluorescence-rich samples. The performance of this flow cytometer was evaluated by enumerating 5.7 mm Eu3+ luminescence microspheres resulting in an ultimate 100% of counting efficiency. This work presented the novel design of UV LED excitation in flow cytometry, which reduced both cost and physical size of flow cytometer without sacrificing the counting accuracy.

6380-23, Session 4

Fluorescence immunoassay diagnostic improvement with a compact diode pumped solid state laser at 315 nm

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The demand on fast reliable medical diagnostic techniques like Fluorescence Immunoassay (FIA) increases dramatically. Homogeneous FIA analytics based on Europium-Cryptate are well known and applied in a wide range of blood diagnostics utilizing Förster Resonant Energy Transfer (FRET): the Eu3+-cryptate-donor is excited with light between 300 to 340 nm leading to an emission at 660 nm from the acceptor when coupling via antibody-antigen interaction has taken place. Mostly nitrogen laser at 337 nm emission are deployed for excitation. Compact diode pumped solid state (DPSS) laser with emission between 300 to 320 nm would be perfect for this application as the donor gets excited in its absorption maximum.

A newly developed DPSS-laser device at 315 nm emission based on the quasi-three-level transition in Nd:YAG at 946 nm is demonstrated. The pulsed operation is either realized by an active Q-switch using an electro-optical device or by introduction of Cr4+:YAG saturable absorber as a passive Q-switch element. By extra cavity second harmonic generation in different nonlinear crystal media we achieved blue light at 473 nm. Subsequent mixing of the fundamental with the second harmonic in β-Barium-Borate crystal provides pulsed emission at 315 nm with 20 μJ maximum pulse energy and 17 ns pulse width.

Substitution of a nitrogen laser in a FIA-system by the DPSS-laser succeeded in considerable improvement. Despite significantly lower pulse energies (10 μJ DPSS-laser versus 150 μJ nitrogen laser) the limit of detection was reduced by a factor of two for a typical FIA in preliminary investigations.

6380-24, Session 5

Simultaneous acquisition of the real and imaginary components in Fourier domain optical coherence tomography using harmonic detection

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Fourier domain optical coherence tomography (FD-OCT) is an interferometric imaging technique that allows imaging to depths of 1 to 2 mm in scattering biological tissues with high resolution on the order of 1 μm. However, the usefulness of FD-OCT is limited by background and autocorrelation interference terms that reduce the sensitivity and by phase ambiguity that halves the useful imaging depth range. These limitations can be overcome by obtaining the full, complex spectral interferogram. Simultaneous detection of the imaginary and real terms is obtained by phase modulating the reference arm of the interferometer and simultaneously detecting the first and second harmonics. A mathematical derivation of harmonically detected FD-OCT and experimental measurements showing that ambiguity artifacts can be suppressed by at least 40 dB will be presented. This method has low sensitivity to phase noise and can be easily applied to swept source optical coherence tomography. Beyond the removal of artifacts, the ability to obtain the full, complex interferogram is key to the development of spectrally resolved optical coherence tomography which would add chemical specificity to the structural information currently obtainable from FD-OCT.

6380-25, Session 5

Near-infrared applications for tissue identification

E. Botonjic, Axsun Technologies Inc.

Identifying injuries, deformities, and diseases by non-invasive instrumental means has been a major innovation in medicine. Diagnostic and imaging medical devices have revolutionized diagnosis and surgery, providing more efficient way to identify injuries and diseased or damaged tissues. In this paper, identification of different animal tissues using a miniature near-infrared (NIR) spectrometer will be demonstrated. Each tissue type contains different amounts of moisture and proteins, and by using this miniature spectrometer, a miniature fiber-optic probe and chemometrics; the ability to recognize tissues spectral differences is established.

The initial analysis of the data showed promising results for the use of spectral guidance during medical procedures. In addition, this process could permit the collection of a significant body of data that can be used for future algorithm development. In the future, this method can allow for online monitoring during operating procedure, to identifying correct organs or tissues as an addition to the visual process currently used. The utility of this methodology will become more apparent with the continued growth of biotechnology and the desire of biotechnologists for spectral information.

6380-27, Session 5

Back-scattering angular domain imaging of objects within highly scattering media

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Coherence or Time Domain Optical tomography within highly scattering media observes the shortest path photons over the dominant randomly scattered background light. Back-Scattering Angular Domain Imaging employs micromachined collimators detecting photons within small angles of reflected laser light sources from turbid medium. These angular filters are micromachined silicon collimator channels 51 microns wide by 10 mm long on 102 micron spacing, giving an acceptance angle of 0.29 degrees at a CMOS detector array. Phantom test objects were observed in scattering media 3 mm back from the collimator at effective scattered to ballistic ratios from 1:1 to greater than 5E9:1. the laser beam makes the 54 degrees angle beside the scattering medium. Line and space test objects detection limits are set by detector pixel size (5.5 microns) not collimator hole spacing. Thin layer carbon coating the SMCA using Sputtering system to reduce reflectivity shows that at high scattering levels absorbing walls will reduce background light, improving contrast.

6380-28, Session 5

Development of molecular signatures for identifying known and unknown viruses

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The ability to identify and characterize a previously unknown or emerging pathogen is critical to mounting timely and effective responses to both natural and deliberately released biothreats. Recent focus on species-specific methods for identification of high-threat pathogens has given way to important and necessary advances in their detection and characterization. Meanwhile, the relative lack of focus on developing assays for identifying unknown pathogens has generated a huge scientific gap in our ability to identify emerging, evolving and engineered biological pathogens. The bridging of this gap represents a significant challenge that is compounded by the huge predicted viral diversity on earth, the rapid evolution of certain types of viruses (e.g. RNA viruses), and the lack of cultureable viruses to characterize. To better prepare ourselves against emerging biological threats, we are combining informatic and bioanalytical techniques to develop a novel method for reproducibly identifying both known and unknown pathogens in complex clinical or environmental samples. As a preliminary demonstration of our approach, we will describe the development of multiplexed, nucleic acid-based identification assays designed to test genetic signatures that were computationally generated for rapid, species/strain level identification of a representative single viral family.

6380-30, Session 5

Determination of protein biomarkers in serum by surface plasmon resonance spectroscopy

K. S. Booksh, M. R. Malone, J. Masson, T. M. Battaglia, M. Barnhart, Arizona State Univ.

The rapid quantification of biomarkers for prognosis of acute myocardial infarction (AMI) has been previously demonstrated in saline solution (HBS) and fetal calf serum using a fiber optic surface plasmon resonance biosensor. The performance of the sensor was tested in human blood serum, total protein concentration ~8mg/mL. Calibration plots were constructed from spiked human serum, previously determined to be negative for AMI. A validation study using the AMI biomarker, cTnI, was performed to compare SPR quantification in human blood serum to levels determined in a clinical lab that utilized current immunoassay methodology. The sampling followed standard protocols from patients emitted for AMI. These protocols involve the batch sampling of blood serum over a set time course to monitor cTnI levels. The blood samples were divided into two volumes, one for clinical lab testing for patient care, the other for quantification using the SPR biosensor. The clinical lab results are used in tandem with other markers for AMI, such as monitoring of CK-MB levels, and EKGs to determine a positive or negative diagnosis of AMI. The rapid response (4-6 minutes) of the SPR sensor is advantageous over current clinical immunoassay methods that result in much longer response times due to required incubation with secondary antibodies. The clinical viability of the SPR biosensor will be discussed.

6380-29, Session 6

Noninvasive approaches to measuring respiratory patterns using a PtTFPP-based phase-lifetime self-referencing oxygen optrode

D. M. Porterfield, J. L. Rickus, Purdue Univ.; R. Kopelman, Univ. of Michigan

It was Robert Boyle (1680) who first noted that living organisms require a “life sustaining substance” from the air based partially on his experiments with luminescent fungi and bacteria. Early electrochemist studied oxygen reduction on platinum and gold wire electrodes, but these early “sensors” were subject to fouling and stir sensitivity due to their activity, which consumed oxygen in the process. In addition, electronic noise and electrode drift has been a constant challenge to researchers, in biological studies that attempt to adapt and use polarographic oxygen sensors. Fundamentally this has technically plagued and challenged all researchers who have taken up the art of

polarographic oxygen microsensors. These problems with noise and drift were partially addressed by the development of the self-referencing electroanalytical oxygen sensor (Porterfield et al., 1998; Land et al., 1999; Porterfield and Smith, 2000), an adaptation of the vibrating voltage probe.

Optically transduced sensors (optrodes, or optodes) do offer significant advantages over polarographic techniques but in the past have required significantly more investment in instrumentation. They also have been limited in their adaptation to dynamic, multidimensional sensing. In biology and medicine, how we make measurements is just as important as what we measure. In terms of the biophysics of physiological transport and exchange this is especially true. Cellular and tissue oxygenation is a function of background concentration and respiratory demand. In pure physical terms this is best expressed in terms of molecular flux based on Fick's law, but most sensor technology development stops at making measurements of concentration profiles. Measuring dynamic flux from biological systems requires sensing technology that can measure activity in multiple dimensions, because the physiological activity of cells and tissue are heterogeneous in terms of basic metabolism and pathology. Here we report the development of a self-referencing oxygen optrode (SRO) for reliably making non-invasive measurements of oxygen flux from a variety of biological systems. The self-referencing microsensor technique was adapted to operate optrodic oxygen sensors through the integration of optical sensing instrumentation with software-controlled data acquisition and micro-stepping motion control. This allows the sensor to scan biologically active gradients of oxygen flux directly, as it relates to cellular and tissue respiratory activity. The technique was validated first using artificially generated oxygen gradients, which are theoretically modeled and compare with measured signals. Subsequently, the SRO was applied in basic research applications to non-invasively measure molecular oxygen flux from a variety of animal and plant systems, including rat osteogenic sarcoma UMR-106 cells, and a nerve chord trauma model system.

6380-31, Session 6

Feasibility of monitoring patient motion with opposed stereo infrared cameras during supine medical imaging

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Patient motion during single photon emission computed tomographic (SPECT) acquisition causes inconsistent projection data and reconstruction artifacts which can significantly affect the diagnostic accuracy. We have investigated use of the Polaris stereo infrared motion-tracking system to track the 6-Degrees-of-Freedom (6-DOF) motion of spherical reflectors (markers) on stretchy bands about the patient's chest and abdomen during clinical imaging. The marker position information, obtained by opposed stereo infrared cameras, requires processing to correctly record tracked markers, and map Polaris co-ordinate data into the SPECT co-ordinate system. One stereo camera views the upper chest and lower abdomen bands from the patient's head direction, and the other from the patient's foot direction. The need for opposed cameras is to overcome anatomical torso shapes and geometrical limitations imposed by the gantry of the imaging system which sometimes prevents all markers from being seen by a single stereo camera. The two sets of marker data then require processing to determine the rotational and translational 6-DOF motion of the patient to ultimately be used for SPECT image corrections. The processing utilizes an algorithm involving least-squares fitting, to each other, of two 3-D point sets using singular value decomposition (SVD) resulting in the rotation matrix and translation of the rigid body centroid. We have demonstrated the ability to monitor multiple markers for twelve patients. We employ a neural network to separate the periodic respiratory motion component of marker motion from aperiodic body motion. We plan to initiate routine 6-DOF tracking of patient motion during SPECT imaging in the future, and are herein evaluating the need for opposed stereo cameras.

6380-32, Session 6

Noninvasive sensors in critical care medicine: near-infrared spectroscopy for the detection of altered microvascular blood flow in severe sepsis and septic shock

J. M. Walz, B. R. Soller, O. O. Soyemi, Y. Yang, M. R. Landry, S. O. Heard, Univ. of Massachusetts Medical School

Background: 750,000 cases of severe sepsis occur in the United States annually, 225,000 of which are fatal. Alterations in microvascular blood flow play a central role in the development of multi-system organ dysfunction. The ability to monitor regional and microvascular blood flow is desirable for both, early detection of these changes as well as the assessment of response to therapy. Most tools available to clinicians to date however remain experimental and are not routinely used in clinical practice.

Hypothesis/Methods: We have developed and validated a noninvasive sensor based on Near Infrared Spectroscopy (NIRS) which allows us to accurately measure tissue oxy- and deoxyhemoglobin as an indicator of microvascular blood flow, as well as tissue pH as an indicator of anaerobic metabolism. We are in the process of evaluating the utility of NIRS in detecting changes in microvascular blood flow in early sepsis as well as their resolution during therapy with recombinant human activated protein C, a drug with anti-inflammatory and anticoagulant properties.

Results: Preliminary data suggests good correlation between tissue oxygenation as determined by NIRS with central venous oxygen saturation in patients with severe sepsis/septic shock.

Discussion: Assessment of tissue perfusion and oxygenation on a regional level in the ICU remains challenging, current tests and technologies measure global parameters of a mismatch in oxygen supply and demand. We suggest that NIRS may allow physicians to identify patients at risk for septic shock based on alterations in the patient's microcirculation before the onset of organ failure. Application of therapeutic interventions early in the disease process may decrease morbidity and mortality from severe sepsis/septic shock.

6380-33, Session 6

Astronaut health monitoring

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Extended weightlessness causes numerous deleterious changes in human physiology, including space motion sickness (SMS), cephalad fluid shifts, reduced immune response, and loss of bone and muscle mass. Furthermore, these physiological changes also influence metabolism of therapeutic drugs used by astronauts. The need to monitor and assess these effects is critical to developing exercise programs or drug regimes that would maintain astronaut health. Many of these physiological changes are reflected in the chemical composition of urine. For example, biochemical markers indicative of bone loss, muscle loss, and renal stone formation, are available for analysis, as are the metabolites of anti-SMS drugs. Unfortunately, current earth-based analytical laboratory methods that employ liquid or gas chromatography for separation and fluorescence or mass spectrometry for trace detection are labor intensive, slow, massive, and not cost-effective for operation in space. In an effort to overcome these instrument limitations we have been developing a lab-on-a-chip device to both separate these biomarkers and drug metabolites from urine and generate surface-enhanced Raman spectra (SERS). We have incorporated standard chromatography materials to aid separation, as well as a porous material containing metal particles that generate SERS. Generally no more than 1 milliliter of sample is required and complete analysis can be performed in 5 minutes. The detailed molecular vibrational information allows chemical identification, while the increase in Raman scattering by six or more orders of magnitude allows detection of microgram per liter concentrations. Measurements of biomarkers and anti-SMS drug metabolites extracted from synthetic urine will be presented.

6380-34, Session 6

Aculaser therapy: a comprehensive approach for the treatment of cerebral palsy

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A single, open and non comparative study was conducted at Anwar Shah's First C.P. & Paralysis Clinic and Research Center in collaboration with the Departments of Neurology and Neurosurgery, Children Hospital Lahore, Pakistan to evaluate the effects of ACULASER THERAPY in childern suffering from Cerebral Palsy (CP) and associated Neurological Disorders. In all 100 childern were treated and the data was gathered during a period of 18 months from December 2003 till June 2005.

This article shows results of the treatment with ACULASER THERAPY in CP childern who were treated for minimum 6 weeks and more or had minimum of 10 treatment sessions and more. This paper also shows that those childern who were given a break in the treatment for 4 -12 weeks did not show any reversal of the symptoms. These children were classified according to the associated Neurological Disorders.

Analysis of the data showed that out of 81 children with Spasticity and Stiffness 69 showed marked improvement showing 85% improvement rate, out of 54 children with Epileptic fits there was a significant reduction in the intensity, frequency and duration of Epileptic fits in 34 children showing 63% success rate, out of 18 children with Cortical Blindness 13 children showed improvement accounting for 72% efficacy rate, out of 45 children with Hearing Difficulties, 31 showed marked improvement accounting for 69% improvement rate, out of 100 children with Speech Disorders 67 showed improvement reflecting 67 % improvement rate, out of 46 children with Hemiplegia 32 showed improvement in movement, tone and power accounting for 69% improvement rate, out of 36 children with Quadriplegia 25 showed improvement in gross and fine motor functions showing 69% success rate and out of 18 children with Paraplegia of lower limbs 12 showed improvement in weight bearing, standing and movement accounting for 67% improvement rate .

6380-35, Session 6

Hollow fiber optic probe for in vivo Raman measurement

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A fiber-optic probe based on a hollow optical fiber was developed to apply in remote Raman spectroscopy via an endoscope. Recent in vivo investigations performed with optical fiber probes were promising but generally limited to one excitation wavelength, often generating significant background noise. We have proposed a novel Raman probe using hollow optical fiber, which generate no Raman scattering or fluorescence noise, as a guiding medium. The probe was designed to maximize collection efficiency, and has resulted in high S/N ratio. The collection efficiency became maximum near the end face of the probe, and converges to zero quickly when the probe is moved away from the sample. The depth-resolution was estimated as below 70 micrometer. The diameter of distal end of the Raman probe is 0.56 mm that is possible to apply enough to a measurement in vivo with an endoscope. In vivo experiments in a stomach of a rat demonstrated the ability of hollow fiber optic probe to collect Raman signal from a living body.

6380-36, Poster Session

Development of structured light illumination based endoscope

C. Wong, N. Chen, C. J. R. Sheppard, National Univ. of Singapore (Singapore)

Confocal microscopy is a well established method in optical sectioning that allows for increased axial resolution. However, it has the disadvantage of a long scanning time and often poor image contrast. Structured illumination is wide-field microscopy technique which exhibits an optical sectioning capability, yet with an improved contrast. Compared with confocal microscopy, structured illumination requires capturing of only three image frames to obtain both an optical sectioned image and a conventional image, thus allowing for multiple display styles. With these advantages, structured illumination presents excellent opportunities for usage in non-invasive imaging. This study on structured illumination is done as a part of an effort to develop an endoscopy system. The fringe projection system is based upon light reflected from a TI-DMD digital micromirror and is projected on to the specimen (Allium cepa, onion) via a 10x/0.25 NA lens. The superimposed image is then captured with a Pixelink PL-741 camera with a frame rate of 30 frames/seconds. The three captured images are then processed by a computing unit which removes the imposed fringe pattern and recovers both the sectioned and conventional image. The study has shown appreciable sectioning capabilities in structured illumination, and the fast scan rates demonstrates its feasibility for endoscopy development. Usage of a DMD also allows for variable sectioning strength which would prove useful in biological applications. Our study finally discusses the common fringe residual problem, and how to correct this, especially with regards to usage of a rectangular grating.

6380-37, Poster Session

Bio-compatible optical interfaces

F. Causa, Univ. of Bath (United Kingdom); J. Robbins, King's College London (United Kingdom); A. V. Sapelkin, Queen Mary Univ. of London (United Kingdom); S. Surguy, King's College London (United Kingdom); B. Unal, Queen Mary Univ. of London (United Kingdom); W. N. Wang, D. Masanotti, J. T. Taylor, Univ. of Bath (United Kingdom)

Interest in direct measurement of neural activity has given rise to a profusion of interest and research effort to develop new, reliable, efficient and compact techniques. Patch clamping is the technique that has been most widely used to detect neuronal activity. However, although it offers the advantage of bi-directionality, this technique is invasive to some degree and can produce irreversible damage to nerve cells - therefore, it cannot be used for long-term (\>a few hours), reliable connections to individual neurons. On the other hand, optical recording is non-invasive and flexible since a variety of fluorescent dyes are now available to record several different parameters with essentially no ill effect on cells. The aim of this paper is to present new optical interfaces that are bio-compatible. Porous Silicon has been already been demonstrated by some of the authors of this paper as an excellent bio-compatible substrate, providing a very suitable base for bi-directional interfacing of neurons with standard CMOS-based electronics. From the optical point of view, since most of the excitation wavelengths of fluorescent dyes used for optical recording are in the visible and near-UV regions of the spectrum, GaN-based semiconductor materials have been used to test bio-compatibility. Excellent results have been obtained with neurons growing on wafer for extended periods of time. Details of such experimental observations will be presented. This then opens up the possibility of in-situ monitoring of cell cultures using compact and efficient optical circuits.

6380-38, Poster Session

Detection of inflammatory cytokines using a fiber optic microsphere immunoassay array

T. M. Blicharz, D. R. Walt, Tufts Univ.

A multiplexed fiber-optic microsphere-based immunoassay array capable of simultaneously measuring five inflammatory cytokines has been developed. Five groups of amine-functionalized 3.1 micron microspheres were internally encoded with five distinct concentrations of europium dye and converted to cytokine probes by covalently coupling monoclonal capture antibodies specific for human VEGF, IFN-gamma, RANTES, IP-10, or Eotaxin-3 to the microspheres via glutaraldehyde chemistry. The microspheres were pooled and loaded into the wells of a 1 mm diameter fiber-optic bundle containing ~50,000 individual etched microwells, producing the multiplexed cytokine immunoassay array. Multiple arrays can be created from a single microsphere pool for high-throughput sample analysis. Sandwich fluoroimmunoassays were performed by incubating the probe array in a sample, followed by incubation in a mixture of biotin-labeled detection antibodies that are complementary to the five cytokines. Finally, universal detection of each protein was performed using a fluorescence imaging system after briefly immersing the array in a solution of fluorophore-labeled streptavidin. The multiplexed cytokine array has been shown to respond selectively to VEGF, IFN-gamma, RANTES, IP-

10, and Eotaxin-3, permitting multiplexed quantitative analysis. Ultimately, the multiplexed cytokine array will be utilized to evaluate the potential of saliva as a noninvasive diagnostic fluid for pulmonary inflammatory diseases such as asthma and chronic obstructive pulmonary disease (COPD).

6380-39, Poster Session

Molecularly imprinted polymerization-based surface plasmon resonance sensing for glucose detection in human urine

K. S. Booksh, S. Banerji, W. Peng, Y. Kim, Arizona State Univ.

Surface Plasmon Resonance (SPR) has been traditionally used as a probe for surface interaction of large molecules like proteins and peptides but harder to measure small molecules since the effective change in the SPR condition (thickness change of the layer bound to the gold) becomes smaller. The accurate measurement of glucose in complex physiological fluids like urine is particularly challenging since the constituents of these fluids vary significantly from person to person and even throughout the day for a particular individual. A novel SPR sensor to detect glucose using molecularly imprinted polymer will be presented in this paper. The polymer was prepared by crosslinking poly (allyl amine) in the presence of Glucose Phosphate, monobarium salt (GPS-Ba) and attached to a thin film of gold (50 nm) which had been sputtered on top of a glass slide, via amide coupling. Upon removal of the template, this sensor was used to detect glucose in human urine in physiologically significant levels (1-20 mg/ml). Enhancement of the glucose sensor was made possible by incorporating gold nanoparticles which improved the signal. This study has demonstrated the specific detection of glucose in a complex physiological fluid using SPR spectroscopy. The association of glucose to the imprinted polymer results in the swelling of the polymer that can be tracked by the minima in SPR spectra. The sensitivity of this method, while lower than protein based detection schemes, is sufficient for quantitative measurement of glucose in urine at physiologically significant levels without extensive pre-treatment of the sample. Lower detection limits can be achieved by the incorporation of gold nanoparticles in the polymer matrix, which have been shown to increase the sensitivity of SPR signal significantly. Given the nature of the weak non-covalent binding of glucose to the amine functional groups, the scheme used here can be adapted to detect a number of different molecular species of sizes comparable to that of glucose without the need for extensive sample preparation or use of chemicals with limited shelf life.

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6381-02, Session 1

Hyperspectral imaging based techniques applied to polluted clay characterization

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Polluted soils analysis and characterization is one of the basic step to perform in order to collect all the information to design and set-up correct soil reclamation strategies. Soil analysis is usually performed through “in-situ” sampling and laboratory analysis. Such an approach is usually quite expensive and does not allow to reach a direct and detailed knowledge of large areas for the intrinsic limits (high costs) linked to direct sampling and polluting elements detection. As a consequence numerical strategies are applied to extrapolate, starting from a discrete set of data, that is those related to collected samples, information about the contamination level of areas not directly interested by physical sampling. These models are usually very difficult to handle both for the intrinsic variability characterizing the media (soils) and for the high level of interactions between polluting agents, soil characteristics (organic matter content, size class distribution of the inorganic fraction, composition, etc.) and environmental conditions (temperature, humidity, presence of vegetation, human activities, etc.). Aim of this study was to evaluate the results obtainable in the investigation of an “ad hoc” polluted bentonic clay, usually utilized in rubbish dump, in order to define fast and reliable cntrol strategies addressed to monitorate the status of such a amterial in terms of insulation.

6381-03, Session 1

Using ASTER image for soybean plant residue coverage estimation

H. Yao, D. Lewis, R. Kincaid, Institute for Technology Development

Soil erosion and its related runoff is a serious problem in U.S. agriculture. USDA has classified 33% of U.S. agricultural land as being highly erodible. Because of the erosion, rivers, lakes, and water table are contaminated due to the agriculture chemicals such as nitrogen, phosphorus, and pesticides contained in the runoff water. This is a serious environmental problem nationwide. It is well recognized that residue coverage on the soil surface can reduce soil erosion. The objective of this paper was to explore the potential of using ASTER data for soybean plant residue cover estimation. In the spring of 2004, personnel from Natural Resource Conservation Service (NRCS) and Institute for Technology Development (ITD) did a traditional windshield survey in three Indiana Counties, Wabash, Huntington, and Grant. Fields with \>30% residue cover were classified as conservation tillage (no till); those with 16-30% residue cover as reduced tillage; and those with <15% residue cover as traditional tillage. ASTER data was collected over the study sites on April 14, 2004. The image data was used to extract spectral information for the analyses. Different methods such as discriminant analysis and image classification were used to determine if the image bands or indices could be used to predict crop residue levels. The residue cover fraction estimate was used for the field and the field-average index value. The initial results indicated that ASTER imagery has moderate capability to identify residue within the soybean fields.

6381-04, Session 1

Development of multifunctional remote sensing system for greenhouse production

S. Chen, H. Lu, National Taiwan Univ. (Taiwan); K. Hsieh, Y. Huang, National Chung-Shing Univ. (Taiwan); C. Chen, I. Yang, G. Yeh, C. Chang, National Taiwan Univ. (Taiwan)

This study is aimed to develop a multi-functional remote sensing system based on spectral imaging and environmental sensing for seedling production in the greenhouses. The spectral images were grabbed with exposure time and signal gain controls through IEEE-1394 interface, and a color camera and a monochrome camera with optical filter at 780 nm were used. A control program was developed to grab the good quality images using the automatic exposure algorithm with Matlab 6.5 and LabVIEW 7.1 software. To obtain necessary spectral information regarding tray locations and seedling growth status on benches, a serial image processing procedures, including spatial calibration, image stitching, gray-level calibration and image segmentation were developed. The data of tray positions were transferred to the look up table (LUT) and delivered to the water management module through the data socket server and wireless network. Besides, the environmental sensing sub-system, including temperature, relative humidity, and photo-quantum measurements, was also developed with the PCI-6023 interface to analyze the spatial distribution of these parameters in the greenhouse. The information of environmental status will provide a better management for seedling growth.

6381-05, Session 1

Application of plant impedance for diagnosing plant disease

H. Xu, Y. Ying, X. Jiang, S. Zhu, Zhejiang Univ. (China)

Biological cells have components acting as electrical elements that maintain the health of the cell by regulation of the electrical charge content. Plant impedance is decided by the state of plant physiology and pathology. Plant physiology and pathology can be studies by measuring plant impedance. The effect of tomato mosaic virus (ToMV) on electrical resistance of tomato leaves was studied by the method of electrical resistance measurement. It was found that the value of resistance of tomato leaves infected with ToMV was smaller than that in sound plant leaves. This decrease of resistance in leaf tissue was occurred with increased severity of disease. The decrease of resistance of tomato leaves infected with ToMV could be detected by electrical resistance detecting within 5 days after inoculation even though significant visible differences between the control and the infected plants were not noted until after 10 days, so that the electrical resistance technique for measurement of tomato leaf tissue resistance is a rapid, clever, simple method on diagnosis of plant disease.

6381-07, Session 2

Noninvasive forward-scattering system for rapid detection, characterization, and identification of Listeria colonies: image-processing and data analysis

B. P. Rajwa, B. Bayraktar, P. P. Banada, K. Huff, E. Bae, J. P. Robinson, E. D. Hirleman, Jr., A. K. Bhunia, Purdue Univ.

Bacterial contamination by Listeria monocytogenes not only puts the public at risk but also is costly for the food-processing industry. Traditional biological and chemical methods for pathogen identification require complicated sample preparation for reliable results. Optical scattering technology has been used for identification of bacterial cells in suspension, but with only limited success. Therefore, we have developed a noninvasive optical forward-scattering system for rapid detection, characterization, and identification of Listeria colonies grown on solid surfaces.

The presented work includes application of computer vision and pattern recognition techniques. Bacterial colonies with a diameter of approximately 1.8 to 1.9 mm and a thickness of around 0.3 to 0.4 mm were analyzed with a laser scatterometer. Circular scatter patterns formed by bacterial colonies illuminated by red laser light were analyzed using Zernike or Tchebichef (discrete) moment invariants. Discrete moments do not possess the discretization errors inherent in continuous moments. This important advantage allows better fulfillment of orthogonality and invariance properties. Use of discrete moments improves also the speed of our image processing algorithms. This is attained by calculating discrete polynomial coefficients directly from their definitions employing arbitrary precision arithmetic, rather than using recurrence relationships.

Principal component analysis and hierarchical clustering were performed on the results of feature extraction for colony differentiation. Classifications using linear discriminant analysis, neural networks, and support vector machines were used to test the feasibility of automated determination of bacteria pathogenicity on the basis of colony scatter patterns. The overall system is robust and can be extended into an automated user-friendly device for detection and classification of various pathogenic bacteria.

6381-08, Session 2

Fiber optic biosensor employing Alexa-Fluor conjugated antibody for detection of escherichia coli O157:H7 and Shiga-like toxins

S. Tu, USDA Agricultural Research Service; T. Geng, Purdue Univ.; J. Uknalis, USDA Agricultural Research Service; A. K. Bhunia, Purdue Univ.

We developed an antibody-based fiber-optic biosensor to rapidly detect low levels of Escherichia coli O157:H7 and shiga-like toxins (SLTs) in ground beef samples. The principle of the sensor is a sandwich immunoassay using an antibody which is specific for E. coli O157:H7 or toxins. A polyclonal antibody was first immobilized on polystyrene fiber waveguides through a biotin-streptavidin reaction served as a capture antibody. An Alexa Fluor 647 dye-labeled antibody to E. coli O157:H7 or SLTS was used to detect cells and generate a specific fluorescent signal, which was acquired by launching a 635 nm laser-light from an Analyte-2000. Fluorescent molecules within several hundred nanometers of the fiber were excited by an evanescent wave, and a portion of the emission light from fluorescent dye transmitted by the fiber and collected by a photodetector at wavelengths of 670 to 710 nm quantitatively. This immunosensor was specific for E. coli O157:H7 compared with multiple other foodborne bacteria. The approach was able to detect as low as 103 CFU/ml pure cultured E. coli O157:H7 cells grown in BHI. Artificially inoculated E. coli O157:H7 at concentration of 1 CFU/ml in ground beef could be detected by this method after only 4 hours of enrichment. The approach was also able to detect ~0.5 ng of pure SLTs and the the SLTs associated with 200 E. coli O157:H7 cells at stationary phase.

6381-09, Session 2

Optical light scatter images of Listeria growing at different time periods and on different substrates: a proposed biophysical model

E. Bae, P. P. Banada, A. K. Bhunia, E. D. Hirleman, Jr., Purdue Univ.

We have developed a bacterial detection platform based on optical forward light scattering where the bacterial colony growing on the surface of a solid nutrient agar plate produced unique scatter images for different bacterial species. Bacterial colony size is highly variable, and fully developed colonies may be in the range of 1-10 mm in diameter and dependent on the growth rate and substrate availability. Early detection and identification is possible if a Scatterometer is capable of providing unique scatter patterns in the early phase of growth. The aim of the present investigation was to model the light scatter patterns obtained at different time periods and on different substrates using scalar diffraction theory. We studied the variations in the forward-scatter signatures of three species of Listeria; L. monocytogenes, L. innocua and L. ivanovii. Among these L. monocytogenes causes fatal listeriosis in immunocompromised people. Cultures were grown on brain heart infusion agar (BHI) and the scatter images were captured every six hours for a period of 42 h. The colonies were examined by phase contrast microscopy and the precise diameter of each colony was measured. Growth curve and the scatter pattern curves were plotted against time. Similar studies were carried out when L. monocytogenes was grown on different substrates. Growth and the scatter curve corresponding to the colony diameter demonstrated the variations seen in the scatter patterns in relation to time of incubation. Changes in the physical properties of colony such as density, colony diameter, and transmission coefficient correlated well to the scattering patterns. The developed physical models explain that when the colony was modeled as an opaque circular disc with nonuniform phase changes, we compute patterns very similar observed in the experiments. Thus, a reproducible scatter pattern appears to be a time and substrate dependent process. Based on these we determined that Listeria colonies can be identified at an earliest time period of 24 h when grown in BHI agar plates. This model could be successfully used in understanding the scatter images for further improvements in the instrumentation.

6381-10, Session 3

Prediction of ethanol in bottled Chinese rice wine by NIR spectroscopy

Y. Ying, H. Yu, Zhejiang Univ. (China)

To evaluate the applicability of visible and near infrared (vis-NIR) spectroscopy for determination of ethanol in bottled Chinese rice wine, transmission spectra of bottled Chinese rice wine and the empty bottle were collected in the spectral range from 350 to 1000 nm. Statistical equations were established between the reference data and spectra by partial least squares regression (PLSR). Performance of two spectral pretreatments multiplicative signal correction (MSC) and standard normal variate (SNV), and three kinds of mathematical treatment of original spectra, first derivative spectra and second derivative spectra were also discussed. The PLSR model of second derivative spectra using SNV pretreatment turned out better prediction results, with correlation coefficient (r) of 0.80. The results demonstrated that vis-NIR spectroscopy could be used to predict the concentration of ethanol in Chinese rice wine.

6381-11, Session 3

Age determination of bottled Chinese rice wine by VIS-NIR spectroscopy

H. Yu, Y. Ying, Zhejiang Univ. (China)

The feasibility of visible and near infrared (VIS-NIR) spectroscopy for discrimination between bottled Chinese rice wine of different age (1, 2, 3, 4, and 5 years) was presented. Vis-NIR spectra of bottled Chinese rice wine and the empty bottle were collected in transmission mode in the wavelength range of 350-1000 nm, respectively. Discriminant models were developed based on discriminant analysis (DA) together with raw, first and second derivative spectra. The result for raw spectra was better than that of the second derivative spectra. The percentage of samples correctly classified for raw spectra was 75 %. The results demonstrated that vis-NIR spectroscopy technique could be used as a rapid method for discrimination of wine age of bottled Chinese rice wine.

6381-12, Session 3

Improvements in optical sorting of mold-damaged wheat

S. R. Delwiche, USDA Agricultural Research Service

In the United States, the authority to regulate mycotoxins, inclusive of deoxynivalenol (DON), a by-product of the fungal disease Fusarium Head Blight (FHB), is codified in the Federal Food, Drug and Cosmetic Act, which places authority with the Food and Drug Administration (FDA). Certain mycotoxins, such as aflatoxin, a recognized carcinogen, are regulated through action levels, which can then necessitate official testing for the mycotoxin and can result in the condemnation of grain lots in excess of the action level. Other mycotoxins, including DON, are not regulated by FDA, per se, but instead are voluntarily controlled under the guidelines of advisory levels. Depending on the intended use, the advisory level for DON in the United States ranges from 1 mg/kg. The current study will describe the use of three forms of optical measurement of single wheat kernels for FHB for eventual incorporation in high-speed optical sorters. Our previous research has demonstrated a sorting efficiency of approximately 50 percent with existing high-speed equipment, but a much higher efficiency (~95%) when analytical spectrometers are used. The intention of the current work is to bridge this efficiency gap. Twenty wheat lines, each with 100 normal and 100 Fusarium-damaged kernels, are scanned with an analytical spectrophotometer, passed through a commercial sorter, and observed by a high frequency fiber optic and filter assembly with silicon detector. Knowledge gained from analysis of the latter two forms will provide design criteria for improvement of high-speed optical sorters for recognition of mold damaged wheat.

6381-13, Session 3

Hyperspectral bright greenish-yellow fluorescence (BGYF) imaging of aflatoxin contaminated corn kernels

H. Yao, Z. Hruska, K. DiCrispino, Institute for Technology Development; R. L. Brown, T. E. Cleveland, USDA Agricultural Research Service

Aflatoxin contaminated corn is dangerous for domestic animals when used as feed and causes liver cancer when consumed by human beings. Therefore, the ability to detect A. flavus and its toxic metabolite, aflatoxin, is important. Traditionally, corn kernels have been examined for evidence of bright greenish-yellow fluorescence (BGYF), which is an indication of possible presence of A. flavus, when illuminated with a high-intensity ultra-violet light. The BGYF is typically the first step that leads to an in-depth chemical analysis for possible aflatoxin contaminations. The objective of the present study was to analyze hyperspectral BGYF response of corn kernels under 365 nm UV radiation. The target corn samples were collected from a Texas commercial corn field in 2005 and showed abundant BGYF response. The BGYF positive kernels were manually picked out and imaged under a visible near-infrared hyperspectral imaging system under UV radiation with excitation wavelength centered at 365 nm. Initial results exhibited strong emission spectra in the 480 to 500 nm wavelength for BGYF positive kernels. Aflatoxin levels on the BGYF positive and negative corn kernels (used as control) were measured subsequently using single kernel chemical extraction and high performance liquid chromatography (HPLC). The relationship between the hyperspectral BGYF signature and toxin concentration was also investigated in the study. The results of this research will be used to develop a non-invasive, cost effective inspection method for the grain industry.

6381-14, Session 4

Optical scattering coefficients are correlated with muscle structure properties

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We recently found that optical scattering coefficients of beef muscle can be used as a predictor for beef tenderness. However, it is still not clear what specific muscle properties are responsible for optical scattering. As an effort to answer these questions, we conducted a series of controlled experiments in which we studied the changes of scattering coefficient during rigor mortis as well as its correlation with muscle sarcomere length. The optical scattering coefficient of beef muscles were measured based on a diffusive fitting of spatially resolved reflectance measurements. Samples with different sarcomere lengths were obtained by proper carcass hanging strategies. Our results indicated that muscle scattering coefficient decreased during rigor mortis and increased as the sarcomere length increased. These experimental observations can be qualitatively explained based on previous research on single muscle scattering. This study suggests that the physiological and physical properties of muscle sarcomere structures have a significant impact on muscle optical scattering coefficients.

6381-15, Session 4

Characterizing fiber formation in meat analogs using an anisotropic photon migration model

J. C. Ranasinghesagara, F. Hsieh, G. Yao, Univ. of Missouri/Columbia

Animal meat products may not be the best choice for many people in the world due to various reasons such as cost, health problems, or religious restrictions. High moisture (40-80%) extrusion technology shows a great promise for texturizing vegetable proteins into fibrous meat alternatives. Soy protein which is healthy, highly nutritious, low in both fat and carbohydrate has been used in high moisture extrusion process to produce meat analogs with well formed fiber that resemble chicken or turkey breast meat. Assessing fiber formation in extruded products is important for controlling extrusion quality in manufacturing process. Although several methods have been studied for quantifying fiber formation in extrudates, their applications for real time quality control in manufacturing process have been challenging. We explored the possibility of applying a nondestructive method based on backscattered reflectance to measure the fiber formation of extruded soy proteins. An image processing method was developed to extract the light reflectance profile at the extrudates' surface. We applied the anisotropic continuous time random walk (CTRW) theory to quantitatively describe the fiber formation in extrudates based on extracted surface reflectance profiles. This method has a potential to be used as a non-destructive, fast, real time quality control tool for products with fibrous structures.

6381-17, Session 4

Bone fragment detection in chicken breast fillets using diffuse scattering pattern of back-illuminated structured light

S. Yoon, K. C. Lawrence, B. Park, D. P. Smith, W. R. Windham, USDA Agricultural Research Service

This paper is concerned with the detection of foreign materials, such as bone fragments embedded in de-boned skinless chicken breast fillets and uses optical scattering patterns characteristic to chicken breast fillets with embedded foreign materials as the detection strategy. Chicken fillets are often dominated by strongly multiple scattering properties within the fillets. Thus, the resulting images from multiple scattering are diffused, scattered, and low contrast. In this study, hyperspectral optical imaging, which is a non-ionized and non-destructive imaging modality, is investigated as an alternative method to the conventional X-ray imaging technique which is an ionizing imaging modality. As a way of reducing the influence of light scattering on images and thus increasing image contrast, the use of a structured line light is investigated in the range from 500-nm to 900-nm. Spatial scattering patterns, with or without embedded bones, are measured over the wavelength range. Important factors affecting scattering patterns, such as sample thickness, wavelengths, and fiber orientation of sample, are identified. The measured transmittance values are calibrated by a set of certified neutral density filters. The preliminary study shows that scattering patterns of bones embedded in meat samples are different from image patterns from normal meat samples in terms of shape and intensity profile. Experimental results with chicken breast samples and bone fragments are provided.

6381-18, Session 4

The statistical and fractal properties of surface reflectivity of raw chicken tissue with application to public health safety

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Images of packaged raw chicken purchased in neighborhood supermarkets were captured via a digital camera in laboratory and home settings. Each image contained the surface reflectivity information of the chicken tissue. The camera's red, green and blue light signals fluctuated and each spectral signal exhibited a random series across the surface. The Higuchi method, where the length of each increment in time (or spatial) lag is plotted against the lag, was used to explore the fractal property of the random series. (Higuchi, T., "Approach to an irregular time series on the basis of fractal theory", Physica D, vol 31, 277-283, 1988). The fractal calculation algorithm was calibrated with the Weierstrass function. The standard deviation and fractal dimension were shown to correlate with the time duration that a package was left at room temperature within a 24-hour period. Comparison to packaged beef results suggested that the time dependence could be due to the presence of surface cell decay and salmonella growth. The fractal dimension results in this study were consistent with those obtained from yeast cell and mammalian cell studies. This analysis method can be used to detect the re-refrigeration of a "left-out" package of chicken. The extension to public health issues such as consumer shopping is also discussed.

6381-19, Session 4

An examination of ham color fading using optical fiber methods

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In the modern retail environment, the appearance of a product is frequently the only quality indicator available to consumers. This is especially true of products such as sliced ham that are sealed into packages to maintain product freshness. Sliced ham products undergo discolouration from their original pink colour to a dull grey colour when displayed in retail cabinets. This is an unavoidable phenomenon caused by illumination of the cabinet, the OTR (Oxygen Transmission Rate) of the packaging, product to headspace ratio and percentage of residual oxygen when sealed. The fading of ham is not directly related to the best before date and slices can have faded to an unappetising grey colour before this date.

This paper presents initial investigations into the development of a sensor to measure the rate of colour fading in cured ham, in order to predict an optimum colour sell-by-date. The sensor will make this prediction based on the initial ham colour after production. Two methods for the measurement of the discolouration were investigated - CIE L*a*b* measurements and analysis of the spectral reflectance of the colour of the ham. Reproducibility of CIE L*a*b* values proved to be difficult and significant overlapping of the L* (lightness) and a* (redness) values measured for pink and grey coloured ham was observed. Artificial Neural Networks and Self-Organising Maps (SOMs) were then compared for the purpose of classifying the reflected spectral data into five colour fading stages, from very pink to grey. The results presented here show that the SOM was more suited to the application.

6381-20, Session 5

Effect of wavelet denoising techniques on the determination of navel orange sugar content with near-infrared spectra

L. Xie, Y. Ying, Zhejiang Univ. (China)

Near infrared (NIR) spectroscopy is an ideal analytical method for rapid and nondestrctive measurement of the properties of agriculture products. The efficient use of this method is dependent on multivariate calibration methods determined by the sensitivity to variations. However, fluctuation of background and noise are unavoidable during collecting spectra, which will not only worsen the precision of prediction, but also complicate the multivariate models. Therefore, the first step of a multivariate calibration based on NIR spectra data is often to preprocess the data for the purpose of removing the varying background and noise. In this study, wavelet transform (WT) was used to eliminate the varying background and noise simultaneously in the near infrared spectroscopy signals of 55 navel oranges. Three families of mother wavelets (Symlets, Daubechies and Coiflet), four threshold selection rules (Rigrsure, Heursure, Minimaxi, Fixed form threshold), and two threshold functions (soft and hard) were applied to estimate the performances. The sugar content of intact navel orange was calculated by partial least squares regression (PLSR) with the reconstructed spectra after denoised. The results show that the best denoising performance was reached via the combination of Daubechies 5, “Fixed form” threshold selection rule, and hard threshold function. Based on the optimization parameter, wavelet regression models on sugar content in navel orange were also developed and resulted in a smaller prediction error than a traditional PLSR mode.

6381-21, Session 5

Temperature influence for Fourier transform near-infrared transmittance measurement of citrus fruit soluble solids contents

H. Lu, Y. Ying, Zhejiang Univ. (China)

Near infrared transmittance spectroscopy has been used successfully to measure soluble solids in citrus fruit. However, for practical implementation, the technique needs to be able to compensate for fruit temperature fluctuations, as it was observed that the sample temperature affects the near infrared transmittance spectrum in a non-linear way. Temperature fluctuations may occur in practice because of varying weather conditions or improper conditioning of the fruit immediately after harvest. To develop the models several different NIR transmittance spectra were acquired for each fruit from a commercial supermarket. Different spectra correction algorithms (standard normal variate (SNV), multiplicative signal correction (MSC)) were used in this work. The relationship between laboratory SSC and FT-NIR spectra of citrus fruit were analyzed via principle component regression (PCR) and partial least squares (PLS) regression method using TQ 6.2.1 quantitative software (Thermo Nicolet Co., USA). Two techniques were found well suited to control the accuracy of the calibration models for soluble solids with respect to temperature fluctuations. The first, and most practical one, consisted of developing a global robust calibration model to cover the temperature range expected in the future. The second method involved the development of a range of temperature dedicated calibration models. The drawback of the latter approach is that the required data collection is very large. When no precautions are taken, the error on the soluble solids content reading may be as large as 4%brix.

6381-22, Session 5

Measurement of internal quality of watermelon by Vis/NIR diffuse transmittance technique

H. Tian, Zhejiang Univ. (China)

Watermelon is a popular fruit in the world. Sugar content (SC) and firmness (FM) are major characteristics used for assessing watermelon internal quality. This study was about a method for nondestructive internal quality detection of watermelons by means of visible/Near Infrared (Vis/NIR) diffuse transmittance technique. Vis/NIR transmittance spectra of intact watermelons were acquired using a low-cost commercially available spectrometer when the watermelon was in motion (0.14m/s) and in static state. Spectra data were analyzed by two multivariate calibration techniques: partial least squares (PLS) and principal component regression (PCR) methods. The influences of different data preprocessing and spectra treatments were also investigated. Performance of different models was assessed in terms of root mean square errors of calibration (RMSEC), root mean square errors of prediction (RMSEP) and correlation coefficient (r) between the predicted and measured parameter values. Results showed that spectra data preprocessing influenced the performance of the calibration models and the PLS method can provide the best results. The nondestructive Vis/NIR measurements provided good estimates of SC index and FM index of watermelon both in motion and in static state, and the predicted values were highly correlated with destructively measured values for SC and FM, respectively. The results indicated the feasibility of Vis/NIR diffuse transmittance spectral analysis for predicting watermelon internal quality in a nondestructive way.

6381-23, Session 5

Integrating fluorescence and reflectance measurements to improve apple maturity assessment

H. K. Noh, R. Lu, USDA Agricultural Research Service

The maturity of apples determines the time to harvest, which in turn influences the post-harvest quality of fruit. Apple maturity is assessed based on multiple quality parameters, including both external (color and size) and internal (firmness, sugar, acid, starch level). Recently fluorescence and reflectance have been researched as a promising tool for measuring fruit post-harvest quality and condition. In previous research, we proposed a technique of integrating spectral fluorescence and reflectance for measuring multiple fruit quality attributes. Fluorescence spectra were collected over a period of time until a steady state was reached. The integrated technique resulted in improved predictions of selected quality parameters compared to single sensing techniques. The objective of this research was to improve the integrated system so that both fluorescence and reflectance spectra could be acquired more rapidly and reliably. Rapid acquisition of fluorescence spectra was achieved via a computer controlled electric shutter, while a ring guide lighting was used for acquiring reflectance in interactance mode. Experiments were performed during the 2005 harvest season. ‘Golden Delicious’ apples were harvest over a period of four weeks. UV light induced fluorescence and reflectance spectra were measured from the apples within one day after harvest, using a visible/near-infrared spectrometer. Standard destructive tests were performed to measure multiple quality parameters including firmness, flesh and skin color, starch index, sugar and acid content from the apples. Principal component analysis (PCA) was applied to extract critical information from the reflectance and fluorescence data. PCA data were input into neural networks for

predicting individual quality attributes of apples. Integrating reflectance and fluorescence improved predictions of all parameters except flesh color; values for the correlation coefficient for firmness, soluble solids content, starch pattern index, and skin color were 0.77, 0.77, 0.89, and 0.99, respectively, with the corresponding standard error of 6.93 N, 0.90%, 0.97, and 0.01 rad. These results represented 4% to 100% improvements in terms of standard error, in comparison to the better results from the two single sensing methods. The method of integrating reflectance and fluorescence can provide a better means for assessing apple maturity/quality

6381-24, Session 5

NIR assessment of soluble solids and firmness for pears of different cultivars

X. Fu, Y. Ying, Zhejiang Univ. (China)

Development of nondestructive measurements of soluble solids and firmness, which are two important ripeness and quality attributes of fruits, benefits the producers, processors and packers. The objective of this research was to evaluate the use of near-infrared (NIR) spectroscopy in detecting soluble solids and firmness for pears of three cultivars 'Cuiguan', 'Xueqing' and 'Xizilv' (n=160 of each cultivar). Relationships between nondestructive NIR spectral measurements and firmness and soluble solids of pear fruits were established by partial least square regression (PLSR) method. Models were developed for each cultivar, every two cultivars, and for all three cultivars in the spectral range of 800-2500 nm. For soluble solids assessment: correlation coefficients (r), root mean standard errors of calibration (RMSEC) and root mean standard errors of prediction (RMSEP) were 0.91, 0.40, 0.55 for 'Cuiguan', 0.92, 0.28, 0.46 for 'Xueqin', 0.91, 0.28, 0.41 for 'Xizilv', 0.89, 0.39, 0.50 for 'Cuiguan' and 'Xueqin', 0.93, 0.28, 0.50 for 'Xueqin' and 'Xizilv', 0.92, 0.42, 0.56 for 'Xizilv' and 'Cuiguan', and 0.93, 0.35, 0.51 for all three cultivars, respectively. For firmness assessment: r, RMSEC and RMSEP were 0.88, 1.48, 2.52 for 'Cuiguan', 0.88, 1.87, 2.45 for 'Xueqin', 0.89, 2.44, 3.34 for 'Xizilv', 0.90, 1.60, 2.66 for 'Cuiguan' and 'Xueqin', 0.90, 2.86, 3.42 for 'Xueqin' and 'Xizilv', 0.91, 2.42, 3.10 for 'Xizilv' and 'Cuiguan', and 0.92, 2.15, 3.14 for all three cultivars, respectively. The results indicate that NIR spectroscopy can be used for predicting soluble solids and firmness of pear fruit and are the basis for the development of NIR analyzer suitable for on line application.

6381-25, Session 6

Fruit edge detection based gradient vector flow

J. Gui, Y. Ying, Zhejiang Univ. (China)

Applications of machine vision in automated inspection and sorting of fruits have been widely studied by scientists and engineers, and the promise of this technology for improving grading efficiency was proved. Before the grading fruits, the fruit edge detection is important. In this paper, gradient vector flow was used to detect fruit edge, which is computed as a diffusion of the gradient vectors of a gray-level or binary edge map derived from the image. The resultant field has a large capture range and forces active contours into concave regions. Promising results were obtained on experiments showing the efficiency and accurate of our algorithm

6381-26, Session 6

Hyperspectral reflectance and fluorescence line-scan system for on-line detection of fecal contamination on apples

M. S. Kim, B. Cho, Y. Chen, C. Yang, A. M. Lefcourt, K. Chao, USDA Agricultural Research Service

A prototype, fast line-scan hyperspectral imaging system integrated with a commercial apple-sorting machine was evaluated for rapid detection of animal feces matter on apples. Apples obtained from a local orchard were artificially contaminated with cow feces. For the on-line trial, hyperspectral images with 70 spectral channels, reflectance in the visible to near infrared regions and fluorescence emissions with UV-A excitation, were acquired from apples moving at a processing line speed of 3 samples per second. Reflectance and fluorescence imaging required passive light source, and each method used independent continuous wave (CW) light sources. In this paper, integration of the hyperspectral imaging system with the commercial apple-sorting machine and preliminary results for detection of fecal contamination on apples based on the reflectance and fluorescence methods are presented.

6381-27, Session 6

Development of video technology to analyze dynamics of inertia-based apple orientation

A. M. Lefcourt, USDA Agricultural Research Service; P. Narayanan, U. Tasch, R. Rostamian, Univ. of Maryland/Baltimore County; M. S. Kim, Y. Chen, USDA Agricultural Research Service

Development of machine vision systems to examine fruit for quality and contamination problems has been stalled due to lack of an inexpensive, fast, method for appropriately orienting fruit for imaging. We recently discovered that apples could be oriented based-on inertial properties. Apples were rolled down a ramp consisting of two parallel tracks. When sufficient angular velocity was achieved, the apples moved to a configuration where the stem/calyx axis was perpendicular to the direction of travel. This discovery provides a potential basis for development of a commercially-viable orientation system. However, many question remain concerning the underlying dynamic principles that govern this phenomena. An imaging system and software were constructed to allow detailed observation of the orientation process. Sequential 640x480 monochrome images are acquired at 60 fps and 1/500 sec exposure. The software finds the center of the apple in each image as well as the vertical movement of the track at a selected coordinate. Early tests revealed that the compliance of the track played a significant role in the orientation process. These data will be used to compare results from empirical tests with predictions of dynamic models.

6381-28, Session 6

Application of multispectral reflectance for early detection of tomato disease

H. Xu, Y. Ying, S. Zhu, H. Jiang, Zhejiang Univ. (China)

Automatic diagnosis of plant disease is important for plant management and environmental preservation in the future. The objective of this study is to use multispectral reflectance measurements to make an early diagnosis of symptoms in tomato plants at different stages of tomato mosaic virus (ToMV) infection. Chlorophyll degradation in the infected leaves could be detected by normalized phaeophytinization index (NPOI) using reflectance at visible region and there is a distinct decreasing of reflectance at near infrared (NIR) region in the infected leaves within 5 days after infection even though significant visible differences between the control and the infected plants were not noted until after 10 days. A discriminating model based on the NIR reflectance was developed and could correctly classify diseased and healthy plant with a success rate of 96%.

6381-29, Session 7

Hyperspectral waveband selection method: chicken tumor detection applications

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Detection of skin tumors on chicken carcasses is considered. A chicken skin tumor consists of an ulcerous lesion region surrounded by a region of thickened-skin. Chicken carcasses with skin tumors present a direct public health risk to consumers; they thus must be detected and removed from food processing lines at slaughter plants to prevent them from being sold to customers. Hyperspectral reflectance data of chickens has been shown to be useful for detection of tumors. We propose using a new adaptive branch-and-bound feature selection algorithm to choose only the few wavebands in hyperspectral data to use in a real-time multispectral camera. Since the spectral responses of the lesion and the thickened-skin regions of tumors are considerably different, we train our feature selection algorithm to separately detect lesion regions and thickened-skin regions of tumors. We then fuse the two HS detection results to reduce false alarms. Initial results show that our method gives an excellent tumor detection rate and a low false alarm rate.

6381-30, Session 7

Egg fertility detection with hyperspectral imaging

K. C. Lawrence, D. P. Smith, G. W. Heitschmidt, W. R. Windham, B. Park, USDA Agricultural Research Service

In the U.S., over nine billion brown broiler eggs and over 400 million white layer eggs are hatched per year with a hatching rate of around 80% - 90%. Currently the industry does not have a good means to identify and remove the unfertile eggs from the hatching cabinet. Moreover, there is a significant risk that unfertile eggs could contain pathogenic bacteria and can explode within the cabinet which has the potential to contaminate all the eggs in the cabinet. Thus, there is a need to discriminate fertile from infertile eggs as early as possible in the incubation process and remove them to prevent possible contamination.

Hyperspectral imaging was used to determine the fertility of both white and brown shell eggs. Intact eggs were back-illuminated and hyperspectral images from about 450 - 880 nm were collected for each egg at incubation days zero, one, two and three. These eggs were then broken out and visibly inspected to confirm fertility. For both white and brown shell eggs, hyperspectral data were able to detect the egg fertility around day two with brown-shell eggs being slightly more difficult to detect.

6381-31, Session 7

Detection of fecal/ingesta contaminants at slaughter plants from a number of characteristic visible and near-infrared bands

Y. Liu, Univ. of Maryland/College Park; K. Chao, Y. Chen, X. Nou, M. S. Kim, USDA Agricultural Research Service; C. Yang, Univ. of Kentucky; D. Chan, USDA Agricultural Research Service

USDA's Food Safety Inspection Service (FSIS) inspectors use the established guidelines to identify fecal remains at surfaces of equipment, utensils, and walls at slaughter plants. Certainly, the verification process is both labor intensive and prone to both human error and inspector-to-inspector variation. Therefore, researchers at the USDA Agricultural Research Service (ARS) have been developing hyper- and multi- spectral reflectance and fluorescence imaging techniques for the use in real-time on-line detection of fecal contaminants. One key factor in the successful applications is to have a few essential spectral bands, which not only reflect the chemical / physical information in the samples, but also maintain the successive discrimination and classification efficiency. Here, we first determined the characteristic bands from visible and NIR spectra of a set of chicken feces and ingesta samples as well as control ones (rubber belt and stainless steel), then we developed a number of algorithms to classify chicken feces / ingesta ("F/I"), as objectives, from rubber belt / stainless steel ("RB/SS"), as backgrounds. Meanwhile, both principal component analysis (PCA) and 2-class SIMCA (soft independent modeling of class analogy) models were used to examine the effectiveness of separation and classification. Results indicated that using ratio algorithms in the visible or NIR region could separate "F/I" objectives from "RB/SS" backgrounds with a success of over 97%.

6381-32, Session 8

Poultry carcass inspection by a fast line-scan imaging system: results from in-plant testing

K. Chao, Y. Chen, C. Yang, M. S. Kim, D. E. Chan, USDA Agricultural Research Service

Currently, each chicken intended for sale to U.S. consumers is required by law to be inspected post-mortem by a USDA/FSIS inspector for its wholesomeness. These inspectors visually examine the exterior, the inner surfaces of the body cavity, and the organs of each carcass for indications of diseases or defects. For effective inspection and occupational considerations, each inspector is limited to a maximum of 35 birds per minute. This current inspection system limits the production efficiency of processing plants that are seeking to satisfy increasing consumer demand for poultry products. One possible solution to this problem is for poultry processing plants to install on-line instrumental inspection systems that can accurately screen for wholesome carcasses. Inspectors then would only have to "re-inspect" questionable carcasses to insure that wholesome carcasses are not discarded. This approach would dramatically reduce the number of birds requiring human inspection. An obvious benefit of automatic poultry inspection would be improved overall production efficiency of the processing plants. The current study will describe a fast line-scan multispectral imaging system for poultry carcass inspection. In-plant testing of the automated poultry carcass inspection system is scheduled in June 2006 at a commercial poultry processing plant in Gainesville, GA.

Using such an automated inspection system would greatly improve overall production efficiency of processing plants.

6381-33, Session 8

Real-time multispectral imaging system for online application using UML

B. Park, K. C. Lawrence, M. Kise, W. R. Windham, USDA Agricultural Research Service; C. N. Thai, The Univ. of Georgia

The imaging research group of Russell Research Center in ARS has developed a prototype real-time multispectral imaging system for fecal and ingesta contaminant detection on broiler carcasses. The prototype system includes a common aperture camera with three optical trim filters (517, 565 and 802-nm wavelength), which were selected by visible/NIR spectroscopy and validated by a hyperspectral imaging system with decision tree algorithm. The camera, lighting, and electronic control systems were assembled in a transportable NEMA4 stainless enclosure for harsh environments in poultry slaughter house. The on-line testing results showed that the multispectral imaging technique can be used effectively for detecting feces (from duodenum, ceca, and colon) and ingesta on the surface of poultry carcasses with a processing speed of 140 birds per minute. The accuracy for the detection of fecal and ingesta contaminates was over 93% with moderate false positives including scabs, feathers, and boundaries. The objectives of this paper are to demonstrate both multispectral imaging hardware and real-time image processing software. For the software development, the Unified Modeling Language (UML) design approach was used for on-line application. The UML is specification language used in software engineering for object-oriented programming. UML includes a standardized graphical notation that may be used to create an abstract model of a system for system modeling. The UML models including class, object, activity, sequence, and collaboration diagram will be discussed. The test results of both hardware and software for real-time contaminant detection at the pilot-scale poultry processing plant prior to in-plant trials will also be discussed for system evaluation.

6381-34, Session 8

Stereovision-based multispectral imaging system for contaminant detection on poultry carcasses

M. Kise, B. Park, K. C. Lawrence, W. R. Windham, USDA Agricultural Research Service

Food safety in the poultry industry, especially small plants is ongoing problem. Several deaths occur each year from public consumption of contaminated poultry and/or meat. Potential contamination can occur when feces or ingesta is deposited on the surface of the carcass. Identification and separation of the birds contaminated by feces is very important to protect the consumer from a potential source of food poisoning.

The current method of inspecting fecal contamination is through human visual observation with the criteria of color, consistency, and composition used for identification. Therefore, there is a need to develop science-based instrumentation which can reduce inspector fatigue, variability, insure continuous inspection, and provide a safe poultry food supply for the consumer.

The objective of this research is to design and fabricate a compact multispectral instrument and to collect and analyze spectra for real-time contaminant detection for small poultry processing plants. It was revealed by our previous research that the fecal contamination on the surface of the poultry carcass could be detected by sensing the spectral reflectance of the surface in two specific color channels, namely 515 and 565nm. The core of the prototype system developed in this research consists of two identical monochrome cameras with a narrow band-pass filter whose center of the wavelength are 515 and 565 nm, respectively, installed in front of the sensor of each camera.

Two images in those spectral channels are acquired simultaneously and then registered by using stereovision technique to form a two-spectral image. The prototype system was tested in the actual environment and showed that it could effectively detect feces and ingesta on the surface of poultry carcasses.

6381-35, Session 8

Development of online line-scan imaging system for chicken inspection and differentiation

C. Yang, K. Chao, Y. Chen, M. S. Kim, D. E. Chan, USDA Agricultural Research Service

An online line-scan imaging system was developed for differentiation of wholesome and systemically diseased chickens. The hyperspectral imaging system used in this research could be directly converted to multispectral operation and would provide the ideal implementation of essential features for data-efficient high-speed multispectral classification algorithms. The imaging system consisted of an electron-multiplying charge-coupled-device camera and an imaging spectrograph to scan lines. The surfaces of chicken carcasses were scanned on an eviscerating line from the poultry processing plant in 2005. From the difference spectra between wholesome and systemically diseased chickens, the wavelengths where the greatest differences were observable were selected as the key wavelengths; and where the greatest spectral reflectance and the low reflectance difference were observable was selected as the reference wavelength. The ratio of relative reflectance between each key wavelength and the reference wavelength was calculated for algorithm inputs. The algorithm was developed to obtain the decision output for each pixel. The outputs from the region of interest in a carcass were averaged to represent the chance for the carcass to be systemically diseased. The result shows a very high confidence in applying the imaging system to online identification of systemically diseased chickens. With proper selection of key wavelengths and image features, the algorithm could accurately differentiate systemically diseased chickens from wholesome ones. This hyperspectral imaging system can operate as a multispectral imaging system without the need of cross-system calibration. The high-speed imaging and satisfactory results from the proposed line-scan imaging system show significant benefits for online inspection applications.

6381-36, Poster Session

Heating effects on optical scattering properties in beef muscles

J. Xia, Univ. of Missouri/Columbia; A. Weaver, D. Gerrard, Purdue Univ.; G. Yao, Univ. of Missouri/Columbia

Our recent studies indicated that the optical scattering has the ability to characterize the micro structures in beef muscles. In this study, optical scattering spectra of beef Semitendinosus and Psoas major muscle samples were measured at different cooking temperatures along with the corresponding Warner-Bratzler shear force values. Overall, scattering coefficients increased first and then decreased. The increase was suggested to be induced by the denatureation of myosin and the thermal-stable collagen cross links depending on the temperature ranges; while the decrease was thought to be caused by the gelatinization of thermal-labile collagen cross links. The collagen content and the relative proportionality of the thermal-stable and the thermal-labile collagen cross links could affect the relative changes of the scattering coefficients from temperature to temperature. Our results indicated that the optical scattering can indeed reflect the states of the micro structures in beef muscles and have the potential to be used as an indicator for beef quality prediction.

6381-37, Poster Session

A fast ellipse detection algorithm for multiple rice seeds images

F. Cheng, Y. Ying, Zhejiang Univ. (China)

With increased expectations for seeds of high quality and safety standards, the need for accurate, fast and objective quality determination of these characteristics in grain continues to grow. Computer vision provides one alternative for an automated, non-destructive and cost-effective technique to accomplish these requirements. Rice production is dominant in south of China. This inspection approach based on image analysis and processing is adopting for the quality inspection of rice seeds. A fast and robust ellipse detection algorithm is needed for automation applications area. Hough transformation is valid for ellipse detection, but the algorithm needs huge computation. We describe an algorithm for the detection of ellipse shapes in multiple rice seeds images. The method is compared with Hough-based algorithm. Tests are performed using both noise-free and noisy images. The algorithm was found to give improvements in accuracy, and a reduction in computation time.

6381-38, Poster Session

Early detection of plant disease using infrared thermal imaging

H. Xu, Y. Ying, S. Zhu, H. Jiang, Zhejiang Univ. (China)

By using imaging techniques, plant physiological parameters can be assessed without contact with the plant and in a non-destructive way. During plant-pathogen infection, the physiological state of the infected tissue is altered, such as changes in photosynthesis, transpiration, stomatal conductance, accumulation of Salicylic acid (SA) and even cell death. In this study, these alterations in tomato leaves infected by tomato mosaic virus (ToMV) were recorded by LI-6400 Portable photosynthesis system. Results from these hypersensitive responses (HR) were change in leaf temperature. Thermal imaging monitored an early change in leaf temperature at the points of ToMV-infection before the appearance of visible necrosis on leaves.

6381-39, Poster Session

Geometrical calibration of a combined x-ray and laser system

F. Jin, H. Jing, L. Qin, T. Yang, Univ. of Maryland/College Park

Detection of bone fragments and other physical contaminations in deboned poultry meat has become increasingly important to ensure food quality and safety. Traditional X-ray imaging detection technologies have significant difficulties in detecting contaminations because of the meat tissue thickness variation. In order to address this problem, a laser 3D subsystem is added to provide depth information from the laser 3D image. The depth information will be further combined with the X-ray image to achieve accurate contamination detection. In this combined system, a set of CCD cameras are used to get accurate thickness profile for each piece of meat and an X-ray line-scan camera is used to capture high resolution X-ray image in real time. A unique three-step calibration procedure is proposed to make these two kinds of cameras work properly. In the first step, the CCD camera is calibrated to link the CCD pixels to points in 3D world coordinate system. Secondly, the X-ray line-scan camera is calibrated to link points in 3D world coordinate system to the X-ray line sensors. The X-ray fan beam effect is also compensated in this stage. Finally direct mapping from CCD pixel to X-ray line sensor is realized using the information from the first two calibration steps. Based on the calibration results, look-up tables are also generated to replace the runtime computation. Experiments show that RMS (root mean square) error of the whole system can be as good as 0.2mm.

6381-40, Poster Session

A near-infrared diffuse reflection type measuring system for chlorophyll content of tomato leaves

H. Jiang, Y. Ying, Zhejiang Univ. (China)

In this study, a measuring system for chlorophyll content of tomato leaves is developed based on near-infrared spectral techniques. The system mainly consists of a FT-IR spectrum analyzer, optic fiber diffuses reflection accessories and data card. Diffuse reflectance of intact tomato leaves was measured by optics fiber and calibration models were developed from spectral and constituent measurements. 80 samples served as the calibration sets and 40 samples served as the validation sets. Partial least squares (PLS) technique was used to develop the prediction models by different data preprocessing. The best model for chlorophyll content had a high correlation efficient of 0.973 and a low standard error of prediction SEP of 2.21 when we select full range (800-2500nm), 3 points for spectrums smoothing and spectrums by first derivative. The results of this study suggest that FT-NIR method can be feasible to detect chlorophyll content of tomato leaves rapidly and nondestructively.

6381-42, Poster Session

Laser scatter feature of surface defect on apples

X. Rao, Y. Ying, Zhejiang Univ. (China)

A machine vision system for real-time fruit quality inspection was developed. The system consists of a chamber, a laser projector, a TMS-7DSP CCD camera (PULNIX Inc.), and a computer. A Meteor-II/MC frame grabber (Matrox Graphics Inc.) was inserted into the slot of the computer to grab fruit images. The laser projector and the camera were mounted at the ceiling of the chamber. An apple was put in the chamber, the spot of the laser projector was projected on the surface of the fruit, and an image was grabbed. Each was imaged twice, one was imaged for the normal surface, and the other for the defect. The red component of the images was used to get the feature of the defect on the fruits. The average value, STD value and comentropy Value of red component of the laser scatter image of a fruit can be used to separate the normal and the defect surface of the fruit.

6381-44, Poster Session

Egg weight detection on dynamic machine vision system

Y. Cen, Y. Ying, X. Rao, Zhejiang Univ. (China)

A dynamic machine vision system for egg weight detection was developed, which could improve to sort eggs into different weight categories. For each egg on deferent belt, the dynamic image was grabbed with a CCD camera and a frame grabber, and its external surface quality information was collected. An indicator composed of every pixel's R, G, B intensities was used for image segmentation. Taper Curve Edge Approach (TCEA) was developed to detect the size of egg based on the egg edge extracted before. The size of the egg's vertical diameter and maximal horizontal diameter were obtained using the TCEA computer program. A regression model between the egg's weight and its size of vertical diameter/maximal horizontal diameter was established based on SAS, which was used to evaluate egg's weight. The test results demonstrated that, for egg weight detection in the dynamic machine vision system, the absolute error was no more than 2 g, which showed that the automation of the egg real-time grading process was feasible and its benefits would be lower work load on human graders and an increased flexibility in the egg quality control process.

6381-45, Poster Session

Rapid analysis of sugar content of intact orange fruit using ultraviolet and visible transmittance techniques

Y. Liu, Jiangxi Agriculture Univ. (China); Y. Ying, Zhejiang Univ. (China)

Some issues of rapidly measuring the sugar content and the characteristics of the transmittance spectra of the orange juices were investigated in the spectra range of 200-800 nm using Ultraviolet and Visible (UV-VIS) spectrophotometer. PLS calibration technique were used to create calibration models and the performance of calibration models using different spectra measurement factors were also compared by Matlab 7.0 software. The prediction ability of the models was evaluated on fruit juices and compared with laboratory chemical analysis method. Calibration models generated from transmittance spectra gave the best performance with the correlation coefficient of determination (R2) of 0.90% and standard error of prediction (SEP) of 0.56 %that accurately and precisely predicted the soluble solids levels in juices when the five elements regression were used and the wavelength range of 400nm-800nm. Based on the results, it was concluded that UV-VIS spectroscopy technique would be use to the rapid, accurate and non-destructive analysis of soluble solids content in intact orange fruit and could be applied in quality control of fruits.

6381-46, Poster Session

Imaging processing technique to measure plant infection severity

S. Zhu, Y. Ying, H. Xu, H. Jiang, Zhejiang Univ. (China)

Imaging techniques give us an immediate way to detect the plant healthy situation without destructing the plant tissue. When plants recognize the attacking virus, they can generate a hypersensitive response. The plant physiological state of the infected site will alter. The infection sites appear as "necrotic spots" which caused plant-pathogen interaction and it changes in a specifically way. In our research, color feature, morphological feature and area feature of these "necrotic spots" were extracted by imaging processing technique. And the plant damage severity was determined by this way. Imaging processing technique could detect different severity level (SL) of plant disease with a good accuracy.

6381-47, Poster Session

Effect of biological variability on the robustness of FT-NIR models for soluble solids content of oranges

Y. Liu, Jiangxi Agriculture Univ. (China)

A statistical analysis was performed on a large spectral data set to analyze the effect of orchard, season and cultivar and the results for fruit FT-NIR spectroscopy have been obtained employing the variance analysis. Season and cultivar were responsible for a major amount of the spectral variability, whereas the influence of the orchard was low and only appeared for certain cultivars during specific seasons. The robustness of the calibration models for sugar content with respect to the three factors was tested based on external validations. It was found that the accuracy of the models increased considerably when including more variability in the calibration set. Further, over-fitting of the calibration model was avoided. On the other hand, adding more data to the calibration set increased the chance of adding a typical data, which resulted in reduced model accuracy. It is, therefore, important to construct the calibration data set in such a way that it is representative for future measurements. When the effect of a certain factor is known a prior, e.g. cultivar, it is recommended to use specific calibration models

6381-48, Poster Session

Design and validation of the real-time determination software for soluble solids content estimation of juicy peach by visible/near infrared spectroscopy

M. Jiang, Y. Ying, H. Lu, Zhejiang Univ. (China)

visible/near infrared spectroscopy on-line determination had been widely used in agricultural products and food samples non-destructive internal quality determination.This research proposed to design a real-time determination software in order to estimate soluble solids content (SSC) of fruit on line.Functions of the software included real-time spectroscopy pre-processing,real-time spectroscopy viewing,model building,soluble solids content (SSC) estimating,etc. In addition, Fenghua juicy peaches were used to validate the practicability and the real-time capability. And SSC of the peaches were predicted by the software on line. The research provided some help to the real-time non-destructive internal quality determination of the fruit. As the important part of the real-time determination, the determination method and technology were fully accordance with the need at real-time and model's precision.

6381-49, Poster Session

Influence of humidity on spectral performance for near-infrared detection of fruit

Y. Zhou, Y. Ying, Zhejiang Univ. (China)

Near infrared (NIR) spectroscopy is a rapid and nondestructive method for quality detection of various products. Spectral performance would be affected by many factors such as temperature, equipment parameters and so on. It has been proved that NIR reflectance spectroscopy is sensitive to the moisture content of the detected object. Humidity fluctuations may occur in practice because of varying weather conditions. The objective of this research was to establish an airproof, humidity-controllable test-bed to investigate the influence of humidity on spectral performance during the process of NIR detection. Because of the absorption of the vapor in the air in NIR region, the spectral result changed with the humidity of the environment. The result of this study shows that humidity compensation for NIR measurement is necessary and effective to improve the accuracy.

6381-50, Poster Session

Fragrant pear sexuality recognition with machine vision

B. Ma, Y. Ying, Zhejiang Univ. (China)

An algorithm for the automatic recognition of kuler fragrant pear was eveloped.

There are shape differences between male pears(undetached calyx) and female pears(detached).. In this research, color feature, shape feature and area feature of these “fragrant pear bottom “ were extracted by imaging processing technique. And the fragrant pear sexuality was determined by BP net Result shows this way could detect male pears and female pear with a good accuracy.

6381-51, Poster Session

MEMS-based spectrometers and how they work

M. Ramani, Polychromix, Inc.

This paper introduces a new technology that enables low cost, small footprint spectrometers to be developed without the high costs imposed by the InGaAs detector arrays. The new systems, known as DTS systems, feature a unique MEMS-based component that enables a spectrometer to be built featuring a standard, single element detector.

The DTS system is a modified monochromator style of system, where the diffraction grating is fixed, and instead of a mechanical scanning device, the individual wavelengths that are separated within the monochromator are uniquely encoded. In this method, the operating wavelengths are separated by a diffraction grating and the image of these separated wavelengths is projected on a MEMS-based component that modulates the wavelengths. The modulated wavelengths are recombined and imaged on a single element detector, as shown in Figure 1. The resultant signal is digitized and transformed into usable spectral data.

6381-52, Poster Session

Computational analysis of Pelton bucket tip erosion using image processing

B. P. Shrestha, S. K. Suman, M. Adhikari, P. Manandhar, Kathmandu Univ. (Nepal)

Theoretically, the top thickness of the Pelton bucket splitter used in hydropower plants should be zero. However due to subsequent erosion from sand particles, the thickness of the splitter increases causing loss in efficiency by back hitting of the water. It has been reported that ‘When the thickness of the splitter increases to 1 percent of the bucket width, the drop in relative efficiency at full load is 1 percent.’

Traditionally, micro-meter screw gauge is used to measure the tip thickness. The splitter is a wedge-shaped structure with zero (theoretical) thickness at the top and thickness increases as we go down the cross-section. Due to its peculiar shape, the conventional methods of measurement are often erroneous.

In this work, the experiment is carried out to measure splitter tip of pelton bucket using image processing. The image of the runner is grabbed with the help of Sony XCHR70 CCD camera and the thickness is measured counting calibrated pixels in MATLAB 7.0 platform and MATROX imaging library. It was found that the imaging technique used for estimating bucket tip erosion results higher degree of accuracy.

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6382-01, Session 1

Recent trends in white-light interferometry

K. Kitagawa, Toray Engineering Co., Ltd. (Japan)

1. Introduction

The technique of surface profile measurement utilizing optical interference is widely used in industry as a non-contact and non-destructive method to quickly and accurately measure the profile of microscopic surfaces. However, it has some shortcomings such as (1) slow measurement speed; (2) poor accuracy in case of white-light interferometry; and (3) error caused by a transparent film on the surface.

To solve these problems, we can now use much more sophisticated algorithms, which would have been impractical ten years ago, thanks to the recent rapid advances in electronics and computer technology. As a result, far more effective commercial products are now possible.

This paper introduces some of such developments in white-light interferometry.

2. Speed Improvement by Sub-Nyquist Sampling

We have developed a new signal processing technique, named SEST. This algorithm is based upon the fact that the interference fringe waveform can be reconstructed from sub-Nyquist sampled data by using the sampling theorem for band-pass signals. We have developed a generalized sampling theorem that reconstructs the square envelope function of the interferogram directly from its sampled values. As a result, the number of sample points required can be reduced to one-tenth of that of the conventional method. To make this algorithm effective, a narrow-band interference filter is used in the illumination. The utilization of this algorithm has led to the world's fastest scanning speed of over 50 um/sec, which is seven (7) to fifteen (15) times faster than with conventional algorithms.

3. Accuracy Improvement by Using Phase Information

Most of the conventional WLI profilers detect the envelope peak of the interferogram. But we can improve the measurement accuracy by using the phase information, too. This technique, sometimes called WLPSI, at first finds the envelope peak frame, and then calculates the relative phase at the position. Although this theoretical possibility has been known for a long time and has been expected to have both advantages of VSI and PSI methods, its practical use was not accomplished until recently, probably because of its weak robustness. We have developed an algorithm for this technique, and have found that it provides about ten (10) times better accuracy than the conventional VSI method.

4. Profiling of a Thick Transparent Film

We have developed an algorithm, named KF, which can automatically detect the positions of two contrast peaks in an interferogram generated by vertical scanning interferometry. This algorithm at first calculates the interference amplitudes from interferogram. Then the optimal threshold for peak separation is obtained using Otsu's automatic threshold selection method in the field of image processing. From the peak positions determined for each of the separated peak regions and the known refractive index of the film, the surface height, the back surface height and the film thickness are obtained. Using this algorithm, we have developed a non-contact Film Profiler SP-500F. Oxide films with 0.5-2 microns thickness on a Si wafer were measured, and the minimum measurable thickness was found to be about 0.8 microns.

This development enables the following measurements, which would have been difficult using conventional methods:

(1) Profiling of a surface covered with a transparent film,

(2) Profiling of a bottom surface through a transparent film, and

(3) 2D measurement of film thickness distribution.

5. Profiling of a Thin Transparent Film

When the film becomes very thin, the KF algorithm cannot be applied any more due to the overlap of two interference peaks. To solve this problem, we have pursued several approaches, and finally developed an algorithm, named NF, which is robust enough to be practically used in industry.

Oxide films with 0-2,000 nm thickness on a Si wafer were measured, and the minimum measurable thickness was found to be about 50nm. The repeatability (1 sigma) of the film thickness measurement is within 0.5nm.

6. Conclusions

Thanks to the recent rapid advances in electronics and computer technology, we can incorporate newly developed, sophisticated algorithms in the interferometric profiler, with dramatic results. The future is bright. I'd like to say that 'the 2nd generation of interferometry' has begun.

6382-02, Session 1

Toward on-line non-contact roughness profile measurements with a sensor based on conoscopic holography: current developments

I. Alvarez, J. Marina, J. M. Enguita, C. Fraga, R. Garcia, G. Ojea, Univ. de Oviedo (Spain)

On-line non-contact roughness metrology is still an open problem. Usual methods involve either contact (stylus-type devices) or perform indirect evaluations of some roughness parameters, such as Ra, with light scattering techniques or speckle measurement (among the most common optical techniques), inductance (only for magnetic materials) or ultrasound methods. However, a generic method able to obtain every roughness parameter (what means recording the real distance profile), able to work with a variety of surface types, and able to be installed in production lines is still to be developed.

In this paper, the ongoing work towards the construction of a non-contact optical profile measuring sensor with sub-micron precision that could be used for roughness measurements is presented. Our approach is based on conoscopic holography, an interferometric technique that offers relatively high precision measurements with a wide range of working distances while keeping a very simple setup and being robust against vibrations and air turbulence as it is common-path interferometry. These characteristics make it a good choice for industrial applications where the environment is adverse.

Even if, in theory, this technology can work with incoherent illumination (as the interfering waves are two polarisations that come from the same original ray), all the actual devices use laser as active illumination, usually projecting either a small spot or a thin line over the inspected specimen. The use of a coherent light source results in the appearance of high amounts of speckle noise, which affects the quality of the obtained fringe patterns, reducing accuracy and preventing the use of these systems for accurate sub-micron measurements from safe distances. Moreover, speckle is generated by the roughness topography that has to be measured, so the noise is in the range of the measurements to be obtained.

This paper shows current research towards enhancing accuracy in these systems, by both reducing the coherence of the illuminating source and changing the hardware and software setup, with the aim of building a sensor able to capture a profile of an object's surface in a single shot with sub-micron precision from a relatively long standoff (several cm). This way it could be possible directly calculate roughness parameters from distance measurements in on-line applications.

In order to perform an in-depth study with real data, a prototype of such an interferometer has been built, including a reduced speckle linear laser source and a small triangulation.

The obtained fringe pattern can be recorded by a digital camera, where the phase of the fringes relates to the distance profile from the sensor to the specimen. Resolutions in the range of 4.6 microns (measured as the 95% confidence interval) for 300 mm standoff have already been obtained. Theoretical and experimental studies show a linear variation

of the resolution with the stand-off, provided that the adequate optic elements are also scaled.

6382-03, Session 1

Chromatic confocal and two-photon imaging

K. Shi, S. Nam, P. Li, S. Yin, Z. Liu, The Pennsylvania State Univ.

We present 3D surface measurement result of a high-performance chromatic confocal microscope, which is implemented by using white light supercontinuum generated from a nonlinear photonic crystal fiber, and compare it with that obtained by a commercially available Stylus instrument. In addition, theoretical calculation is performed to analyze and optimize the system performance. Next, we show that the chromatic imaging idea can also be extended to two-photon excited fluorescence imaging by chromatically dispersing or aberrating the incoming femtosecond laser pulses. As a result, different wavelengths of the femtosecond pulses are used to excite fluorescence at different locations through two-photon absorption. Preliminary two-photon imaging results will be shown. Finally, we present analysis of focusing ultra-short laser pulses by a Fresnel lens and calculate the spatial-temporal field distribution near the focal point. The chromatic two-photon imaging techniques can be potentially used to monitor fast biological processes.

6382-04, Session 1

White-light geometric phase interference microscopy for mapping complex microsurfaces

M. Roy, The Univ. of Sydney (Australia); C. J. R. Sheppard, National Univ. of Singapore (Singapore); P. Hariharan, The Univ. of Sydney (Australia)

An area of increasing importance in machine vision is the development of noncontact techniques for rapidly and accurately mapping micromachined surfaces. Interferometric profilers using monochromatic light offer excellent vertical resolution, but a serious limitation to their use is 2pi * phase ambiguities that arise if the measurement range involves a change in the optical path difference greater than a wavelength.

One way to overcome the problem of ambiguities is by using white light. Because of the low coherence length of the illumination, interference effects are observed only over a very limited range of depths. As a result, a three-dimensional image can be extracted by scanning the object in depth and locating the position corresponding to maximum fringe visibility for each pixel in the image. Various digital filtering techniques have been used to recover the fringe visibility curve; they tend to be numerically intensive. An alternative method is based on phase shifting. Phase shifting is traditionally performed with laser illumination, and with a broad-band source a problem is encountered in that the phase shift of the different spectral components, when reflected from a mirror, varies. This problem has been overcome by performing geometric phase shifting in which polarization components are used to effect an achromatic phase shift. We have developed a computer-controlled white-light interferometric microscope based on ferro-electric liquid crystals, which can rapidly and accurately map the shape of micro-machined surfaces exhibiting steps and discontinuities.

6382-05, Session 1

White light displacement sensor by spectro-polarization modulator

Y. Otani, D. Orlov, T. Wakayama, N. Umeda, T. Yoshizawa, Tokyo Univ. of Agriculture and Technology (Japan)

We propose a white light displacement sensor using a novel spectro-polarization modulator which generates spiral liner polarized light sorted along wavelength concentrically. It consists of a polarizer, a retarder with high order retardation, and a quarter wave plate. If we set the spiral polarizer after the spectro-polarization modulator, we can observe spectroscopic color concentrically. A displacement measurement method is proposed using chromatic aberration method and white light interferometer.

6382-07, Session 2

Machine vision method for online surface inspection of easy open can ends

P. Marino, V. Pastoriza, M. Santamaría, Univ. de Vigo (Spain)

In the food canning sector, for the easy open can end manufacturing process, a manual, non-destructive testing procedure is carried out to guarantee can end repair coating quality. This surface inspection is based on a visual inspection made by human inspectors. Due to the high production rate (100 to 500 ends per minute) only a small part of each lot is verified (statistical sampling), then an automatic, inline, inspection system, based on machine vision, has been developed to improve this quality control.

In this work, the machine vision system algorithm is presented. This algorithm has the following steps: 1) can end image acquisition; 2) evaluation, that is divided into: a) can end centre location and orientation to put de region of interest (ROI), b) the ROI is converted into a look-up table (LUT), c) the repair coating quality (RCQ) of each LUT column is evaluated via a fuzzy system that uses as inputs: the maximum pixel intensity, the standard deviation of pixel intensity and the centre of mass of such column, d) the can end RCQ is computed as the average value of LUT column RCQ; 3) decision, the can end is rejected if its RCQ is lesser than a prefixed threshold value.

This surface inspection system checks the total production, classifies the ends in agreement with an expert human inspector, supplies interpretability to the operators in order to find out the failure causes and reduce mean time to repair during failures, and allows to modify the minimum can end repair coating quality.

6382-08, Session 2

Optical crack following on tunnel surfaces

G. Paar, M. d. P. Caballo-Perucha, Joanneum Research (Austria); H. Kontrus, DIBIT Messtechnik GmbH (Austria); O. Sidla, Joanneum Research (Austria)

Observation and inspection of concrete surfaces are necessary for the maintenance and security of tunnels. These tasks allow the recognition and detection of changes and artefacts in the concrete surface that threat and deteriorate tunnels surfaces and allow water intrusion, destabilize the static framework and may cause harmful loss of material. One of the most important monitoring tasks of tunnel inspection is the observation of cracks. Current practical techniques that can detect cracks in concrete use acoustic impact, infrared thermography, ground penetrating radar, as well as human vision based on-site methods.

This paper describes an approach for crack following based on the processing of mid-resolution (2-5mm per pixel) images of the tunnel surface. A mosaic on the basis of the tunnel design surface is built from images taken with a mobile platform. On this image representing the unwrapped tunnel surface texture the starting points of cracks are found semiautomatically using a modified Hough transform. Crack following takes place on the basis of local line fitting and exhaustive search in both directions of the crack, taking into account several restrictions, rules and optimization criteria to find the correct crack trajectory. A practical implementation polygonizes the extracted cracks and feeds them into a tunnel inspection data base. The method is applicable to various types of background texture as expected in the tunnel environment.

6382-09, Session 2

Optical inspection of holes in jet engine blades

D. Shetty, T. A. Eppes, Univ. of Hartford

The need for improved engine efficiency of jet engines has led to changes in the design of combustor turbine blades. By operating at higher exit temperatures and pressure levels, combustors can achieve improved efficiency and reduced fuel consumption. Modern turbine stage inlet temperatures now exceed the melting point temperatures of turbine blade materials. Super alloys, based on nickel, have been developed for use as blades, guide vanes, afterburners etc.

To combat and avert turbine blade failure caused by excessive operating temperatures, film cooling has been incorporated into blade design. In film cooling, cool air is bled from the compressor stage,

ducted to the internal chambers of the turbine blades, and discharged through small holes in the blade walls. This provides a thin, cool, insulating blanket along the external surface of the turbine blade. Large numbers of shaped holes have allowed designers to maximize the cooling effect.

Much research in recent years has been focused on improving the manufacturing cost and quality of laser-drilled holes. At present, it is necessary to inspect components for defects commonly associated with laser drilling such as taper, barreling, presence of recast layers and micro-cracks. One inspection process involves manual inspection for the cooling holes to ensure that a hole penetrates to the inner chamber. Although this process is near error free, it is very labor intensive.

This paper explores a new design for inspecting turbine blade cooling holes. In the paper, we examine the inspection techniques currently in use and present a novel optical technique as an alternative. Our design consists of two stages of inspection, each optically based. The first stage uses a camera positioned axially in line with a laser beam. A sample is mounted on an XY micro-positioning stage, and a vision system captures an image of the sample and displays the size and shape of each entrance hole. To measure the presence of a bottom, a second XYZ inspection stage is used. Using a small collimating tube, a micro-beam illuminates a drilled hole in a programmed fashion. Depending on the level of reflected intensity and where it occurs, the presence of a bottom is determined. The optical inspection system consists of a laser, motorized micro-positioning stages, collimating tubes, vision system, data acquisition software and a customized fixture for manipulating the samples.

6382-10, Session 3

3D vision methods and selected experiences in micro and macro applications

H. Hügli, Univ. de Neuchâtel (Switzerland)

No abstract available

6382-11, Session 3

Passive range measurement through wavefront coding

S. A. Lis, LightLine Technologies, Inc.

By the introduction of a simply designed phase mask at the pupil of a conventional imaging system, the range to objects in view can be precisely determined. The mask allows for roughly 50% light transmission, and is segmented to introduce a 1⁄4 wave phase shift into half of the transmitted light. The resulting point spread function is highly sensitive to object range and is incorporated into the resultant image. Through comparison of the wavefront coded image with a conventional image of the same scene, the precise range to the object can be determined. The range measurement precision obtained is directly related to image contrast. For objects having a simple linear edge possessing a contrast of 32 gray levels above noise, range can be measured to 1% precision.

While based on an interference effect, wide-band polychromatic light can be used to determine object range. No actively moving components in the optical system are required for operation. The resultant approach allows for simultaneous imaging and range determination simultaneously. Based on a fundamental interference phenomenon, this approach is applicable to all passive optical imaging systems ranging from the UV to the infrared. Both a theoretical analysis and an experimental verification of the approach showing the expected performance is provided.

6382-12, Session 3

Regularization of the deflectometry problem using shading data

J. Balzer, S. Werling, Univ. Karlsruhe (Germany)

Reconstructing a specular surface from observation of structured illumination is mathematically a severely ill-posed problem. A previous contribution discussed the close relationship of Shape-from-Shading and the deflectometry problem and how classical solving techniques could be employed with the task at hand. Consequently, a novel regularization approach for partially diffuse objects is elaborated in this paper. By recording a sequence of coded illumination patterns over the mirror surface, the pixel correspondence between camera and pattern generator is established. In a second step, the pattern generator is operated as a point source, stimulating diffuse reflection properties of the surface. Introducing the so-called deflectance mapping, we achieve a decoupling of sensitivity of deflectometric measurement with respect to surface height. It is joined by the reflectance mapping of Shape-from-Shading in an objective functional. Subsequently, variational considerations lead to an optimization problem which can be solved pointwise. We give a rigorous prove for existence and uniqueness of a solution when portions of Lambertian reflection are considered in addition to deflectometric data, i. e. convergence of the numerical algorithm will be guaranteed. Special attention is paid to the case of a distant point source where illumination is quasi-parallel. An outline of suitable solution procedures - such as CG methods for the general case and monotonous approximation schemes for the latter - is followed by a presentation of experiments based on real and synthetic data that justify the method.

6382-13, Session 3

Edge profile measurement and its enhancement using stereovision

Q. Hu, K. G. Harding, D. Hamilton, GE Global Research

Edge profile measurement is critical in blade manufacturing due to the stringent requirements on aerodynamic performance of blades. Optical metrology techniques provide very good tools in terms of speed and accuracy, but face some challenges as well, such as discontinuity, irregularity, and size variation in the edge shape, etc. This paper presents a method that uses stereovision technique to capture the edge profile. Two cameras are used to view the edge from different directions. The captured images are processed to obtain the profile. In this paper, different illumination methods were investigated and some enhancement techniques like pixel matching and pixel interpolation were also discussed. Different edges were measured. Comparison with the model shows that stereovision is a practical technique in obtaining accurate edge profile.

6382-14, Session 3

Inner profile measurement of pipes and holes using a ring beam device

T. Yoshizawa, Saitama Medical Univ. (Japan); M. Yamamoto, Softron Corp. (Japan); T. Wakayama, Saitama Univ.

Many trials have been proposed to measure inner diameter of pipes, however most of them are classified into contact methods with any kind of stylus.

Here we propose to measure inner diameter and profile of a pipe using a ring beam device which consists of a conical mirror. and a LD. The beam form the LD is directed to the top of the conical mirror which is precisely angled and polished and forms a l ring (ring beam) to make an optical sectioning of an inner wall. This optical section is calculated into the inner diameter and profile. In addition to pipes such as water mains, engine blocks for automobiles are tested to know the inner size of cylinders and to check defects of inner surfaces.

6382-15, Session 3

Depth-from-defocus: blur equalization technique

T. Xian, M. Subbarao, Stony Brook Univ.

A new spatial-domain Depth-from-Defocus (DFD) technique named Blur Equalization Technique (BET) is presented. The theoretical basis of BET relies on equalizing the blur or defocus of two different images recorded with different camera parameters. In contrast, comparable spatial-domain techniques rely on equalizing the deblur or focus of the two images. Also, BET facilitates modeling of images locally by higher order polynomials with lower series truncation errors. These differences seem to make the new technique very stable and accurate, even for low contrast objects with high levels of blur over a wide range of object distances. The accuracy of BET is further enhanced by discarding pixels with low Signal-to-Noise ratio by thresholding image Laplacians, and relying more on sharper of the two blurred images in estimating the blur parameters. These steps, combined with careful calibration for

sensor response, vignetting, and magnification correction, makes BET a very accurate and robust technique useful in practical applications such as depth recovery and autofocusing. BET is found to be superior to some of the best comparable DFD techniques in a large number of both simulation and actual experiments. Actual experiments used a large variety of objects including very low contrast digital camera test charts located at many different distances. In autofocusing experiments, BET gave an RMS error of just 1.2% in lens position compared to 1.8%, 2.0%, and to 2.3% respectively for three other highly effective methods. This error of 1.2% is very close to the best possible accuracy of about 1.0% due to the inherent quantization errors in lens positioning (about 0.5%), spatial resolution (1 pixel), grey-level resolution (8 bits/pixel), and noise.

6382-16, Session 4

Accuracy problems in phase shift based 3D machine vision inspection systems

I. Dunin-Barkowski, J. Kim, Synapse Imaging Co., Ltd. (South Korea)

Booming demand for high speed and high accuracy 3D inspection, especially in the area of manufacturing of electronic devices and components, causes fast progress in research related to this area and significant improvement in these systems capabilities, specification and features. Accuracy can be considered as one of the most important features for 3D machine vision inspection systems, probably along with speed and robustness.

Phase shift based systems are believed to be among the most accurate 3D measurement systems with resolution at sub-micron level, though to achieve such a high resolution and accuracy considerable efforts should be made and various physical effects should be taken into consideration.

3D accuracy problems comprise of 2D accuracy problems, such as camera radial and perspective distortions, subpixel measurement problems, etc. combined with special issues related specifically to the phase-shift measurement profilometry. Among them there are distortions of the projected light pattern, including projector radial, perspective distortions and non-sinusoidality of the projected pattern (harmonic distortion) and dynamic range problems caused by camera's signal to noise ratio and by constraints of limited digitized signal bit width. To eliminate or minimize negative influence of the above mentioned factors, a number of measures should be carried out when making 3D measurement head design followed by compensation and calibration procedures. Experimental results on various accuracy problems based on real 3D measurement system developed by authors as well as simulation results are presented in this paper.

6382-17, Session 4

Metric projector camera calibration for measurement applications

J. W. Horbach, T. Dang, Univ. Karlsruhe (Germany)

Structured light is widely used for shape measurement of surfaces using the triangulation principle. To fulfill this task precise information about the optical path is necessary. We propose a novel method for the overall calibration of a setup consisting of a structured light source, a projection screen (reference object) and a camera. As computer controlled video projectors become cheaper and cheaper, it is reasonable to use these off-the-shelf devices for measurement applications. However, to achieve high accuracy with standard components, a precise calibration of the measurement system is indispensable. Absolute position and orientation of the camera, the projector and the projection screen has to be known. Furthermore, intrinsic calibration of both the camera and the projector is necessary. After acquiring a large set of data points using a versatile phase encoding technique, we estimate the optimal parameters using bundle adjustment. We consider all extrinsic and intrinsic parameters for the optical mapping including a distortion model for the projector and for the camera, respectively. We propose a method which ensures complete knowledge about the optical mapping of each ray observed by the camera. The proposed metric calibration method has also importance for other measurement applications as e. g. shape reconstruction of specular surfaces. Hereby structured light patterns are projected on the screen and their reflection on the specular surface is observed by the camera.

6382-18, Session 4

On improving the accuracy of structured light systems

P. S. Huang, X. Han, Stony Brook Univ.

We have previously developed a novel calibration method for structured light systems that use digital video projectors. By treating the projector in a structured light system as a camera, we developed a simple, systematic method for calibrating structured light systems. This paper describes our further effort in this area, which is aimed at improving the accuracy of the calibration method. Nonlinear models, as compared to the linear models used previously, for both the camera and the projector are used to reduce the errors caused by lens distortions. Experimental results are presented to demonstrate the effectiveness of the proposed nonlinear models in improving the accuracy of the system.

6382-19, Session 4

Automated geometry measurement of wheel rims based on optical 3D metrology

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One of the economically most important branches is the automotive industry with their component suppliers. The high degree of automation in the manufacturing processes equally requires automated control and quality assurance. Thus, we present a complex 3D measuring device, consisting of multiple and different optical 3D sensors, which is designed to capture the geometry of wheel rims. This system is integrated in the online manufacturing process to continuously assure a constant quality. The principal challenge for automated measurements is the variety of rims with respect to design and dimensions. Therefore, the sensors are mounted on precise motion devices to flexibly measure at different positions. Together with connected conveyers, the systems automatically sorts good rims without interrupting the production flow.

In our work we consider three major steps. At first we discuss the application of the used 3D sensors and the underlying measuring principles for the 3D geometry capturing. Furthermore, we describe the complex hardware architecture, which is needed to fulfill the requirement concerning to the variety of shapes and to the measuring conditions in industrial environments.

In the second part we focus on the 3D geometry extraction and the mathematical and physical models which are used for CAD comparisons. This includes the efficient and robust fitting of geometric primitives as well as methods for temperature compensation.

Finally, we examine an automated self-calibration procedure with respect to the basic concept and the underlying mathematical methods. This procedure is needed for the self-adjustment of the system in the continuous operation.

6382-20, Session 4

Embedded 3D vision system for automated micro-assembly

J. Mure-Dubois, H. Hügli, Univ. de Neuchâtel (Switzerland)

Machine vision plays an important role in automated assembly. However, present vision systems are not adequate for robot control in an assembly environment where individual components have sizes in the range of 1 to 100 micrometers, since the bulky system cannot be brought close enough to the components. A small-size system 3D vision is expected to provide two decisive advantages: high accuracy and high flexibility. The presented work aims to develop a 3D vision sensor easily embedded in a micro-assembly robot. Deployment constraints put drastic limits on the size and weight of sensor package. A screening of 3D sensing methods, performed in order to identify the best candidates for miniaturization, resulted in the selection of the "depth from focus" principle (which elegantly avoids the depth of field problem encountered for example in stereo vision). Depth is measured by determination of sharpness maxima in a stack of images acquired at different elevations. The measurable depth range is directly determined by the amplitude of the camera displacement, while the depth resolution varies proportionally to the optical depth of field. In one configuration, the developed system delivers images of a 1300x1000

micrometers field of view with lateral resolution better than 5 micrometers and vertical resolution better than 10 micrometers. Future steps in development of a real-time embedded depth from focus sensor are presented, with a discussion of the most critical tradeoffs.

6382-21, Session 4

Multiresolution 3D measurement using a hybrid fringe projection and moire approach

K. G. Harding, Q. Hu, GE Global Research

Projected fringe methods have lead to a wide selection of commercial sensors for 3D measurement applications. The basis of these systems is a projector such as an LCD presentation projector which is used to generate a coarse pattern that is shifted across the part and viewed by a camera. Three or more images with a small pattern shift between each is sufficient to obtain a detailed 3D map using phase shift analysis methods. The limitation of these systems has been that to obtain high resolution the system is limited to viewing only a small field of view. Moire methods are a way to leverage this resolution, particularly on flat or only slightly contoured areas. The approach described here takes advantage of moire methods used in connection with the fringe projection method to provide high resolution over key reference areas, while still provided a less precision measurement over a larger region.

6382-24, Poster Session

An improved achromatic half-wave plate phase shifter for white-light interferometry

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Polarization components can be used as nearly achromatic phase shifters in a interferometers[1,2]. Here we present an improved achromatic half-wave plate (HWP) phase shifter that can be incorporated at the input end of a white light interferometer.

A nearly achromatic HWP phase shifter that can be used at the input of an interferometer consists of a rotating HWP followed by a quarter wave plate (QWP) fixed at an azimuth of 45o [3]. An improved achromatic phase shifter for the input end can be constructed using achromatic circular polarizers. The achromatic circular polarizer consists of a HWP fixed at an azimuth of 15o and a QWP at 75o. The improved achromatic HWP phase shifter consists of two achromatic circular polarizers mounted back to back followed by a fixed achromatic circular polarizer.

The performance of this achromatic HWP phase shifter when used at the input end of a white light interferometer is studied using Jones calculus. The calculated values of the phase shifts between the interfering beams and their amplitudes are very nearly same for all the wavelengths. This phase shifter thus gives much improved performance but uses larger number of wave plates.

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6382-25, Poster Session

A flexible photogrammetric stereo vision system for capturing the 3D shape of extruded profiles

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Modern manufacturing requires continuous quality control to assure a constant quality. For highly automated processes industrial 2D and 3D image processing methods are often used. And, in the recent years the need for 3D geometry measuring significantly increases. Therefore, we present a photogrammetric stereo vision system, including hardware as well as software components, which is designed to online measure the 3D shape of complex extruded plastic profiles. Thus, the main challenge is to capture the profiles while they are moving and deforming at the same time. The profiles are measured at several defined points in the time and the geometry of the front faces are extracted respectively. This enables us to reconstruct and evaluate the deformation and shaping process. Based on these results we are able to simulate the viscous flow of plastics in the extrusion process. The 3D geometry capturing and the simulation are repeated iteratively to generate reliable simulation input close to reality on the one hand and to optimize the extrusion tool and the involved mechanical parts on the other.

Our work is primarily concerned with the 3D data acquisition. Thus, we especially focus on the used stereo matching algorithms in comparison to typically used methods in the literature. Additionally we discuss the optimal system configuration, consisting of the camera devices and a special laser matrix point projector, to achieve numerical stability and robustness as well as to fulfill the requirements of the external measuring conditions in industrial environments and a flexible application of the system.

6382-26, Poster Session

Dynamic out-of-plane profilometry for nanoscale full-field characterization of MEMS with automatic detection of vibratory modes and MHz measurement bandwidth

L. Chen, Y. Huang, National Taipei Univ. of Technology (Taiwan); C. C. Chang, Industrial Technology Research Institute (Taiwan)

A dynamic out-of-plane nano-scale surface profilometer with automatic vibratory mode detection was developed using stroboscopic white-light interferometric principle. Micro-Electro-Mechanical-Systems (MEMS) possess system functionality essentially replying on the dynamic displacement properties of the microstructure and accurate characterization. Time-averaged interferometry with a fringe contrast function can perform a quantitative analysis of the interference pattern contrast to obtain vibration mode shapes, but only suit for low vibration frequency measurement. Time-resolved stroboscopic measurements using either white light or single wavelength LED light or pulsed laser, can be applied for high bandwidth full-field interferometric measurement. To characterize MEMS accurately and effectively, an interferometric microscopy based on LED stroboscopic interferometry was developed to achieve dynamic full-field profilometry and characterization of MEMS with a measurement bandwidth higher than 1 MHz. Furthermore, a detection algorithm based on image contrast measure was developed for the automatic resonant frequency identification. A series of natural resonant modes of an AFM cantilever microbeam can be accurately detected and to be consistent with the corresponding theoretical values. To verify the effectiveness of the developed methodology, the cantilever beams were measured to analyze its full-field resonant vibratory shapes. The experimental results confirmed that the resonant vibration of the tested beams can be fully characterized and 3-5 nm of vertical measurement accuracy as well as tens micrometers of vertical measurement range can be successfully achieved. The measured results were consistent with the theoretical simulation outcomes from ANSYS.

6382-27, Poster Session

Stereovision-based vegetable row recognition algorithm for agricultural vehicles

F. Zhang, Y. Ying, Zhejiang Univ. (China)

It is a basic function for a agricultural filed robot to follow along vegetable rows. A stereovision-based vegetable recognition algorithm was developed for the robot navigation system. As the view range in the top of image was larger than the one in the bottom, a type of nonrectangular correlation window was used to match the left and right images. Thus, we got a more accurate disparity image than the general rectangular correlation windows. Based on the disparity images, the vegetable rows were located by the robot. The results indicated that the developed method is useful to the navigation system of agricultural robot.

6382-28, Poster Session

Optical on-line product inspection system and its application

W. Sun, Y. Yang, H. Jiang, X. Wang, Harbin Engineering Univ. (China)

It is very important to guarantee the quality of products in industry. Many methods of product inspection are developed to check out products off-line. The real-time on-line checkout systems are required wildly. The 2-D, 3-D product optical online product inspection system is designed basing on the principle of image subtraction technique.

The principle of this optical product inspection method is comparing the image of products on-line with the image of standard sample. The defects of the product are distinguished clearly after subtracting the image of products from that of the standard product.

The quick development of Liquid Crystal Display (LCD) brings opportunity to simplify the optical inspection system. The optical inspection includes four steps, i.e. image collection, the image preprocessing, the image subtraction and the defects display. The image of the standard product is shown on a half part of the LCD, while the image of the products on-line, captured by a CCD camera, is shown on another half part. A 4-f Fourier-transform system is used to obtain the difference of the two images with a sine grating as the filter in the spectrum plane. The difference between the products on-line and the standard one is easy to be found in the image plane. Another CCD camera is used to capture the difference and transmit it to a computer.

To get the 3-D information, a fringe projective system is used to generate a group of fringe on the surface of the products. This system shows the effectiveness of this method in product inspection on-line.

6382-29, Poster Session

Optimal image enhancement for phase shift analysis sensors

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Phase shift Analysis fringe-projection sensors are popular in inspection and metrology applications. The image captures the region of interest with projected fringes overlaid on it. These fringes bend according to the surface topography. The image profile perpendicular to the fringes is assumed to be sinusoidal. When noise, such as surface texture, appears in the image, the profile loses its sinusoidal behavior and results in phase jumps that cause an inaccurate or noisy measurement. In this study, local and global digital filters are optimized to remove surface-texture related noise from fringe projection images. The intent is to retrieve the sinusoidal image profile shape while precisely retaining fringe locations. The enhancement process must be compatible with real-time processing. Statistical performance assessment is followed by measurement of certification parts. The most effective enhancement algorithm of our selection is based on local edge detection followed by steered Gabor filtration that was found to significantly improve the measurement precision and repeatability.

Monday-Tuesday 2-3 October 2006

Part of Proceedings of SPIE Vol. 6383 Wavelet Applications in Industrial Processing IV

6383-01, Session 1

Quaternionic wavelet transform: application to color images

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In this paper we present a quaternionic wavelet transform (QWT) defined for colour image processing.

The classical wavelet approaches for 2-D images analysis were to perform 1-D real Wavelet Transforms on both rows and columns but this was not adapted to describe properly greyscale image structures. Baraniuk et al. proposed recently a QWT for greyscale images that resolves the problem.

A proper greyscale 2-D analysis was given by T. Bullow with 2-D analytic signal theory: the spectral representation of an image is given by a quaternionic Fourier transform (QFT). Each quaternion of the spectrum can be expressed with its magnitude and three phases representation. In this case, when a shift occurs in an image, it could be characterized properly in the spectrum with these phases. The new QWT proposed by Baraniuk et al. mixed that theory with the wavelet one to detect shifts in images and was used for local edge detection for example, we propose in the first part of this paper to review in details this approach.

To encode colour information in our new transformation, a pixel in the spatial domain is represented by a quaternion as described by S. Sangwine. Secondly we propose to use the discrete quaternionic Fourier transform to study the spectral information of the colour image.

It is well known that the frequency space of a real signal is a complex hermitian signal, we then studied the digital spectral domain of the quaternionic Fourier transform in order to demonstrate and illustrate symmetry properties. This study gives us a characterization of the colour Fourier domain.

Finally we use the quaternion formalism to define a wavelet transform for colour images. We propose to generalize the filter bank construction to quaternionic formalism. Particularly, we describe conditions on quaternionic filters in order to obtain a perfect reconstruction. We build a first color quaternionic wavelet family: the colour Shannon Wavelet. This family of functions is based on a windowing process in the quaternionic Fourier space.

With our new approach, the image is decomposed in the low estimation at scale n and the remaining details in each and both directions x and y at the same scale and iteratively up to scale one. The details show the local structures as usual but it has also the appropriate colour meaning since edges for example are represented in the details views by some shapes composed of their corresponding colours. In the paper, we study in details this new domain for the colour image analysis.

6383-03, Session 1

Power production monitoring based on a sensor instrumentation system

F. Poza, P. Mariño, S. Otero, V. Pastoriza, Univ. de Vigo (Spain)

The Condition Monitoring of On-Load Tap Changers is very important because they have proved to be the elements with noticeable failures in a power transformer. This article describes the development of a portable virtual instrument for monitoring this kind of elements. The monitoring task is based in the measurement and analysis of the vibrations that a tap change produces. In contrast with other methods that can be used, this one has the advantage of being able to do continuous monitoring because the transformer can be operated on line.

6383-04, Session 1

Application of wavelet transform to analysis of instantaneous speed signals of diesel engines

M. G. Mehrabi, Univ. of Detroit Mercy

Instantaneous speed of diesel engines (IES) contains useful information that is otherwise difficult to extract due to the nature of extremely small variations under different operating conditions. This paper is focused on condition monitoring of diesel engines where wavelet transform is used to extract sensitive information from signals collected during the engine operation. In this regard, wavelet transforms are reviewed in detail; their inherent advantages are discussed; and criteria for their selection are presented. The experimental setup used in this study and the data collection process are described. Then continuous wavelet transform is applied to the analysis of the instantaneous engine speeds obtained under two different conditions namely internal pressure of the engine and throttle valve positions. To demonstrate the usefulness of the approach, the results are compared with both the Fourier transform and the time domain of the same signals which demonstarte the significant advantage of wavelet transform in this signal analysis. The results can be further extended to more areas of engine diagnostic development.

6383-05, Session 2

Ensuring multimedia content adaptability by means of data hiding techniques

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The advent of the Internet technologies and the continuously increasing non-linear multimedia content consumption require new types of digital products. These are the so called enriched multimedia products. They are obtained by enhancing the traditional media types (still image, video, audio, 3D) with additional information: content presentation and/or description, outside references, etc. Consequently, new types of objects (visual, audio, metadata) complete the traditional ones.

This new paradigm naturally complies with the Internet related applications: any type of information (regardless its format or representation) can be reliably transmitted, stored, and processed. On the contrary, it is incompatible with Digital Television, where only audio and video data can be properly dealt with.

At our best knowledge, this paper is the first to address this problem by means of data hiding techniques. The principle consists in transmitting the metadata (the enrichment information) via in-band channels obtained by means of data hiding (watermarking) techniques. The challenge is to design data hiding techniques reaching the trade off among transparency (the enrichment process should not alter the perceptual quality of the host media), robustness (possibility to recover the metadata at the end user even when high distortions occur through the channel) and data payload (the amount of metadata which can be inserted).

The paper presents a prototype affording the enriched video content compression and distribution, while observing to the MPEG 4 requirements. The scalable video functionality with respect to network and terminal is obtained under the framework of MPEG-4 SVC. The practical validation consists in implementing a VoD (Video on Demand) platform, featuring intelligent access to video content and (real time) streaming distribution.

Let us now present some details about the method:

(1) The compression schemes we considered are based on DWT (Discrete Wavelet Transform), according to MPEG-4 requirements. The main advantage of DWT approach results from its low complexity (linear complexity) implementation (e.g. lower than the Discrete Cosine Transform).

(2) The authors developed an original watermarking technique by hybridising the Spread Spectrum and Informed Embedding paradigms in the DWT domain. The use of the DWT enables the metadata to be directly inserted into the video MPEG elementary bit stream. For such an application, the watermarking method is not designed to stand malicious attacks but only to resist very strong compressions; consequently, with respect to conventional watermarking applications, the data payload is boosted. Moreover, note that the good results concerning transparency, robustness, and data payload were also

derived from the DWT inner properties.

(3) The inserted metadata correspond to an indexation application, and represent MPEG shape and motion descriptors.

(4) The VoD application is tested on mobile and fixed networks, and on three types of terminals (a PC, a PDA, and a mobile phone).

6383-06, Session 2

High-quality scalable video coding based on integer-to-integer wavelet transform

Z. Yang, Q. Qin, Wuhan Univ. (China)

Integer to integer wavelet transform (ITI DWT) can compress image and video signals losslessly or lossly. In addition, the computation complexity of ITI DWT is below float-DWT. For these reasons, ITI DWT is very useful in image and video coding.

In video coding, this paper presents a hybrid coding scheme called WVM based on ITI DWT and motion compensation. In WVM scheme, variable sizes block compensation and OBMC are used. In addition, we provide an intra coding mode for macroblocks in prediction frames which is suitable for wavelet transform. We use intra macroblocks' average values as "prediction", so we can get a full predict image. In this case, the predication error image can be stationary, and we can use wavelet transform for the whole predication error image. To code error images of motion compensation efficiently, a specially optimized compression algorithm called LL-SBPC is given. LL-SBPC is carefully designed in wavelet basis, decomposition levels and LL-subband coding. The experiments show that WVM is free from blocking-artifacts, and the subject quality of WVM is better than H.163+'s.

Based on WVM, a fine granularity scalable video coding scheme called FGS-WVM is provided. In encoding module of FGS-WVM, all subbands bit-planes are encoded, but only a part of subbands bit-planes which are called basic bit-planes are sent to the feed-back loop. As long as the basic bit-planes are transmitted to decoding module, propagation of prediction errors can be avoided. The enhancement layer coded stream of FGS-WMV can be truncated at any point. By decoding the whole enhancement layer coded stream, the reconstructed video sequence is lossless.

6383-07, Session 2

Joint source and channel coding of embedded wavelet-based coded images using LDPC codes

M. R. L. Stoufs, A. Munteanu, J. P. H. Cornelis, P. Schelkens, Vrije Univ. Brussel (Belgium)

The last decade has been marked with the appearance and rapid multiplication of wireless multimedia applications. The transmission of images over variable-bandwidth wireless packet-based networks to a large variety of end-users induces the need for (1) efficient scalable image coding, and (2) adapted error control mechanisms needed to protect the compressed bit stream against degradations caused by packet losses.

The majority of today's state-of-the-art scalable image coders perform a global wavelet-transform followed by successive approximation quantization and context-based adaptive arithmetic coding of the resulting transform coefficients [1-3]. This type of source coding is attractive because it offers very competitive rate-distortion performance combined with support for resolution and quality scalability. However, since variable-length entropy coding is used in these image coding schemes, the produced bitstreams are very sensitive to transmission errors; i.e. even a single bit-error may propagate and cause the decoder to lose synchronization and eventually collapse. Efficient error protection is therefore of crucial importance.

In the area of error correcting coding, many new developments have been realized since the invention of capacity-approaching codes like the turbo codes in 1993 [4] and the re-discovery of Low-Density Parity-Check (LDPC) codes in 1996 [5]. Driven by these results, other codes have since been introduced, e.g. [6], [7].

In this paper we focus on the specific problem of the error protection of embedded wavelet-based coded images corrupted by packet erasures. We consider fixed-length channel packets and model the channel as a binary erasure channel (BEC). The erasure channel is a good model for modern packet networks, in which the elements of interest are the network's packets, each of which either arrives at the destination or is lost, due to congestion or corruption [8]. As typically done in wireless standards [9], an interleaver is included in our error-protection scheme. The interleaver merely provides a rearrangement of the symbols such that the packet losses are converted into binary erasures. Since the produced bitstreams are progressive, the priority of the first bits is higher than that of the following bits. In this context, we propose a joint source channel coding (JSCC) approach based on unequal error protection (UEP), enabled by means of punctured regular LDPC codes. The aim of this approach is to deliver different protection levels according to the importance of the data and, knowing the channel's condition, to allocate the available bits optimally between the scalable source and channel coders such that the overall expected distortion is minimized subject to a total rate constraint.

In order to solve this constrained-optimization problem we propose a formulation for the evolution of the distortion of each subband when an increasing number of packets is transmitted. In this context, it is theoretically proven that the estimated average distortion of a subband when transmitting an increasing number of packets always follows a convex hull, no matter what path is taken. Moreover, we prove that a similar conclusion can be drawn when UEP is employed, constrained by some bounds on the allowable code rates. Therefore, our JSCC allocation process based on UEP can rely on a Lagrangian-multiplier method. With this respect, we develop a Viterbi search-based algorithm, which determines for every subband the optimum number of packets and their corresponding code-rates. We differentiate ourselves with other similar research recently presented in the context of error-resilient coding of JPEG2000-coded images [10-12] in that our algorithm (1) is applicable to any coder based on a wavelet transform followed by embedded coding, (2) considers transmission over BECs, (3) our Viterbi-search is not a complete Viterbi-list algorithm [10], which makes our proposed approach less complex than the one of Banister [10].

For our experiments we used a five-level (9,7) wavelet transform. Embedded coding is performed by means of successive approximation quantization (SAQ) and entropy coding is performed using non-adaptive arithmetic coding. Although it can be proven that the allocation produced by the proposed JSCC is not necessarily optimal, our preliminary coding results are very close to the optimal results that are found through an UEP-based exhaustive search. We also see that important gains are achieved with the proposed UEP approach compared with the use of equal error protection. More extensive results will be included in the full paper.

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6383-08, Session 2

Unequal error protection of the reference grid for robust transmission of MeshGrid-represented objects over error-prone channels

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In the context of robust 3D object transmission over bandwidth-limited error-prone channels, simultaneously providing scalability of the employed object representation and resilience against transmission errors are of primary concern. MeshGrid is a novel, scalable 3D-object representation method that is part of MPEG-4. A MeshGrid object comprises one or several surface layers attached to and located within a volumetric reference-grid. This paper proposes a novel approach for scalable error-resilient coding of MeshGrid's reference-grid. In MeshGrid, the reference-grid is encoded in a scalable manner using a wavelet-based octree coding technique. Hence, an unequal error protection approach is followed, in order to acquaint for the different error-sensitivity levels characterizing the various resolution and quality layers produced by the reference-grid coder. The layers are protected using low-density parity check codes. The optimal code rates to be employed for each layer are determined for any given packet-loss rate subject to a total channel-bandwidth constraint. This problem is formulated and solved as a joint source and channel coding problem, wherein the estimated distortion is minimized subject to a total rate constraint. We chose to minimize the L-infinity distortion instead of the classical L-2 distortion, as this has been proven to be a better option, particularly in low-rate coding of surfaces.

The benefits of scalable error-resilient reference-grid coding are practically demonstrated. Numerical simulations over binary erasure channels show that the performance of the proposed unequal error protection is superior to that of the common equal error protection. We conclude that the proposed approach offers resilience against transmission errors while preserving all the scalability features and animation capabilities that characterize MeshGrid.

6383-09, Session 3

M-band filter banks and dual-tree wavelets for engine combustion and geophysical image analysis

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Lifting schemes for applications in vibration and geoscience

6383-10, Session 3

Appearance-based robot localization using wavelets-PCA

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In appearance-based localization, the robot environment is implicitly represented as a database of features derived from a set of images collected at known positions in a training phase. For localization the features of the image, observed by the robot, are compared with the features stored in the database. The robot position is then considered as being the position of the most similar image in the database.

In this paper we propose a novel image based feature extraction approach to solve the robot localization problem. The approach has two stages. In the first stage the image is transformed to the wavelet domain using the fast wavelet transform. In the second stage, Principal Component Analysis (PCA) is applied to the wavelet coefficients in order to further reduce the feature dimension by selecting the significant feature elements.

The main advantages of using wavelets before PCA are their ability to extract texture information that remains relatively unharmed under illumination changes and because the compacted wavelet coefficients will reduce the l calculation effort of the eigen-space in the second stage.

The approach was tested under illumination changes and under the image transformations that occur when the a mobile robot navigates. Since the images were obtained by an indoor mobile robot, translation and scale were the main image transformations that were considered. The results were also compared with another well known approach that employed PCA without wavelets.

To test the approach under illumination changes a set of four groups of images were used. Each group was taken with a given illumination condition. Training was done with one group and testing was done with the other three. Different training and testing combinations were considered. This experiment was repeated using different wavelet resolution and different number of eigen-values.

The results showed that when comparing Wavelets-PCA with a PCA-based approach, Wavelets-PCA exhibited better localization accuracy specially under illumination changes. Also, the localization rates of Wavelets-PCA were always better than the PCA-based approach under all different choices of eigen-values. The computation time of feature extraction in the case of Wavelets-PCA is much less than in the case of PCA since the former has more compact input space than the latter. Therefore the proposed approach is suitable for real-time robot localization

6383-11, Session 3

Multiresolution approach to identification of recurring signal patterns

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Manufacturing processes are generally monitored by observing uniformly sampled process signals collected from application specific sensors. Effective process monitoring and control requires identification of different types of variation, including recurring patterns, in process variables. From the process control view point, any repeating patterns in the process measurements will warrant an investigation into potentially assignable causes. In order to devise an effective process control scheme, a novel universally applicable method for identifying the repeated occurrence of patterns in process measurements is described in this paper. First the sampled process signal is decomposed into multi-resolution signal using a wavelet transform. Next, a frequency index is assigned to every sampling point of the process signal at every resolution level to improve the pattern recognition. Recurring patterns are detected at different resolutions and then integrated to the final results. The experimental results show that the method used in this work accurately detects a broader family of recurring patterns even in presence of noise.

6383-12, Session 3

Application of wavelet analysis in active infrared thermography for nondestructive testing of carbon composites

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Active infrared thermography is a non-destructive testing (NDT) technique that allows the non-contact inspection of components and materials by temporal mapping of thermal patterns excited by well defined heating mechanisms (e.g. spot light, flashlight, laser, inductive heating,...). The subsurface defect detection principle in active thermography is based on the fact that a difference in thermal properties exists between the sound (non-defective) area and a defective region, which can be used for detection or quantification purposes.

A uniform illumination is important in thermographic inspections because it improves the probability that spatially varying features in the thermal response data will relate to underlying structural features and not to thermal artefacts introduced by uneven heating. Unfortunately, in practice a perfect uniform illumination can hardly be achieved especially when examining larger objects. Further sources of error are spatial variations in the object surface emissivity. A relatively new processing technique which is remarkably robust in this context is the pulse phase thermography (PPT). PPT employs a direct Fourier

transform applied time-wise to each pixel of the thermal image sequence to form a phase map at a prescribed frequency. In this way, PPT combines the practical advantages of the pulsed acquisition technique of pulsed thermography (PT) with the frequency-phase concept of lock-in thermography (LT) where the tested object is submitted periodical excitations.

Through the application of a short heat pulse, thermal waves of various amplitudes and frequencies are launched into the specimen. The duration of the pulse may vary from a few milliseconds (laser) to several seconds (using lamps), depending on the thermo physical properties of both, the specimen and the flaw. Thus, the standard approach for data evaluation is Fourier analysis to extract the various frequencies. A disadvantage of this method is intrinsic to the Fourier transform which suppresses all temporal information, i.e. direct defect depth information is lost as, in first approximation, subsurface defect depth is proportional to the square root of time. The Wavelet transform (with complex wavelets providing phase and amplitude information) can be used with PPT data in a similar way as the Fourier transform but with the advantage of preserving time information of the signal which can then be correlated to defect depth, and in this way allowing a quantitative evaluation.

Results of finite element simulations (taking into account different defect geometries and defect depths) and practical experiments conducted on various materials, like carbon fibre reinforced composites, show the advantages and the potential of the Wavelet analysis in the context of active thermography data analysis. Through a calibration process a relationship between the Wavelet translation factor (as the time variable) and the depth of an observed structure can be established. Different acquisition parameters (acquisition time, sampling rate / time resolution, ...) are simulated and the results are compared with those of Fourier based approaches for defect depth and defect size estimation. Special focus is put on infrared camera noise properties and the resulting influence on the measurement result. Additionally, image processing and wavelet based signal denoising techniques are briefly discussed to further enhance the quality of active thermography images.

6383-13, Session 3

Wavelet-based feature extraction method for inspection using cross-sensor image data

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We developed a new mathematical technique for combining cross-sensor image data that preserves sensor-unique characteristics of each contributing sensor while optimizing the extraction of information from the resultant fused product. Our development effort will lead to a new approach for optimally combining imagery collected from different sensors to achieve results not possible with current technology. Our approach takes full advantage of the fundamental properties of the wavelet transform and has broad applicability to any image fusion problem involving sensor data having different spatial, spectral or temporal characteristics. The basis of our approach is a set of forward wavelet transforms, optimized to preserve the individual information content of each sensor image followed by a common inverse transform that is designed to simultaneously preserve the most desirable information characteristics from each image after fusion. We attempt to reconstruct a fused image that will retain the information content from disparate domains while enhancing the information content of the fused image product. This approach is quite novel and challenging because an optimal inverse transform from different forward transforms has not been devised. We envision a broad application space for this approach in a set of diverse image products that must be quickly and optimally combined to support detection, and identification of objects through feature extraction.

There are several methods commonly employed today to combine imagery from different. In all cases, a compromised solution occurs due to non-optimal retention of information from each source. Typically, the fused solution favors one set of information characteristics over the other in a non-optimal and often times, unpredictable manner. The more straightforward methods use a linear combination of images, such as pixel averaging, some sort of pixel-by-pixel comparison by energy, or a projection method, such as principle component analysis (PCA). More advanced methods use intensity contrast, a technique that is more useful as the number of images increases. With intensity methods, an image set, is thought of as a surface and the maximum contrast is determined at each point to construct a contrast vector field. Using differential geometry, a two-dimensional vector field representing the absolute contrast and direction is found. Therefore, the maximum contrast at each point is determined and a 2-D representation can be formed. Although methods based on maximizing the contrast of a scene with information from multiple images may be a useful, problems occur when in contrast-based treatments whenever sensors with different spatial or spectral characteristics are combined.

The common thread between all these methods is that regardless of how they combine images, they are fundamentally limited by their reconstruction treatments. When data from different sensors are used, one of two cases exists. The reconstruction must favor one type of sensor over the other causing a loss in information in one set of data. Or, the reconstruction favors neither sensor (an average for example), and the reconstruction is not optimal for either sensor resulting a loss in information content in the fused product.

Although there are several initiatives underway on advanced fusion methods, no approach, to our knowledge, attempts to optimize the reconstruction of the final image product with respect to the unique characteristics of each contributing sensor image. By understanding and exploiting the fundamental mathematical principles of the underlying fusion problem, we believe a new approach is possible that will offer results not currently attainable. The only a priori knowledge needed for our approach is the type of imagery being dealt with, for example, infrared and visible. Our approach will combine the results from two “optimal” transforms (one for each type of imagery) and reconstruct them with a third to give “optimal” results. If we focus on reconstructing features for example, they can be reconstructed optimally even though the remaining portion of the data cannot. This remaining data usually contains far less information than the features. Therefore, the reconstruction error associated with data that are not features is minimized and spread across the fused image as evenly as possible. Such an approach has not been investigated, but could lead to a method that gives fusion results not possible with existing methods.

Finding a perfectly reconstructing inverse transform when considering two different forward transforms is not mathematically possible except in simple cases. Our approach for the general case is to use wavelet transforms because of their ability to have multiple versions. We will match the parts of the forward transforms and the inverse transform that are responsible for detecting features. Therefore, features will be optimally reconstructed in the resulting image. The remaining portion of the reconstructed image cannot be mathematically reconstructed perfectly. However, this information is not usually needed for reconstructing features and corresponds to background (non-feature) information. If we can spread out the reconstruction error due to the background of an image evenly, then we have succeeded in developing a new approach to data fusion.

Because the underlying processing approach is a new fundamental mathematical technique, we envision a new processing capability that will offer a wide range of utility in a variety applications.

6383-14, Session 3

Osteoporosis vizualization by densities projection based on kernel convolution method

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The disease of osteoporosis induces both a dramatical reduction of the bone mass and a degradation of the microarchitecture of the bone tissue.1 In this context, several techniques were developed in order to early detect the apparition of this disease. Concerning the detection of the reduction of bone mass, a noninvasive technique based on Dual-energy X-ray Absorptiometry (DXA) is used.2 However, the microarchitecture analysis requires until then invasive methods. This is the reason why much effort was devoted to extract bone texture information from radiographies. More precisely, radiographies of the calcaneus are very often employed because they contain rich informations on microarchitectural patterns. Furthermore, the underlying image acquisition system can be easily adjusted.3 For instance, in our experiments, we have considered regions of interest of size 2.7 cm Å~ 2.7cm located in the posterior part of the calcaneus. An X-ray clinical apparatus, with a tube voltage of 36 kV, a 18 mAs exposure level with a Min-R film is employed during the capture. The

digital conversion is performed by a duoscan scanner: a pixel corresponds to an area of 105?m Å~105?m. The output digital images of size 256Å~256 are coded at 8 bpp.

6383-15, Session 4

Denoising of imagery for inspection tasks using higher-order statistics

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We described a method for denoising of image inspection tasks using third-order correlations that has broad applications for many inspection tasks. Denoising typically involves calculating the wavelet transform of a signal, thresholding the wavelet coefficients, and calculating the inverse wavelet transform. Most methods calculate the threshold based on an analysis of the wavelet coefficients. In most cases the energy of the wavelet coefficients are used as a basis for thresholding or otherwise modifying their values. After the inverse wavelet transform, the denoised signal should ideally be equal to the noise-free signal. Our denoising approach is based on third-order correlations to identify wavelet coefficients that were mostly signal. The correlation between two functions has been often used as a measure of their similarity. The conventional correlation function is a second-order correlation, and is a special case higher-order correlations. Although higher-order correlations have been used for many years, there use has been limited. We thought of wavelet coefficients as correlations between a signal and a wavelet at a particular scale and translation, and used a higher-order correlation to determine if a coefficient was mostly noise or signal. We considered a noisy signal that contained zero-mean noise of unknown spectral density.

Denoising methods work best when a signal can be effectively separated from noise. Current methods are generally devoted to estimating signal or noise statistics so that a signal can be reconstructed with a minimum of error. Unknown statistics of the signal or noise and low signal-to-noise ratios make denoising difficult. A robust method that can extract a signal from unknown noise characteristics would form a particularly useful tool for denoising.

The wavelet transform has been used in denoising because it usually compacts a signal better than noise. Due to this property, the noise and signal can often be separated. A transform coefficient can be thought of as a cross-correlation between a basis function and an input signal. Therefore, a transform is a collection of cross-correlation coefficients between an input and the basis functions of the transform. To denoise a signal, noisy coefficients can be eliminated or the noise subtracted in the case of additive noise. Identifying coefficient values in the presence of noise is crucial to denoising.

Denoising methods are often based on estimates of the magnitude or power of the signal and noise present. Promising results have been obtained with methods that resemble Wiener filtering. Because the Wiener filter is an optimal linear filter if the complete second-order statistics of the signal and noise are known, wavelet image coefficients are modeled as Gaussian random variables. More complicated methods often exploit multiple scale dependicies of the wavelet transform

In contrast to previous work, we decided if wavelet coefficients were noisy based on higher-order correlations. Higher-order correlations are an extension of the more familiar second-order cross-correlation function, but have the advantage of being insensitive to noise of unknown spectral density under certain conditions. In our approach, we applied a third-order correlation detection method to identify wavelet coefficients that contained mostly signal. Because the higher that second-order moments of the Gaussian probability function are zero, a third-order correlation coefficient will statistically not have a contribution from Gaussian noise. The detection of signals using higher-order statistics has been used in a variety of areas. This paper gives the theory of detection of wavelet coefficients using higher-order correlations in the presence of additive noise and reports on its applications.

6383-16, Session 4

Wavelet-based joint video de-interlacing and denoising

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Video sequences are often distorted by noise, e.g., due to reception of television pictures or transmission of video signals over analogue channels. Noise reduction of image sequences is used for various purposes, such as a pre-processing step for superior video coding or for visual improvement in video surveillance, television and medical imaging applications.

In general video sequences can be found in two formats: interlaced and progressive. In the progressive format all frames include all the scan lines, while in the interlaced format half of the horizontal lines are missing in each frame (even lines are skipped in one frame and the odd ones in the next frame and so on). Most of the existing video denoising algorithms treat progressive format only. However, in many industrial applications including television broadcast there is need for processing interlaced video format, for example television signals in common NTSC, PAL and SECAM systems are in the interlaced format. Moreover, many current devices such as personal computers, TFT TV-sets, projectors, and plasma panels and LCD screens use the digital progressive scanning format for display.

Consequently, it becomes more important to convert interlaced sequences to non- interlaced ones at acceptable rate and without artifacts.Converting an interlaced stream to a progressive one is in literature called deinterlacing. The problem of deinterlacing can be defined as follows: the input video fields, containing samples of either the odd or the even horizontal lines of an image, have to be converted to frames. These frames represent the same image as the corresponding input field and with the missing horizontal lines inserted by spatial and/or temporal interpolated sample values. Hence, the reconstructed frames contain all lines.

In general three basic approaches for video deinterlacing can be distinguished:

• (i) fixed interpolation techniques perform either spatial interpolation only or merge two consecutive fields together to produce a frame.

• (ii) motion adaptive techniques such as [1] perform spatio-temporal interpolation in a motion adaptive manner: when motion is detected the interpolation is done spatially; otherwise temporal interpolation is performed.

• (iii)motion compensated techniques [2, 3] perform temporal interpolation through the estimated motion trajectory.

Spatial interpolation tends to reduce the spatial resolution and the temporal interpolation is preferred when motion can be reliably estimated. Temporal interpolation with incorrect motion vectors can cause flickering artifacts, which usually manifests itself as horizontal structures oscillating up and down in vertical direction, from frame to frame, or a comb artifact which introduces horizontal stripes in every second line in the deinterlaced frame. Denoising interlaced sequences for display in progressive scanning format is even more complicated than the deinterlacing by its self. The main problem arises from the fact that noise insensitive and reliable motion estimation is needed, which is difficult considering that only half of the horizontal lines are at our disposal. In this paper, we propose a novel, wavelet-domain joint deinterlacer and denoiser. The problem we meet there is that the inverse wavelet transform (after deinterlacing) has to handle twice as more input lines than the direct wavelet transform. The construction of perfect reconstruction filter banks for such a scenario has been studied in [4]. We solve this problem differently, retaining the classical wavelet transform, but within a specific scheme. We apply the wavelet decomposition to each field of the interlaced sequence and perform spatio-temporal interpolation and denosing in the wavelet domain. Hence, the processed wavelet bands are not only denoised but also have twice as more horizontal lines. We split these full resolution bands into odd and even lines, on which we separately perform two inverse wavelet transforms. Each of these inverse transforms uses the same filter bank that is the dual of the decomposition filter bank. As a final step the odd and even lines being the outputs of the two inverse wavelet transforms are merged in order to produce the denoised sequence in progressive format. Our interpolation and denoising step is based on motion compensated filtering. The proposed motion estimation and motion compensation schemes are extensions of our related recent method for progressive format [5]. The results show good performance of the proposed joint deinterlacing and denoising scheme, for various noise levels tested. Specifically, the noise is efficiently removed and the spatio-temporal interpolation is performed in an advanced manner without introducing visible artifacts. The proposed algorithm shows superior performance in comparison to deinterlacing method of [1], which especially significant for higher noise levels.

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6383-17, Session 4

Spatially adaptive image denoising based on joint image statistics in the curvelet domain

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In recent years, many wavelet-like image transforms have been developed, such as the complex wavelet transform [1], the contourlet transform [2], steerable filters [3] and many others. These new transforms aim at capturing geometric information in images better than the classical wavelet transform. Among these, a mathematically elegant method called the curvelet transform recently gained popularity [4]. Curvelets are directional basis functions, that are highly localized, both in space and frequency. We refer the reader to [4] for a comprehensive description of the curvelet transform.

Image statistics in the curvelet domain has been recently studied in [5] with a comparative analysis to wavelet domain image statistics. There it was shown that for noise-free images marginal subband statistics in the curvelet domain, likewise in the wavelet domain, is well modelled by a generalized Gaussian distribution. The study in [5] also showed that the noise-free curvelet coefficients are strongly correlated in local intra-band neighborhoods and that these local correlations are stronger than those found for wavelets. The local intra-band correlations were found stronger than their inter-scale and inter-orientation counterparts.

In this paper, we make a step further in this direction by analyzing the joint statistics of two classes of the curvelet coefficients: those representing significant image edges on the one hand, and the coefficients dominated by noise on the other hand. The aim of this analysis is development of a mixture prior for curvelet coefficients, related to those that have been shown effective in wavelet processing [6-8]. Next, inspired by a wavelet domain denoising method [8], we define and analyze statistically diffeerent local spatial activity indicators (LSAIs) in the curvelet domain. In general, for each curvelet coefficient we define LSAIs as a function of those coefficients that are well correlated when representing a significant edge. This includes the neighboring coefficients from the same subband, the “parent” coefficient from the coarser resolution scale and the coefficients in adjacent orientation subbands.

Our preliminary results using an intra-band LSAI defined as an averaged coefficient magnitude within a 5x5 window, show improvement over the related wavelet based technique [8] and a significant improvement over denoising by thresholding the curvelet coefficients [4]. For example, for the greyscale Lena image of size 512x512, contaminated with white Gaussian noise with a standard deviation of 20 (PSNR 22.10dB) the wavelet based method of [8] yields PSNR of 32.15dB, hard thresholding the curvelet coefficients [4] yields PSNR of 31.35dB, and the new method yields PSNR of 32.32dB. Hence the improvement over hard thresholding in the curvelet domain is 1dB and the improvement over the wavelet based related method is smaller in terms of PSNR but visually significant. We expect further improvements by including inter-scale and inter-orientation neighbors in the definition of the local spatial activity indicator.

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6383-18, Session 4

Sound analysis for underwater animals (Haddocks sounds) with wavelet denoising techniques

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Introduction:

Sound is important for marine mammals because of communication, navigation and feeding. They produce various sounds such as including grunts, croaks, cliks and snaps that are used to attract mates as well as ward off predators. Water biologist must be defined this sound to give meaning to identification. These sounds are recorded as special sound equipment. At the time of recording, different sounds caused by splashes for example, are added the mammal sounds. This is a problem for mammal sound recognation.

In this work, sound analysis for underwater animals is presented using wavelet denoising techniques. These techniques are stationary wavelet transform with thresholding and wavelet denoising by soft thresholding. Then, the results are compared according to these techniques which are indicated in this paper.

Methods:

In this paper, wavelet denoising techniques are used for drawing off background noise. Two methods are applied to data. Firstly, data are transformed by discrete wavelet transform. Then derived coefficients are implemented by soft thresholding. In the other method, stationary wavelet transform are used, and at each level, thresolding are applied to coefficients.

Results:

Haddock sounds are analyzed to background noise in this work. All data in ‘mp3’ and ‘wav’ formats are dowloaded via internet that is located in different marine laboratuaries. Haddock sounds consisted of long trains of regularly repeated ‘knocks’. Figure 1 shows the analyzing haddock sound by stationary wavelet transform for the recorded three haddock sounds. Similarly, Figure 2 shows the analyzing haddock sound by shoft thresholding for the same data.

In the stationary wavelet transform, wavelet function is ‘Daubechies1’ and level is 8. Thresolding values are th=0.095 for level 1 and th=0.013 for all other levels. As a seen Figure 1 that background noise is seperated from the haddock sound swimmingly, but little haddock sound is interfered to bacground noise.

In the soft thresholding, ‘Daubechies1’ wavelet function is used similar to stationary wavelet transform and transform level is 8. In this method, noise level is not to hold the standart level, on the contrary rescaled thresholding is applied using single estimation of noise level related to coefficients for level 1. In addition to, heurestic, sqrtwolog and minimaxi thresholding are used in the determination of thresold. Best result is found in minimaxi method between these methods. In minimaxi method, a certain threshold consisting of minimax

performance is used for mean square error. As a seen Figure 2, background noise is not include the haddock sound at variance but, there is a little noise in the haddock sound.

As a result, knocks are detected for all data. In the data set, 198 knocks were detected. The overall success rate is %87. It was shown that using the fact that knocks occured in long repetitive series increased the success rate to 92%.

Conclusion:

In this work, bacground noise are pulled up to original signal for analyzing haddock sound. Stationary wavelet transform and soft thresholding are used for analyzing sounds. Results are indicated that soft thresholding is best according to stationary wavelet transform in the haddock sound. In addition to knocks are detected with 87% success rate.

Sound is important for underwater animals. They continues vital activity with their producing sounds. Each sound consist of a significant meaning for biologists. Therefore additinonal noise in underwater sound is not refused. This noise are seperated from the data for this work.

As aresult, wavelet techniques provide a useful method for automatic sound recognation. The methods describe in this paper can count and assign a large number of sounds more quickly than can be done by eye. This technique has the potential to seperate underwater sounds from noise in the sea.

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6383-19, Session 5

Combined statistical-fractal wavelets signatures for texture recognition

F. Mourougaya, Univ. de Poitiers (France)

When characterizing textures in the scope of recognition or segmentation, one can choose from a great number of existing features. They can be seperated in four families: structural (detecting and characterizing the texels and the rules of their layout), statistical, model-based (using the parameters comming from the fitting of a model to the texture), and signal processing-based. Among them, features based on the wavelet transform provide good results and are already used in many applications.

One key point for the success of wavelet-based methods is the choice of the signature used to describe the sub-bands.

Our paper, after a brief reminder on the wavelet decomposition, presents the signatures commonly used in texture recognition. The energy signature was the first one to be proposed. It is the sum of the squared wavelet coefficients. Hence, texture recognition with this signature is based on the assumption that the energy of two different textures will be dispatched in different sub-bands. Another one is the histogram signature, that models the coefficients distribution in each sub-band, bringing more information than a single measure. Anyway, these two signatures only extract statistical information on the coefficients, but not their layout. That’s why other signatures that take into account the spatial layout have also been proposed. For example, the cooccurrence signature (characterizing the sub-bands with the Haralick features) captures spatial relationships between coefficients. Unfortunately, this approach needs too much parameters to be finely tuned in order to be efficient, from a practical point of view.

Since we are convinced that introducing spatial information in the wavelet sub-bands description can lead to a noticeable improvement in the context of texture segmentation, we studied the use of the fractal dimension as a signature, as proposed by Espinal and Chandran in 1998. While these authors were using a covering blanket algorithm to estimate the fractal dimension, we propose to calculate it on the Fourier power spectrum of the sub-band, using the Voss estimator. This way, we reduce the computation load and can also get another feature: the intersect with the origin of the linear regression used in the estimation.

To assess the performance of each signature, we compared their results in a classification experiment led on the complete Brodatz database, using a 3-nearest neighbour classifier and a leave-one-out strategy of sample presentation. Since one of the features captures spatial information, and given that the choice of the wavelet decomposition scheme has an effect on the spatial precision, we also studied the impact of modifying the decomposition level and wavelet size.

During these classification experiments, we showed that the decomposition level choice is crucial for a good recognition, unlike the size of the wavelet. Overall results showed that the fractal signature do not achieve the best classification rate, but can significantly increase it when used in addition to a statistical signature.

From these experiments, the best signature combination, histogram plus fractals, was selected. In a next step, this combination was used for the segmentation of real-world textures acquired by scanning electron microscopy, in order to obtain quantitative measurements for quality control of rolled aluminum products.

6383-20, Session 5

Visual browsing in image collections using wavelets

J. Landre, F. Truchetet, Univ. de Bourgogne (France)

Images have always played an important role in our everyday life. Due to the growth of Internet and to the low price of digital cameras, new image collections are created every day. Searching in these large images collections has been a great challenge for researchers for the ten last years. Many techniques were developed to try to solve this problem.

Content-based image retrieval techniques have recently shown several drawbacks. In these techniques, an image is represented by a feature vector built from information extracted from images. Classicaly, these features are color, shape and texture.

So classical image indexing and retrieval methods have to face several problems:

- Dimensionality curse makes vector distance computation difficult to analyze due to the emptiness of high dimension spaces,

- The search context of the user must be taken in consideration,

- All the processes involved in the indexing and retrieval process have to be fast and accurate to minimize searching time and to maximize the quality of results.

Considering that realtime image search was difficult to realize for large images collections, a new method was proposed: visual browsing. Visual browsing consists in browsing the images collections by navigation through a visual representation of the collection. A very simple interface allows users to move through the collection in order to find the good image. Users are free to choose images following their need and their intuition. To browse an image collection, a search tree is built offline and proposed online to users for navigation.

In this article, we propose a method based on the building af a search tree for images retrieval in which features are extracted from wavelets levels of images. These features have to take in account visual information because navigation is based on visual perception of users. In our method, dimensionality curse is smoothed by reducing the size of feature vectors. The context of search of users is respected by selecting similar features at different levels of wavelets.

Intel image processing libraries IPP and OpenCV are used to increase performances. A wavelet transform that maps integers to integers was used to speed up computation time by only using integer numbers. A system prototype based on our method has been developed using apache web server as a web interface, PHP scripting language for

users' forms and the MySQL database for storing features, search trees and results.

Experimental results are proposed on an image collection. They are based on testing with users browsing precomputed search trees and trying to find given images to

see if our classification process is adapted to their need.

As a conclusion, our method reduces dimensionality curse and takes in consideration the search context of users. We prove our method is fast and accurate for homogeneous images collections. However, our method shows several limitations for heterogeneous images collections. The last part of our article will describe future work to do to extend our method to any images collection with an adaptation of features.

6383-21, Session 5

Informed audio watermarking in the wavelet domain

M. P. Mitrea, S. A. Duta, F. Preteux, Institut National des Telecommunications (France)

Audio watermarking aims at ensuring the property rights for digital audio (music, speech). In this respect, some extra information, referred to as mark or watermark, is embedded into original unmarked clip. By detecting this information, the true owner should be identified and the copy maker should be tracked down.

Nowadays, four general requirements are stated for the watermarking methods:

• transparency: the artefacts induced by mark embedding should not be perceived (heard) by a human observer;

• robustness: the mark should be detected regardless the transforms the marked data are subjected to (e.g. mp3 compression, change of file format, resampling, spatial and/or temporal cropping, malicious attacks);

• obliviousness: the detection should not require the original audio data;

• low probability of false alarm: detecting a mark in unmarked data should occur with a very low probability (e.g. lower than 10-10).

This paper starts by presenting an accurate statistical investigation on the digital audio data in the DWT domain. Specifically, the way in which the DWT coefficients can be modelled by ergodic Gaussian information sources is for the first time identified and pointed out. The original statistical approach we considered combines four types of statistical tests (first and second order statistics). It was obtained by generalising the algorithms we have designed for video data modelling.

Further on, the same type of investigation is carried out on some common transformations and malicious attacks. This time, the popular Gaussian model holds just for some particular types of transformations (e.g. linear filtering) but cannot be considered for their larger majority (e.g. the mp3 compression).

The experiments were carried out in partnership with the SFR (Vodafone group) mobile services provider in France. The results are obtained on a corpus of 600 audio clips of about 4 minutes each, sampled at 44100 Hz, coded at several bitrates, e.g. 128 and 192 Kbit/s. This corpus contains music sequences of several genres (symphonic, pop, rock, hip hop) as well as human speech recordings.

The practical validation of the overall statistical results is realised by developing an original informed embedding procedure for audio watermarking. This procedure is structured into three main steps:

1. The mark is generated starting from the information to be inserted into the audio clip and from the key (the secret information).

2. A salient characteristic vector is extracted from the original audio. In order to do this, the original audio is first divided into short sequences (frames) of length T. The DWT is then individually applied to each frame, at an Nr resolution level. The coefficients in the second lowest frequency band are sorted in the decreasing order of their absolute value. Finally the first N coefficients of the hierarchy (the largest coefficients) in each frame are recorded, thus obtaining the salient characteristic vector.

3. The characteristic vector is then modified by applying an iterative algorithm, so that the modified vector is as close as possible to the original and the mark is detected even after certain modifications and attacks. This algorithm is obtained by adapting a method already developed for video watermarking (joint SFR and GET/INT patent pending). Note that in order for this algorithm to reach its solution, the results of the statistical analysis (the audio and the attack modelling) are considered.

The watermarking experiments were performed on the same corpus of audio sequences that was used for the statistical analysis.

In each second of the audio sequence, we inserted 2.5 bits. As a comparison, for the same degree of robustness (see below) most state of the art papers achieved a data rate of about 1 bit per second.

From the transparency point of view, two types of investigations were carried out: an objective measure - the signal to noise ratio (SNR) - was completed by a subjective evaluation - human subjects were asked to grade the quality of the watermarked sequence. Objectively, the SNR was above 25 dB in almost all the tested sequences, more than half of them being above 30 dB. Subjectively, the human observers could hear the mark in some of the sequences, but they generally did not find it disturbing.

From the robustness point of view, the mark withstood all the state of the art requirements:

• low pass filtering with a cut off frequency as low as 7 KHz (note that the cut off frequency is 3400 Hz in telephony and 15KHz for FM radio),

• mp3 compression up to a rate of 64 Kbit/s,

• non linear attacks (e.g. a -6 dB multiplication for the samples having an amplitude over -15 dB),

• equalizer filter (e.g. a filter having an amplification of +10 dB for the band between 0 and 400 Hz, -5 dB for the band between 3 KHz and 5 KHz and +5 dB for the band between 6 KHz and 12 KHz),

• Gaussian noise addition,

• noise reduction filter, and

• echo addition.

To grant some robustness against the flanger attack is part of our future work. An accurate study on the (de)synchronisation issue in audio watermarking is also a direction for our future work.

6383-24, Poster Session

A comparison of wavelet multiresolution analysis and scale-space edge detection for lithography metrology

Y. Midoh, J. Imada, K. Nakamae, Osaka Univ. (Japan); H. Fujioka, Fukui Univ. of Technology (Japan)

As the feature size of LSIs (large-scale integrated circuits) becomes smaller and smaller into a few tens of nanometers, the inspection and measurement techniques with a sufficient accuracy of microstructures produced in the LSI microfabrication processes have become extremely important. Microstructures to be measured are photoresist patterns. We have tried to measure lithography line edge roughness (LER) from a noisy SEM photoresist image using wavelet multiscale edge detection method. In this method, the edge position is obtained from tracing of the characteristic modulus maxima lines in the scale-space. Also we have reported the scale-space edge detection method where the edge location was traced from the coarse scales back to finer scales on the Gaussian scale-space. The space is constructed by convolving the original image with Gaussians of increasing standard deviation. The method is extended to select the range of standard deviations in the Gaussian automatically. Here we try to compare performance between the wavelet multiscale edge detection and the scale-space edge detection methods as a function of the signal-to-noise ratio of modeled SEM images. We will discuss the performance of both methods as to the measurement accuracies of LER and line width roughness, and measurement time.

6383-28, Poster Session

Lighting inhomogeneities removal by wavelet analysis

O. Laligant, F. Mériaudeau, F. Truchetet, Univ. de Bourgogne (France)

Lighting uniformity is always an issue in visual inspection of industrial parts. While the human visual system is quite able to cope with this kind of problem, artificial vision systems are subject to false and no detection rate increase when the lighting conditions are not well mastered. If many authors have proposed various methods to unbiase image,\ most of the time they are designed in an ''ad hoc" way and they are very dependent on the experimental conditions. It can be

shown that a large class of the inhomogeneities in images due to lighting conditions can be reasonably modelled by a polynomial dependency of the luminance. The wavelet analysis theory proposes a lot of bases with various numbers of vanishing moments. By keeping only some wavelet coefficients it is possible to reconstruct an unbiased signal in which the interesting features, characterized by there resolution pertinence range, are cleaned from the polynomial variations supposed to be due to inhomogeneous lighting conditions. In this paper, after a brief presentation of a realistic lighting model, we show that the luminance image can be approximated by a polynomial function. Then we propose a method for choosing the wavelet basis and the resolution range knowing some a priori characteristics of the features to be detected. A design for a filtering scheme in the wavelet domain is presented. A simulation in 1D and 2D illustrates this proposition. Some results obtained on examples of real artificial vision inspection problems are finally given.

6383-29, Poster Session

Impact of source-independent modeling on unequal error protection for JPEG2000 images

E. Salemi, C. Desset, A. Dejonghe, IMEC (Belgium); P. Schelkens, J. P. H. Cornelis, Vrije Univ. Brussel (Belgium)

Focusing on the transmission of JPEG2000 images, the purpose of the present paper is to study the impact of the distortion model on a UEP algorithm and address the specific issues of having a potentially sub-optimal source model based on a training image set. We demonstrate that a source independent model has no visible impact on the performance for various JPEG2000 transmission scenarios, while enabling a low-complexity practical implementation of the optimization algorithm.

6383-30, Poster Session

Complex network representation of textures: new perspectives for texture characterization and classification

T. Chalumeau, F. Meriaudeau, Univ. de Bourgogne (France); L. Fontoura Da Costa, Univ. de São Paulo (Brazil); O. Laligant, Univ. de Bourgogne (France)

No abstract available.

6383-31, Poster Session

Modelling and predicting flow regimes using wavelet representations

D. A. Goodwin, R. G. Aykroyd, S. Barber, Univ. of Leeds (United Kingdom)

Introduction

Electrical tomography techniques provide a cheap and non-invasive approach to the study of static and dynamic processes. Such techniques are widely used in geophysical, industrial and medical investigations. Electrical tomography measurements have the potential to provide useful data without intruding into the industrial process, but produce highly correlated and noisy data, and hence need sensitive analysis. The commonly used approaches, based on regularized image reconstruction are slow, and still require image post-processing to extract control parameters.

Wavelets have proven to be highly effective at extracting information from noisy data. Using wavelets to relate such electrical measurements to the state of flow within a pipe, the state of the flow can be classified into one of a number of regimes. Wavelets are an ideal tool for our purpose since their multiscale nature enables the efficient description of both transient and long-term signals. Furthermore, only a small number of wavelet coefficients are needed to describe complicated signals and the wavelet transform is computationally efficient.

Method

Tomography results in several time series, all of which are highly correlated. The stationary wavelet transform of these series are found and then the sum of the absolute values of the resulting coefficients is calculated at each resolution level. The idea is that the magnitude of the wavelet coefficients at each level will give a measure of the activity of the flow in the pipe and give a useful predictor to classify the flow at either a fast moving “bubble” flow or a slower moving “churn” flow.

A logistic regression model is then built using data when the true flow type was known and the resulting model can be used for classification of subsequent observations. The logistic regression modelling idea extends to categorical variables with more than two values, using a generalised linear modelling approach. This methodology would allow the classification into more categories of flow regime.

Results

The model was used to predict flow regime in a set of independently generated flow patterns. This consisted of 168 time points of bubble flow, followed by 256 time points of churn flow, followed by 88 time points of bubble, with added Gaussian white noise with the same standard deviation as in the training dataset. The method gave correct predictions of the flow type in over 90% of the simulated cases.

Conclusion

Wavelets break down activity into a representation localised both in time (so we can analyse data at a fixed time point) and scale (so we can distinguish between high frequency bubble flow and low frequency churn flow). The statistical technique of logistic regression has been used to classify flow at a given time into the “bubble” or “churn” regimes.

6383-32, Poster Session

Strategies for improving the interpretability of Bayesian networks using Markovian time models and genetic algorithms

Á. L. Santana, C. R. Francês, Univ. Federal do Para (Brazil); C. A. Rocha, Univ. da Amazonia (Brazil); S. Carvalho, N. Vijaykumar, Instituto Nacional de Pesquisas Espaciais (Brazil); J. C. W. A. Costa, Univ. Federal do Para (Brazil)

One of the main factors for the success of the knowledge discovery process is related to the comprehensibility of the patterns discovered by the data mining techniques used. Among the many data mining techniques found in the literature, we can point the bayesian networks as one of most prominent when considering the easiness of knowledge interpretation achieved in a domain with uncertainty. However, the static bayesian networks present two basic disadvantages: the incapacity to correlate the variables, considering its be-havior throughout the time; and the difficulty of establishing the optimum combination of states for the variables, which would generate and/or achieve a given requirement. This paper presents an extension for the improvement of bayesian networks, treating the mentioned problems by incorporating a tempo-ral model, using Markov chains, and for intermediary of the combination of genetic algorithms with the networks obtained from the data.

6383-33, Poster Session

Support decision system for load forecast and dependencies modeling in power systems

C. A. Rocha, Univ. da Amazonia (Brazil); Á. L. Santana, C. R. Francês, L. P. Rego, Univ. Federal do Para (Brazil); A. Á. A. Tupiassú, V. Gato, REDE Celpa (Brazil); U. H. Bezerra, J. C. W. A. Costa, Univ. da Amazonia (Brazil)

One of the most desired aspects for power suppliers is the acquisition/sell of energy in a future time. However, power consumption forecast is not characterized only by the variables of the power system itself, being related to socio-economic and climatic factors. This way, it is essential for the power suppliers to project and correlate these parameters. This paper presents a system for power supply forecasting based on time series methods, with the purpose of defining the future power consumption of a given region. The system also provides the establishment of correlations among the variables using bayesian networks.

6383-34, Poster Session

Data mining and energy efficiency: future trends

S. A. Chaudhari, West Virginia Univ.

The extent of energy consumption in manufacturing sector is unimaginably high. With increasing energy costs the manufacturing industry is increasingly finding it hard to keep up with global competition. To increase energy efficiency Department of Energy funded Industrial Assessment Centers have helped medium sized

industries by great extent. The field of data stream mining (mining real time data acquired through data acquisition by sensors) and knowledge discovery in databases (KDD) has been growing extremely rapidly. It has tremendous potential of affecting every, day to day human activity as has been professed by intellectual community. The purpose of this paper is to survey many of the existing and future trends in the field of data mining, with a focus on those which are thought to have the most promise and applicability to improve energy efficiency. Major facet of this research can be investigation of cross relationships between production parameters and energy parameters. A lot of data mining techniques exist for mining streaming data or databases. Some techniques can be used more effectively for making plausible inferences about energy efficiency than others. The purpose of this paper is to propose a framework that will enable evaluation of the existing techniques for data mining with energy efficiency standpoint. Some of the established techniques like neural networks, clustering, and pattern recognition will be investigated with respect to potential for energy efficiency improvement.

6383-35, Poster Session

Shape-based mechanisms for content-based retrieval of Aurora images

C. Cao, T. S. Newman, G. A. Germany, The Univ. of Alabama in Huntsville

Every 36.8 seconds for the past 10 years, the NASA Polar satellite's UVI sensor has produced an image of the polar cap area of the earth. In all, over 8 million images have been collected. These images are stored in an image archive and currently can be retrieved based on date of collection and a limited set of descriptive features, such as satellite location. However, retrieval based on auroral oval shape has not been possible, despite certain shape features being of interest for phenomenological study by the scientific community. In this paper, we describe a fully automatic mechanism that allows fast retrieval of images of interest based on automatically mined shape features.

It has been proved recently that the aurora ovals in UVI imagery are elliptic in shape. Our approach exploits this characteristic to guide extraction of fundamental auroral shape characteristics. As shape characteristics are determined, they are saved in a database. Higher-level shape descriptors, such as extent, orientation, and the width of the aurora oval are then computed from the fundamental characteristics and also saved. Furthermore, higher-level aurora classifications are also performed using the shape descriptors, allowing retrieval of aurora by gross class of interest, such as standard, theta and "thick" aurora, etc. A user interface allows a user to query the image archive based on aurora characteristics.

The performance of the method has been evaluated against a subset of the full UVI archive, specifically versus the 582 aurora images from Jan. 10, 1997. Experimental results show that the method is highly accurate when retrieving aurora images with various auroral shape characteristics. The method is currently being integrated into an online search tool.

Conference 6384: Intelligent Robots and Computer Vision XXIV: Algorithms, Techniques, and Active Vision

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6384-01, Session 1

Automated synthesis of distortion-invariant filters: AutoMinace

R. Patnaik, D. P. Casasent, Carnegie Mellon Univ.

No abstract available

6384-02, Session 1

Emerging directions in human-robotic space exploration technologies

P. S. Schenker, Jet Propulsion Lab.

No abstract available

6384-03, Session 1

A telepresence robot system realized by embedded object concept

J. Röning, T. J. Vallius, Oulun Yliopisto (Finland)

This paper presents a test case for the previously introduced Embedded Object Concept (EOC). The EOC utilizes common object oriented methods used in software by applying them into combined Lego-like software-hardware entities. These entities represent objects in object-oriented design methods, and they are the building blocks of embedded systems. The goal of the EOC is to make designing embedded systems easier. This concept enables people without comprehensive knowledge in electronics design to create new embedded systems, and for experts it shortens the design time of new embedded systems.

The test case is a telepresence robot system. The system consists of a two wheeled human height robot and its computer counter part. The robot contains video and audio exchange capability via a WLAN connection and a controlling and balancing system for driving with two wheels only. The robot is built in two versions. The first version consists of a small portable PC device and the Atomi-objects, which are our implementation of Embedded Objects. This version demonstrates the possibility of using the EOC together with a regular computer. The second version consists of only Atomi-objects, demonstrating the flexibility of the EOC for modifications and proving the capabilities of the EOC by replacing a computer. The computer counter part is a regular PC with audio and video capabilities running with a robot control application.

The objectives for this test case, its base techologies, and current status were introduced introduces in the previous SPIE conference. This paper introduces the finalized robot. The purpose of this test case is to validate the suitability of the EOC for relatively complex systems. The test validates several EOC-related issues: the Embedded Object Architecture (EOA) with the AtomiBus II -bus system, an object oriented design method for architecture design, and incremental device development, which is made possible by the architecture. The robot system is analyzed for its functionality, design time and overall costs in respect to a similar system made with computers or a system made as an embedded system without the EOC.

6384-04, Session 2

Pedestrian detection in crowded scenes with the histogram of gradients principle

O. Sidla, M. Rosner, Y. Lypetskyy, JOANNEUM RESEARCH GmbH (Austria)

The implementation of smart surveillance systems today depends heavily on their ability to detect, recognize, and track pedestrians in video streams. The conditions in which these systems are installed ranges from indoor scenes with constant illumination to outdoor scenarios where crowded places are to be observed. But even the reliable and robust person detection in a lightly crowded situations is a challenge for vision algorithms available today. This paper tries to go a step further towards a robust surveillance system with the description of a real-time implementation of a pedestrian detection system which is based on the Histogram of Gradients (HOG) principle.

The HOG Algorithm calculates edge orientation histograms within small subwindows which are called cells. Neighboring cell histograms are combined into normalized feature vector blocks by concatenating them. A set of adjacent overlapping blocks within a detection window of fixed size form the final feature vector. The detection windows are moved across the input image - at each location the features are calculated and classified for background/pedestrian. Not all histogram entries of the feature vector are actually used. Based on a very large number of training samples the pedestrian detector is optimized in size by selecting suitable histogram orientations with the help of a genetic fetaure selection algorithm. For optimization we try to find the best 200 features out of more than 6000 available. The final classifier has a detection accuracy of 99.71% (11 samples out of 14181 in the wrong class). Once the feature vector for a detection window is created, a Support Vector Machine (SVM) classifier decides whether the dection window contains a pedestrian. In order to speed up the detection process, two strategies are implemented

i) Fast pre-classification with a small SVM of only 20 features. Only promising outputs are fed into the full pedestrian SVm classifier.

ii) Not every location in the input image is searched. Based on the classfier output of neighboring detection windows, a possible location is skipped.

Both methods mentioned above allow a significant speedup of detection compared to a brute force search of every possible image location. Their benefits are compared and possible advantages/ disadvantages are discussed. The usability of the HOG algorithm in real world scenarios is demonstrated and evaluated.

6384-05, Session 2

Remote imagery for unmanned ground vehicles: the future of path planning for ground robotics

B. L. Theisen, P. A. Frederick, U.S. Army Tank-automotive and Armaments Command; D. Ward, Lockheed Martin Missiles And Fire Control

Remote Imagery for Unmanned Ground Vehicles (RIUGV) uses a combination of high-resolution multi-spectral satellite imagery and advanced commercial of-the-self (COTS) object-oriented image processing software to provide automated terrain feature extraction and classification. This information, along with elevation data, infrared imagery, a vehicle mobility model and various meta-data (local weather reports, Zobler Soil map, etc...), is fed into automated path planning software to provide a stand-alone ability to generate rapidly updateable dynamic mobility maps for Manned or Unmanned Ground Vehicles (MGVs or UGVs). These polygon based mobility maps can reside on an individual platform or a tactical network. When new information is available, change files are generated and ingested into existing mobility maps based on user selected criteria. Bandwidth concerns are mitigated by the use of shape files for the representation of the data (e.g. each object in the scene is represented by a shape file and thus can be transmitted individually). User input (desired level of stealth, required time of arrival, etc...) determines the priority in which objects are tagged for updates. This paper will examine the test results of the July 2006 field experiment at Fort Knox, Kentucky.

6384-06, Session 2

New experimental diffractive-optical data on E.Land's Retinex mechanism in human color vision

N. Lauinger, CORRSYS-DATRON GmbH (Germany)

A correlator-optical imaging system with three-dimensional nano- and micro-structured diffraction gratings in aperture and in image space allows an adaptive optical correlation of local RGB data in image space with global RGB data - light from overall illumination in the visual field scattered from the aperture of the optical imaging system into image space -, diffracted together into reciprocal grating space (photoreceptor space). This correlator-optical hardware leads to new interpretations of color constancy performances in human vision. Recent experiments have shed a new light on the diffractive-optical information processing rules in human vision. These data will be presented and commented.

6384-07, Session 3

Embodying a cognitive model in a mobile robot

D. P. Benjamin, Pace Univ.; D. Lonsdale, Brigham Young Univ.; D. Lyons, Fordham Univ.

The ADAPT project is a collaboration of researchers in robotics, linguistics and artificial intelligence at three universities to create a cognitive architecture specifically designed to be embodied in a mobile robot. Cognitive science has constructed cognitive architectures that model reasoning and learning in individual tasks and that reason about spatial and temporal relationships in simulated domains. We believe that it is time to embed a cognitive model in the physical world and test these reasoning and learning mechanisms when faced with the full complexity of the real world. However, we have found that there are major respects in which existing cognitive architectures are inadequate for robot cognition. In particular, they lack support for true concurrency and for active perception. ADAPT remedies these deficiencies by modeling the world as a network of concurrent schemas, and modeling perception as problem solving. Schemas are represented using the RS (Robot Schemas) language, and are activated by spreading activation. RS provides a powerful language for distributed control of concurrent processes. Also, The formal semantics of RS provides the basis for the semantics of ADAPT's use of natural language. We have implemented the RS language in Soar, a mature cognitive architecture originally developed at CMU and used at a number of universities and companies. Soar's subgoaling and learning capabilities enable ADAPT to manage the complexity of its environment and to learn new schemas from experience. We describe the issues faced in developing an embodied cognitive architecture, and our implementation choices.

6384-08, Session 3

Visualization of pallets

R. V. Bostelman, T. Hong, T. Chang, National Institute of Standards and Technology

The National Institute of Standards and Technology has been studying visualization of pallets for the automated guided vehicle (AGV) industry. Through a cooperative research and development agreement with Transbotics, an AGV manufacturer, NIST has developed advanced sensor processing and world modeling algorithms to verify pallet location and orientation with respect to the AGV. NIST has developed the 4D/RCS (Four Dimensional/Real-Time Control System) reference model architecture for intelligent systems applying portions to this project as well. Sensor processing utilizes two onboard AGV, single scan-line LADAR units. One is a Safety unit located at the base of a forktruck AGV and typically used to detect obstacles such as humans, and slow or stop the vehicle dependent upon obstacles distance from the vehicle. In this project, the unit was also used to detect pallets and their surrounding area and obstacles, such as the walls of a truck to be loaded with pallets. The second, panning LADAR was rotated 90 degrees, mounted on a rotating motor, and mounted at the top, front of the AGV. The rotating motor allows the LADAR to quickly pan 90 degrees to acquire many scan-lines of range data. The "panner" sensor processing algorithm combines the many single scan-lines into a 3D point cloud and segments out the pallet by a priori, approximate pallet load or remaining truck volumes. A world model is then constructed and output to the vehicle for pallet/truck volume verification. This paper will explain this joint government/industry project and results of using LADAR imaging methods.

6384-09, Session 3

Indoor environment modeling for interactive robot security application

S. Jo, Q. M. Shahab, Y. Kwon, Korea Institute of Science and Technology (South Korea)

This paper presents an easy and simple method to generate 2D and 3D model for virtual indoor environment. The main features of our indoor environment model are as follows. First, the developed indoor 2D/3D model is based on W3C standard format, SVG (Scalable Vector Graphics) format for 2D model and VRML (Virtual Reality Modeling Language) format for 3D model. It has an advantage in view of 2D and 3D model compatibility to users. Second, the 2D and 3D model can be accessed through internet explorer everywhere. Third, we also address mobile application for remote surveillance. Our SVG 2D map can be accessed with cellular phone of J2ME MIDP. Fourth, the texture image with 3D geometry model provides vividness to user, which is generated using wide-angle camera and image stitching techniques

The interactive services are developed while using 2D and 3D indoor model. A real-time current robot position is displayed on the developed indoor model using socket communication between robot server and user client software. The interactive tele-operation of robot position is supported with easy-to-use interface. According to user interaction, the remote physical surveillance robot will move to point of regard in surveillance area.

6384-10, Session 3

Biomimetic sensory abstraction using hierarchical quilted self-organizing maps

J. W. Miller, P. H. Lommel, Charles Stark Draper Lab., Inc.

We present an approach for abstracting invariant classifications of spatiotemporal patterns presented in a high-dimensionality input stream, and apply an early proof-of-concept to shift & scale invariant shape recognition.

The isocortex, which constitutes approximately 80% of the human brain (by mass), is responsible for a large part of its advanced activities, including sensory processing (visual, auditory, somatosensory), motor control, language understanding & generation, logic, math, and spatial understanding / visualization. The isocortex appears to have a uniform structure, and to perform similar information processing operations throughout its varied functional regions.

We are developing an unsupervised learning algorithm using recurrent self-organizing maps (RSOM) arranged in a pyramidal hierarchy, attempting to mimic the parallel/hierarchical pattern of isocortical processing. In the algorithm, sensory input is divided into small regions, which are processed in parallel by a composite layer of SOMs and RSOMs, which cluster patterns in input space and time, respectively. The abstracted output of each composite layer is the input to the next higher layer. It is expected that at the top of the hierarchy, sensory patterns will be compressed into representations which are invariant to any transformation (e.g. shift, scale, orientation) as long as related patterns occur near in time.

The results of experiments with a proof-of-concept implementation are presented, in which the algorithm learns to distinguish multiple shapes, invariant to shift and scale transformations, in a very small (7x7 pixel) field of view.

6384-11, Session 3

A comparison of single and multiple image stereo for real-time robot guidance

E. L. Hall, D. W. Rosselot, Univ. of Cincinnati

A comparison of single, dual and multiple image stereo imaging for visual presentation and three dimensional measurements for real time robot guidance will be made. Some mathematical comparisons and error analysis can be made. Other heuristics for selection of the number of views and camera locations will also be presented. The comparison will be tested on the experimental UC Bearcat Cub robot

during the 14th Intelligent Ground Vehicle Competition in June 2006. The significance of this research is that it provides guidelines for selection and use of stereo imaging for robot guidance.

6384-13, Session 3

Analysis on the jumping of a spherical rolling robot

L. Wang, Beihang Univ. (China); H. Sun, Q. Jia, Beijing Univ. of Posts and Telecommunications (China)

The movement of a spherical rolling robot before jumping is analyzed by use of phase plane on the basis of kinematics and dynamics and the jumping condition is gotten. The dynamic model of the spherical rolling robot after jumping is developed through the D'Alembet principle. The model is simulated and an experiment is completed. The simulation and experiment results prove the analysis and the feasibility of the jumping of the spherical rolling robot.

6384-14, Session 3

Virtual performer: single camera 3D measuring system for interaction in virtual space

K. Sakamoto, S. Taneji, Shimane Univ. (Japan)

A 3D display system is useful technology for virtual reality, mixed reality and augmented reality. We have researched spatial imaging and interaction system.

We developed a prototype musical instrument system using the motion capture. In this system, the performer plays music in the virtual space. The virtual instrument system consists of the image capture, measuring performer's position, detecting and recognizing motions and synthesizing sound system using the personal computer. In this paper, we describe the method of 3D measuring using a single camera for tracking user's position and the cyber music instrument system.

We call this music instrument system "virtual theremin". Performer's right hand is used to control a musical scale. Sounds may be generally characterized by pitch i.e., frequency of sound. For example, middle C in equal temperament = 261.6Hz. The left hand is used to control the volume. The regions of scale and volume are determined by the position of the face in the captured scene. The body, face and hands are extracted from the captured camera image. The result of extracting the body is used for measuring the distance from camera to performer and extracting regions of the face and hands.

In addition, we incorporated funny application software into the virtual performer system. The authors call this additional software as the "virtual puppet." The "virtual puppet" software superimposes a 3D computer graphics character image on the captured camera's scene.

6384-15, Session 3

A method of 3D measuring for finger pointing using a single camera

H. Nakayama, K. Sakamoto, Shimane Univ. (Japan)

We developed interaction media systems in the 3D virtual space. In these systems, the artist draws a picture in the 3D workspace. In this virtual drawing system, the finger-pointed points are superimposed on the captured scene when the user indicates the point on the floor. Hence the user can draw the line art in the virtual space. This virtual drawing system consists of the Windows PC connected with the USB camera for PCs. The drawing system software functions as the video capture, the recognition and detection of interested regions for the motion capture, the measurement for estimating the position of finger pointing and the operation of an interaction. We used the method of measuring the position of fingertip and finger pointing using a single camera without stereo-pair images. The main point of our proposal is this 3D measuring method using a single camera.

In this paper, a finger pointing system is described that can specify the position of pointed target. A 3-D position is generally detected and measured by stereoviewing. This pair of stereo images allows us to obtain the 3-D information about the object. However it is possible to estimate the position of fingertip using a single image without stereo images. The length of arm is approximately calculated from stature and shoulder length, then the 3-D position of fingertip is estimated using the geometric model of human. We have developed a prototype finger pointing system using a single camera and a personal computer. This paper proposes the measuring method of the position of finger using a single camera. This finger recognition and measuring system realizes the finger pointing such that user draws a picture on the floor in a virtual space. We evaluated the result of specified positions by prototype system and made sure the performance required for practical use.

6384-16, Session 3

Functions of images

J. Lehtonen, A. Andriyashin, J. P. S. Parkkinen, Joensuu Yliopisto (Finland); T. Leisti, G. S. Nyman, Univ. of Helsinki (Finland)

The visual quality of images is outward in image presentation, compression and analysis. Depending on the use, the quality of images may give more information or more experiences to the viewer. However, the relations between mathematical and human methods for clustering the images is not obvious. For example, different humans think differently and so, they make the grouping differently. However, there may be some connections between image mathematical features and human selections. Here we try to find such relations that could give more possibilities for developing the actual quality of images for different purposes. In this study, we present some methods and preliminary results that are based on psychological tests to humans, MPEG-7 based features of the images and face detection methods. We also show some notes and questions belonging to this problem and plans for the future research.

6384-17, Session 4

Feature optimization and creation of a real-time pattern matching system

E. Wildling, O. Sidla, JOANNEUM RESEARCH GmbH (Austria)

State of the art algorithms for people or vehicle detection should not only be accurate in terms of detection performance and low false alarm rate but also fast enough for real time applications. Accurate algorithms are usually very complex and tend to have a lot of calculated features to be used or parameters available for adjustments. So one big goal is to decrease the amount of neccessary features while increasing the speed of the algorithm and overall performance by finding the right set of parameters.

In this paper we describe algorithms for people and vehicle detection based on Histograms of Gradients. The HOG Algorithm calculates edge orientation histograms within small subwindows which are called cells. Neighboring cell histograms are combined into normalized feature vector blocks by concatenating them. A set of adjacent overlapping blocks within a detection window of fixed size forms the final feature vector. The detection windows are moved across the input image - at each location the features are calculated and classified into background or pedestrian.

From the possible of more than 6000 features a reasonable classifier has to be constructed.

The classifier creation is done in two steps:

1.) Feature Selection and

2.) classifier optimization. The feature selection process was first an Ada Boost Algorithm, but has then been chosen to be based on evolutionary computation namely a genetic feature optimiztation procedure. Second step of optimization is the SVM brute force parameter optimization. This has been done so because global optimization seemed too expensive in terms of CPU time necessary.

This paper shows the experiments that have been made with automated selection of 3000, 1000, 300, 200, 160 and 20 features, comparison of the corresponding achieved classification performance, comparison of detection performance on real videos (some sample images), visualization of which features have been chosen (which histogram bins on which location in the image search feature) and visualization of the results space of SVM optimisation.

The results of our feature selection and parameter optmization have been used in a 2 step pedestrian system:

1) creation of candidate subwindows with a very fast 20 feature linear SVM

2) final classification with a slower 160 feature 2 degree polynmial SVM

The above combination allows real-time operation of the system on a modern Pentium M system to detect pedestrians scale invariant in images of quarter PAL resolution.

6384-18, Session 4

Vehicle detection methods for surveillance applications

O. Sidla, E. Wildling, Y. Lypetskyy, JOANNEUM RESEARCH GmbH (Austria)

The efficient monitoring of traffic flow as well as related surveillance and detection applications demand an increasingly robust recognition of vehicles in image data. This paper describes two different methods for vehicle detection in real world situations which are based on Principal Component Analysis (PCA) and the Histogram of Gradients (HOG) principle. Both methods are described in detail and their detection capabilities as well as advantages and disadvantages are compared. A very large sample dataset which contains images of cars from the backside and frontside in day and night conditions is the basis for creation and optimiziation of the recognition frameworks. The resulting two detectors allow a recognition of vehicles in frontal view +- 30 deg and views from behind +- 30deg. The PCA component analysis method extracts in the training phase first the most salient Eigenvectors from the data set of sample images. It then uses the projection co-ordinates of 32x32 pixel detection subwindows into the resulting Eigenspace as features which are subsequently classified by a Support Vector Machine.

The current implementation utilizes the first 50 Eigenimages for detection, it is made scale independent by modifying the size of the detection subwindow as sampled from the original input image. The HOG Algorithm calculates edge orientation histograms within small subwindows which are called cells. Neighboring cell histograms are combined into normalized feature vector blocks by concatenating them. A set of adjacent overlapping blocks within a detection window of fixed size form the final feature vector. The detection windows are moved across the input image - at each location the features are calculated and classified for background/vehicle. The HOG detector is made scale invariant by rescaling the input image in several steps so that effectively a resolution pyramid is created. Not all histogram entries of the feature vector are actually used. Based on the large number of training samples the vehicle detector is optimized in size by selecting suitable histogram orientations with the help of a genetic fetaure selection algorithm. For optimization we try to find the best 100 features out of more than 2000 available.

The paper demonstrates that both detection methods can operate effectively even under difficult lighting situations with very high detection rates and a low number of false positives.

6384-19, Session 4

High-quality and small-capacity e-learning video featuring lecturer-superimposing PC screen images

Y. Nomura, Mie Univ. (Japan)

Information processing and communication technology are progressing quickly, and are prevailing throughout various technological fields. Therefore, the development of such technology should respond to the needs for improvement of quality in the e-learning education system. The authors propose a new video-image compression processing system that ingeniously employs the features of the lecturing scene. While dynamic lecturing scene is shot by a digital video camera, screen images are electronically stored by a PC screen image capturing software in relatively long period at a practical class. Then, a lecturer and a lecture stick are extracted from the digital video images by pattern recognition techniques, and the extracted images are superimposed on the appropriate PC screen images by off-line processing. Thus, we have succeeded to create a high-quality and small-capacity (HQ/SC) video-on-demand education content featuring the advantages: the high quality of image sharpness, the small electronic file capacity, and the realistic lecturer motion.

6384-20, Session 4

A parallel unmixing algorithm for hyperspectral images

S. A. Robila, L. Maciack, Montclair State Univ.

This paper describes a new algorithm for feature extraction in hyperspectral images based on source separation and parallel computing. In source separation, given a linear mixture of sources, the goal is to recover the components by producing an unmixing matrix. In multispectral/hyperspectral imagery, the separated components can be associated with features present in the image, the source separation algorithm projecting them in different image bands.

Source separation based methods have been employed for target detection and classification of hyperspectral images. However, these methods usually involve restrictive conditions on the nature of the sources such as orthogonality (in Principal Component Analysis - PCA and Orthogonal Subspace Projection - OSP) or statistical independence (in Independent Component Analysis - ICA) of endmembers and does not ensure neither positivity nor addition to 1 of the abundances. Compared to this, our approach is based on the Nonnegative Matrix Factorization (NMF), a less constraining unmixing method. NMF has the advantage of producing positively defined data, and, with several modifications that we introduce also ensures addition to 1. The endmember vectors and the abundances are obtained through a gradient based optimization approach.

The algorithm is further modified to run in a parallel environment. The Parallel NMF significantly reduces the time complexity and is shown to also easily port to a distributed environment. Experiments with in-house and Hydice data suggest that NMF outperforms ICA, PCA and OSP for unsupervised endmember extraction. Coupled with its parallel implementation, the new method provides an efficient way for unsupervised unmixing further supporting our efforts in the development of a real time hyperspectral sensing environment with applications to industry and life sciences.

6384-21, Session 4

A new algorithm for fruit shape classification based on level set

J. Gui, Y. Ying, Zhejiang Univ. (China)

Applications of machine vision in automated inspection and sorting of fruits have been widely studied by scientists and engineers, and the promise of this technology for improving grading efficiency was proved. Among these quality criteria of fruits, shape classification is one of the major concerns and which is still a difficult problem for citrus inspection. Shape classification techniques require a shape descriptor that can effectively capture the important information regarding a shape, and a similarity measure that can accurately and efficiently compare different shapes. Given that it is evident that several key issues need to be resolved while performing shape classification. In particular, a shape descriptor needs to be employed, alignment and correspondence issues need to be addressed, and a similarity metric needs to be designed. In this research, a new algorithm for fruit shape classification was proposed. The level set representations according to singed distance transforms were used, which are a simple, robust, rich and efficient way to represent shapes. Based on these representations, the rigid transform was adopted to align shapes within the same class, and the simplest possible criterion, the sum of square differences was considered. After align procedure, the average shape representations can easily be derived and shape classification was performed by the nearest neighbor method. Promising results were obtained on experiments showing the efficiency and accurate of our algorithm.

6384-24, Session 5

An embedded vision system for an unmanned four-rotor helicopter

D. Lee, B. Godard, S. Fowers, B. Nelson, J. K. Archibald, Brigham Young Univ.

We introduce an embedded vision system that is capable of controlling an unmanned four-rotor helicopter and processing live video input for various law enforcement, security, and military applications. This embedded vision system includes a newly developed compact FPGA

board (Helios) and a Smooth Automated Intelligent Leveling daughter board (SAIL). The Helios board contains a Xilinx Vertex IV FPGA chip and memory for implementing real time vision algorithms. The SAIL board contains the sensors used for automated, level flight. It contains a logic level converter to convert between the serial logic levels of the FPGA, which uses 3.5v, and the helicopter, which uses 5v. There is a Dinsmore analog compass which is used to monitor yaw (the clockwise or counterclockwise horizontal spinning). The compass has two outputs which follow a sine and cosine voltage curve, respectively. Depending on the voltage of each pin the corresponding angular direction can be determined. The outputs from the compass are passed through an Analog Devices, 4-channel, 8-bit analog to digital converter. The converted voltage is passed to the Helios board which runs c code which determines the correct angular direction. Finally, a Frederick's Electrolytic Sensor is used to measure pitch and roll measurements. The level sensor is excited using an alternating voltage pattern. Four readings are taken to represent the +X, -X, +Y, -Y directions of the level sensor. These readings are passed through the analog to digital converter and then compared on the Helios board to determine the pitch and roll. The idea is that a controller can send commands to the helicopter via the remote control and the Helios board will take readings from the SAIL board to determine pitch, yaw, and roll, and then modify the commands to keep the helicopter level. Eventually, all commands will be generated from the Helios board from control software or as output from a wireless modem. The SAIL board will function by encapsulating the stability control making it easier for control commands to be absolute.

6384-25, Session 5

Framework for autonomy

R. Hildebrant, Charles Stark Draper Lab., Inc.

The development of autonomous planning and control system software often results in the customization of a design concept which is unique for a specific task. This paper describes a software framework for orchestrating the planning and execution of autonomous activities for an unmanned vehicle, or a group of cooperating unmanned vehicles. The framework supports an arbitrary span of autonomous capability, ranging from simple low level tasking, requiring much human intervention, to higher level mission-oriented tasking, requiring much less. The approach is to integrate the four basic functions of any intelligent devise or agent (plan development, plan monitoring, plan diagnosing, and plan execution), with the mathematical discipline of hierarchical planning and control. The result is a domain-independent software framework, into which domain-dependent modules for planning, monitoring, and diagnosing can be plugged. This framework for autonomy, combined with the requisite modules for vehicle operation, is then deployed to realize the desired level of autonomous operation for the vehicle. Examples will be provided to illustrate the suitability of the framework to a variety of control problems.

6384-26, Session 5

Moving target detection through omnidirectional vision fixed on AGV

S. Yang, Tianjin Univ. (China) and Tianjn Univ. of Technology (China); Z. Cao, C. Ren, Tianjin Univ. of Technology (China); P. He, Tianjin Univ. (China)

Extremely wide view of the omni-vision performs highly advanced for the vehicle navigation and target detection. However moving targets detection through omni-vision fixed on AGV involves more complex environments, where both targets and vehicle are in the moving condition. The moving targets will be detected in a moving background. After analyzing the character on omnidirectional vision and image, we propose to use the estimation in optical flow fields, Gabor filter, and cluster statistics over optical flow fields for detecting moving objects. Because polar angle and polar radius R of polar coordinates are changed with the targets moving ,we improve optical flow approach which can be calculated based on the polar coordinates at the omnidirectional center. Gabor filter banks are constructed which have 24 directions every 15°in 360°omnidirectional image.By clustering statistics and comparing to moving vectors from the 24 directions the moving target's optical flow fields could be recognized. Experiment results demonstrate that the proposed approach is feasible and effective.

6384-27, Session 6

A CMAC neural net-based vehicle-controlling algorithm

F. Zhang, Y. Ying, Zhejiang Univ. (China); Q. Zhang, Univ. of Illinois at Urbana-Champaign

It was intended to develop a vehicle-controlling algorithm for an automated agricultural vehicle. A 2D CMAC net was designed to map the parameters of guidance line into the attitude parameters, upside point and downside point. In the training stage, the vehicle was fixed, while a man-made road was moved to every possible position inside the view range. The line parameters were recoded in real time, and the turning angles were set at the same time. After sampling enough data, we trained the CMAC net and obtained a map-weight file. When the vehicle moved, it mapped the guidance line parameters into the CMAC net and obtained the turning angle. The results showed that the CMAC net could produce the right turning set.

6384-28, Session 6

The measure and control system for agricultural robot

T. Sun, Y. Ying, F. Zhang, Zhejiang Univ. (China)

Automation of agricultural field work equipments in the near term appears both economically viable and technically feasible. This paper describes a agriculture robot system for automated field work. It is a computer-controlled vehicle, equipped with a pair of video cameras, one inclinometer, one potentionmeter for measuring turning angle , and two encoders. The measure system was consisted of a PC, 5 ECU. The sensor data were filtered before sending to PC. The test showed that it work efficiently in field.

6384-29, Session 6

Real-time intelligent robot control using an adaptive critic with a task control center and dynamic database

E. L. Hall, X. S. Liao, M. Ghaffari, Univ. of Cincinnati

The purpose of this paper is to describe the design, development and simulation of a real time controller for an intelligent, vision guided robot. The use of a creative controller that can select its own tasks is demonstrated. This creative controller uses a task control center and dynamic database. The dynamic database stores both global environmental information and local information including the kinematic and dynamic models of the intelligent robot.

The kinematic model is very useful for position control and simulations. However, models of the dynamics of the manipulators are needed for tracking control of the robot's motions. Such models are also necessary for sizing the actuators, tuning the controller, and achieving superior performance. Simulations of various control designs are shown. Also, much of the model has also been used for the actual prototype Bearcat Cub mobile robot. This vision guided robot was designed for the Intelligent Ground Vehicle Contest.

A novel feature of the proposed approach is that the method is applicable to both robot arm manipulators and robot bases such as wheeled mobile robots. This generality should encourage the development of more mobile robots with manipulator capability since both models can be easily stored in the dynamic database. The multi task controller also permits wide applications. The use of manipulators and mobile bases with a high-level control are potentially useful for space exploration, certain rescue robots, defense robots, and medical robotics aids. The significance of this approach is that it will aid in showing that such robots are feasible, demonstrable, and applicable to a variety of applications that are needed in society.

6384-30, Session 6

Obstacle avoidance using predictive vision based on a dynamic 3D world model

D. P. Benjamin, T. Achtemichuk, Pace Univ.; D. Lyons, Fordham Univ.

We have designed and implemented a fast predictive vision system for a mobile robot based on the principles of active vision. This vision

system is part of a larger project to design a comprehensive cognitive architecture for mobile robotics. The vision system represents the robot's environment with a dynamic 3D world model based on a 3D gaming platform (Ogre3D). This possesses sophisticated graphics and uses a physics plugin to model the dynamics of the world. This world model contains a virtual copy of the robot and its environment, and outputs graphics showing what the virtual robot "sees" in the virtual world; this is what the real robot expects to see in the real world. The vision system compares this output in real time with the visual data from the stereo color cameras, which consists of color segments, optical flow data, and stereo disparity data. Any large discrepancies between the expected data and the real data are flagged and sent to the robot's cognitive system, which constructs a plan for focusing on the discrepancies and resolving them, e.g. by updating the position of an object or by recognizing a new object, which causes a virtual copy of the new object to be created in the world model. An object is recognized only once; thereafter its observed data are monitored for consistency with the predictions, greatly reducing the cost of scene understanding. We describe the implementation of this vision system and how the robot uses it to locate and avoid obstacles.

6384-31, Session 6

A design approach for small vision based autonomous vehicles

B. Edwards, W. Fife, J. K. Archibald, D. Wilde, D. Lee, Brigham Young Univ.

This paper describes the design of a small autonomous vehicle based on the Helios computing platform, a custom FPGA based board capable of supporting on-board vision. We emphasize the following areas: hardware-software co-design to utilize the unique computational abilities of Helios, vision processing algorithms tailored to specific application environments, and application environment design.

Target applications for the Helios computing platform are those that require light-weight equipment and low-power consumption. To demonstrate the capabilities of FPGAs in real-time control of autonomous vehicles, a small R/C monster truck was outfitted with a Helios board. The environment provided by such a small vehicle is an ideal platform for testing and development. The proof of concept application for this autonomous vehicle was a timed race through an environment with obstacles.

Given the size restrictions of the vehicle and its operating environment, the only feasible on-board sensor is a small CMOS camera. The single video feed is therefore the only source of information of the surrounding environment. The image is then segmented and processed by custom logic in the FPGA which also controls direction and speed based on visual input.

Since the operating environment was not rigidly specified at the outset, certain characteristics of the environment were tailored for this application. Matching visual attributes of the environment to the vision processing capabilities of a platform shortens the development time from initial design to functional operation.

6384-32, Session 6

High-speed tracking active cameras for obtaining clear object images

H. Oike, H. Wu, T. Kato, T. Wada, Wakayama Univ. (Japan)

In this paper, we propose a high performance object tracking system for obtaining high quality images of a high-speed moving object at video rate by controlling a pair of active cameras mounted on two fixed view point pan-tilt-zoom units. In this paper, the 'High quality image' means that the image of the object is in focus and not blurred, the S/N ratio is high enough, the size of the object in the image is kept unchanged, and the position the object appearing at the image center. To achieve our goal, we use K-means tracker algorithm for tracking object in image sequence which taken by the active cameras. We use the result of the K-means tracker to control the angular position and speed of each pan-tilt-zoom unit by employing PID control scheme. By using two cameras, binocular stereo vision algorithm can be used to obtain 3D position and velocity of the object. These results are used for adjust the focus and the zoom. Moreover, our system let two cameras fix its eyes on one point in 3D space. However, this system may be unstable, when time response loses by interfering in a mutual control loop too much, or by hard restriction of cameras action. In order to solve these problems, we introduced a concept of reliability into K-means tracker, and propose a method for controlling active cameras by using relative reliability. We produce the prototype system. Though extensive experiments we confirmed that we can obtain in focus and motion-blur-free images of a high-speed moving object at video rate.

6384-33, Session 7

The 14TH Annual Intelligent Ground Vehicle Competition: intelligent teams creating intelligent ground robots

B. L. Theisen, U.S. Army Tank-automotive and Armaments Command; G. R. Lane, Applied Research Associates, Inc.

The Intelligent Ground Vehicle Competition (IGVC) is one of three, unmanned systems, student competitions that were founded by the Association for Unmanned Vehicle Systems International (AUVSI) in the 1990s. The IGVC is a multidisciplinary exercise in product realization that challenges college engineering student teams to integrate advanced control theory, machine vision, vehicular electronics, and mobile platform fundamentals to design and build an unmanned system. Teams from around the world focus on developing a suite of dual-use technologies to equip ground vehicles of the future with intelligent driving capabilities. Over the past 14 years, the competition has challenged undergraduate, graduate and Ph.D. students with real world applications in intelligent transportation systems, the military and manufacturing automation. To date, teams from over 50 universities and colleges have participated. This paper describes some of the applications of the technologies required by this competition and discusses the educational benefits. The primary goal of the IGVC is to advance engineering education in intelligent vehicles and related technologies. The employment and professional networking opportunities created for students and industrial sponsors through a series of technical events over the three-day competition are highlighted. Finally, an assessment of the competition based on participant feedback is presented.

6384-34, Session 7

Autonomous robot navigation using vision and sensor based algorithm

S. Bhandari, M. I. Restrepo, A. Mathis, D. Pietrocola, K. Mohiuddin, S. H. Lin, D. J. Ahlgren, Trinity College

ALVIN-VII is an autonomous vehicle designed to compete in the Intelligent Ground Vehicle Competition. The competition consists of Autonomous and Navigation challenges. Using tri-processor control architecture the information from various components such as sonar sensors, cameras, GPS and compass is effectively integrated to map out the path of the robot. In Autonomous challenge, the real time data from two IEEE Pyro cameras and an array of four sonar sensors is plotted on a custom defined polar grid to identify the position of the robot with respect to the obstacles in its path. Depending on the position of the obstacles in the grid, a state number is determined and a command of action is retrieved from the state table. The image processing algorithm comprises of a series of steps involving plane extraction, morphological analysis, edge extraction and interpolation, all of which are statistically based allowing optimum operation at varying ambient conditions. In the Navigation challenge, data from GPS and sonar sensors is integrated on a polar grid with flexible distance thresholds and a state table approach is used to drive the robot to the waypoint while avoiding obstacles. Both algorithms are developed and implemented using National Instrument's (NI) LabView platform. The task of collecting and processing information in real time can be time consuming and hence not reactive enough for moving robots. Using three controllers, the image processing is done separately for each camera while a third controller integrates the data received through Ethernet connection. Currently, research and testing is underway to implement fuzzy logic controller for integration of processed data.

6384-35, Session 7

A simple inexpensive and effective implementation of a vision-guided autonomous robo

B. Tippetts, K. Lillywhite, S. Fowers, A. W. Dennis, C. R. Greco, D. Lee, J. K. Archibald, Brigham Young Univ.

This paper discusses a simple, inexpensive, and effective implementation of a vision guided autonomous robot. This implementation is a second year submission for Brigham Young University students to the Intelligent Ground Vehicle Competition. The objective of the robot was twofold; to navigate a course constructed of white boundary lines and orange obstacles, and to locate a series of GPS coordinates while avoiding orange obstacles. A used electric wheelchair was used as the robot base. The wheelchair was purchased from a local thrift store for $28. The base was modified to include tank tracks using a friction drum system. This modification allowed the robot to perform better on a variety of terrains; resolving issues with last year's design. The wheelchair joystick was removed and replaced with a board that emulated joystick operation and was capable of receiving commands through a serial port connection, thus preserving the robust motor controls of the wheelchair. Three different algorithms were implemented and compared: a purely reactive approach, a potential fields approach, and a more sophisticated machine learning approach. Each of the algorithms used color segmentation methods to identify the features of the course. For the second aspect of the competition, the three algorithms were used for obstacle avoidance while maneuvering between GPS coordinates. This paper will be useful to those interested in implementing an inexpensive vision-based autonomous robot.

6384-36, Session 7

Sensor integration and navigation for autonomous mobile robots

R. N. Riggins, Bluefield State College; B. V. Mutter, Cart, Inc.; J. Huntley, J. Farmer, S. Baker, J. Keesler, Bluefield State College

This paper addresses two aspects of autonomous navigation in intelligent vehicles: the use of sensor integration to estimate the state of the vehicle and of the surrounding environment, and the use of path-finding to navigate through a field of obstacles for the purpose of reaching a goal.

Three very different robotic platforms provide test beds for these algorithms. One is a 6-wheel mid-wheel drive system using differential steering, another is a robotic add-on to a p-133 Segway, and the third platform is an automobile-sized custom-built robot. Each robotic platform has a Laser Measurement System (LMS), a video camera, a Differential Global Positioning System (DGPS), a digital compass, and wheel encoders. Since many intelligent vehicles have similar sensors, the methods presented here are general enough for many types of autonomous mobile robots.

Since the data from these sensors are in radically different formats, this paper presents a method to combine the sensor information to estimate vehicle state using an Extended Kalman Filter (EKF). The algorithm iteratively updates a local map of nodes showing the robot position, heading, sensed objects, and ground markings. Each EKF algorithm iteration yields a goal node. A modified wave front navigation method then computes the least cost path from robot node to the goal node. Tests accomplished in simulation as well as on an actual robots show excellent results.

Applications for these types of robots include mine recovery and rescue, planetary and moon exploration, terrorist hide-out reconnaissance, smart automobiles, and bomb detectors.

6384-37, Session 7

Obstacle recognition using region-based color segmentation techniques for mobile robot navigation

R. McKeon, M. Krishnan, M. Paulik, Univ. of Detroit Mercy

This work has been performed in conjunction with the ECE Department's autonomous vehicle entry in the 2006 Intelligent Ground Vehicle Competition (www.igvc.org). The course to be traversed in the competition consists of a lane demarcated by paint lines on grass with the possibility of one or other of the two lines being deliberately left out over segments of the course. The course also consists of other challenging artifacts such as a sandpit, a ramp, potholes, colored tarps that alter the color composition of scenes, and obstacles set up using orange and white construction barrels. In this paper an enhanced obstacle detection and mapping algorithm based on region-based color segmentation techniques is described.

The main purpose of this algorithm is to detect obstacles which are not properly identified by the LADAR (Laser Detection and Ranging) system used to detect solid objects on the course. Only one LADAR is typically used on a vehicle in this competition because of cost considerations, and for optimal detection of obstacles it has to be placed low to the ground. As a result the LADAR is not capable of picking up obstacles that are "hidden" (construction sawhorse cross bars or in-line barrels for example). This can sometimes result in navigation decisions being made that lead the vehicle into a trap. On the other hand, the camera that is primarily used to detect the lane lines is mounted at 6 feet (the maximum permitted by the rules).

In this work we concentrate on the identification of orange/red construction barrels. This paper proposes a general color relationship-based technique which is potentially more versatile and faster than traditional full or partial color segmentation approaches. The developed algorithm identifies the hidden items within the camera's field of vision and uses this to complement the LADAR information, thus facilitating an enhanced navigation strategy. Results detailing algorithm performance in various course scenarios will be provided in the full paper.

6384-38, Session 7

Lane identification and path planning for autonomous mobile robots

R. McKeon, M. Paulik, M. Krishnan, Univ. of Detroit Mercy

This work has been performed in conjunction with the ECE Department's autonomous vehicle entry in the 2006 Intelligent Ground Vehicle Competition (www.igvc.org). The course to be traversed in the competition consists of a lane demarcated by paint lines on grass with the possibility of one or other of the two lines being deliberately left out over segments of the course. The course also consists of other challenging artifacts such as a sandpit, a ramp, potholes, colored tarps that alter the color composition of scenes, and obstacles set up using orange and white construction barrels. This paper describes an improved lane edge detection algorithm that is based on the development of noise filters that enable increased removal of noise prior to the application of image thresholding.

The first step in the algorithm is to implement a row/column-adaptive statistical filter to establish an intensity floor. Following this, cumulative row and column pixel aggregation projections are used in conjunction with an intensity histogram and apriori knowledge about lane thickness and separation to determine a global threshold. The constants identified are dependent on lane quality and image noise. Finally, a connectivity filter is applied to the rows to reduce salt and pepper noise.

Next, a navigation algorithm identifies lanes based on an assessment of the number of significant lines in the filtered and thresholded image. Once salient lanes have been identified, a case-based slope-driven heuristic is applied (a path with two lines, a right line, or a left line etc.) to determine a path. This path can be used on its own for vehicle navigation, or an average angle of direction (developed over multiple frames) can be fused with additional sensor data (from a Laser scanner for example) to develop a composite path vector. Results detailing algorithm performance in various course scenarios will be provided in the full paper.

Sunday-Tuesday 1-3 October 2006

Part of Proceedings of SPIE Vol. 6385 Environmentally Conscious Manufacturing VI

6385-01, Session 1

Computational complexity of a reverse manufacturing line

S. M. McGovern, John A. Volpe National Transportation Systems Ctr.; S. M. Gupta, Northeastern Univ.

Disassembly has recently gained attention in the literature due to its role in product recovery. Disassembly activities take place in various recovery operations including remanufacturing, recycling, and disposal. The disassembly line is the best choice for automated disassembly of returned products. It is therefore important that the disassembly line be designed and balanced so that it works as efficiently as possible. However, finding the optimal balance is computationally intensive with exhaustive search quickly becoming prohibitively large, even for relatively small products.

A disassembly system faces many unique circumstances. For example, it has serious inventory problems because of the disparity between the demands for certain parts or subassemblies and their yield from disassembly. The flow process is also different. As opposed to the normal “convergent” flow in regular assembly environment, in disassembly, the flow process is “divergent” (a single product is broken down into many subassemblies and parts). There is also a high degree of uncertainty in the structure and the quality of the returned products. The condition of the products received is usually unknown and the reliability of the components is a suspect. In addition, some parts of the product may cause pollution or may be hazardous.

In this paper, complexity theory is used to prove that the Disassembly Line Balancing Problem is NP-complete, necessitating specialized solution methodologies including those from the field of combinatorial optimization. Several combinatorial optimization searches are introduced and then compared using previously developed qualitative and quantitative tools.

6385-02, Session 1

Balancing inventory generated from a disassembly line: mathmatical approach

B. O. Johar, S. M. Gupta, Northeastern Univ.

Product recovery is a new trend that many manufacturers practice to minimize the fast depletion of virgin resources and because they realize the economical benefits behind recovering end-of-life (EOL) products. However, the practice of recovering components and materials is challenging, as there are many associated complications that are unique to the disassembly process. One of the complications stems from the disassembly line balancing problem (DLBP). DLBP has recently been actively researched in the literature and several heuristic models have been introduced to provide near optimal work contents at each workstation of the disassembly line. However, due to the disparity between demands for parts and their yields, there are many inventory problems that arise during the disassembly line balancing process. In this paper, we address the balancing of the inventories generated at various workstations of a so called “balanced” disassembly line.

In this paper, we present a general mathematical model that addresses the issue of unbalanced inventories generated at various workstations of a disassembly line, and propose a solution to overcome this. A case example involving a personal computer (PC) is considered to illustrate the approach. In order to provide a full analysis of the problem, measures of performance are defined. Measures of performances reflect the state of the system and the ability to meet the demand while maintaining consistent flow of parts. We also discuss and compare various aspects of inventory issues associated with the traditional and the disassembly systems. While it is clear that the inventory issues surrounding the disassembly line offer a new challenge, the understating that we have gained from solving the traditional inventory problems, nevertheless, provide helpful insights in overcoming this new challenge.

6385-03, Session 1

Dynamic Kanban system for disassembly line applied to an industrial voice recognition client unit

E. A. Kizilkaya, S. M. Gupta, Northeastern Univ.

In this paper, we apply the Dynamic Kanban System for Disassembly Line (DKSDL) to an industrial setting. The product considered is a second-generation industrial voice recognition client unit. The company manufacturing this device has moved on to the next generation device, which has more memory, faster CPU and a standardized OS support. There are many of the older generation clients in the customer base, which are being upgraded to the new generation resulting in a large number of the older units at hand. These units are being returned to the manufacturing facility to be processed. The casing and some other components are being used in the new design and can be disassembled and stocked as refurbished items to be used in returned products processing. The resulting DKSDL for this disassembly process is modeled using simulation and the results are discussed.

6385-04, Session 1

Evolutionary computation with linear physical programming for solving a disassembly-to-order system

P. Imtanavanich, S. M. Gupta, Northeastern Univ.

In this paper, we attempt to solve the disassembly-to-order (DTO) problem by using Evolutionary Computation concept. DTO is a system where a variety of returned products are disassembled to fulfill the demand for specified numbers of components and materials. The main objective is to determine the optimal number of take-back EOL products for the DTO system which satisfy the desirable criteria of the system. Nowadays one of the most widely used forms of Evolutionary Computation is Genetic Algorithm (GA). GA, which has the capability to improve a set of solutions over evolutionary steps, is used to generate the presumably optimal number of take-back EOL products. Moreover, linear physical programming (LPP), which has key features to entirely remove the DM from the process of choosing weights and to handle the vagueness of aspiration levels, is used to calculate fitness values in GA process. A numerical example is considered to illustrate the methodology.

6385-05, Session 2

Using interpretive structural modeling to investigate adoption of ECM programs

J. Sarkis, Clark Univ.

Interpretive structural modeling (ISM) is a technique that allows researchers and practitioners understand the relationships and clustering of issues surrounding programs. We will show an application of this technique for evaluating the relationships for implementation and adoption of various environmentally sound business practices. For example, barriers and enablers to environmental supply chain management may be evaluated using this technique and groupings made. This information can then be used with other procedures to help further evaluation of these programs.

6385-07, Session 2

Modeling the economics of blending organic processing waste streams

K. A. Rosentrater, U.S. Dept. of Agriculture

As manufacturing industries become more cognizant of the ecological effects that their firms have on the surrounding environment, their waste streams are increasingly becoming viewed not only as materials in need of disposal, but also as resources that can be reused, recycled, or reprocessed into valuable products. Within the food processing sector are many examples of various liquid, sludge, and solid waste streams that require remediation. Alternative disposal methods for food and other organic manufacturing waste streams are increasingly

being investigated. Even though extrusion, pelleting, and drying are commonly used to produce finished human foods, animal feeds, industrial products, and components ready for further manufacture, blending and shipping is a commonly used approach to organic waste utilization, especially when these materials are used as animal feeds. This paper discusses the implementation of a computer model that examines the economics of blending organic waste streams with other carrier materials, to improve nutrient content as well as augment storage and handling properties. Not only are these results applicable to food processing operations, but any industrial or manufacturing firm would benefit from examining the trends discussed here.

6385-08, Session 2

Modeling organic product and residue stream flows on a constituent basis

K. A. Rosentrater, U.S. Dept. of Agriculture

As manufacturing industries become more cognizant of the ecological effects that their firms have on the surrounding environment, their waste streams are increasingly becoming viewed not as materials in need of disposal, but rather as resources that can be reused, recycled, or reprocessed into valuable products. Within the food processing sector are many examples of organic processing residues. Alternative disposal methods for these manufacturing waste streams are increasingly being investigated. Direct shipping, blending, extrusion, pelleting, and drying are commonly used to produce finished human foods, animal feeds, industrial products, and components ready for further manufacture. Computer modeling and simulation can aid in these value-added endeavors. This paper discusses a strategy that can be used when constructing computer models for organic processing waste streams. Not only do macro-scale process flows need to be considered, but individual constituents on a micro-scale are also essential in order to develop appropriate models. The development heuristics and hierarchies discussed here can be applied to various liquid, sludge, or solid byproduct streams when simulating reprocessing avenues for specific manufacturing process streams. Thus this methodology is applicable to food processing operations; many industrial and manufacturing firms could also benefit from instituting the principles described here.

6385-09, Session 2

A data envelopment analysis approach for material flow analysis

N. E. Kongar, D. B. Mueller, Yale Univ.

The rapid depletion rate of nonrenewable resources, coupled with the continuously growing amount of generated waste, motivated researchers to analyze the metabolism of entire economies in order to identify potentials for reducing resource consumption and environmental impacts.

Material Flow Analysis (MFA) is the preferred methodology to describe the material cycles, typically through the stages of production, fabrication and manufacturing, use, and end-of-life management. MFA can be applied on regional, national or global scales.

MFA studies provide a solid foundation for the assessment of resource efficiency in different stages of the life cycle. However, there is a lack of literature to systematically analyze and compare performance indicators for cycles of various materials in different countries over time. Such indicators could be used to assess the performance of different stages while identifying bottlenecks of resource efficiency, and therefore providing a better understanding of the overall material cycle.

Data envelopment analysis (DEA) is a widely applied linear programming-based technique to evaluate the efficiency of a set of decision-making units. DEA was first developed by Charnes et al.1 in 1978 and since then has mostly been used for benchmarking and for performance evaluation purposes.

This paper presents a DEA approach to measure the relative efficiencies of production, manufacturing, use, and end-of-life management for specific metals in different countries. The proposed performance criteria are defined through a common system structure so that they also indicate the overall efficiency of the system, while emphasizing the relative importance of the different stages. Steps and implementation of the proposed methodology are explained with the help of a case study for selected metals.

6385-10, Session 2

A multi-criteria framework to maximize profits for product recovery facilities

S. Vadde, S. V. Kamarthi, S. M. Gupta, Northeastern Univ.

Independent and small scale product recovery facilities (PRFs) often struggle to achieve profits under inconsistent inflows of discarded products, varying demand patterns for reusable products, and stringent environmental regulations. Inconsistent inflows coupled with the varying demand cause undue fluctuations in inventory levels and holding costs. The unpredictability in the return flows and demand also affects the cost to disassemble and remanufacture/refurbish the discarded products. To streamline the product returns, PRFs can proactively collect discarded products from customers by offering them incentives. Carrying inventory for longer periods is detrimental to the profits of PRFs because it increases the disposal costs. The disposal is usually governed by environmental regulations which specify an upper limit on the quantity that can be disposed of. To circumvent the penalties imposed by the local governing bodies on violation of the disposal regulation, PRFs should either clear or dispose its inventory at appropriate time intervals. This research presents a multi-criteria decision making framework that maximizes the financial returns of the PRFs by considering the interplay of, (a) the cost of acquiring discarded products from customers, (b) the production cost of reusable products, (c) the inventory holding cost, (d) the price of reusable products, and (d) the disposal cost. The framework provides the optimal price to acquire discarded products from customers, optimal price to sell reusable products, and the optimal disposal quantity. The effectiveness of the framework is demonstrated via a case example.

6385-11, Session 3

A six sigma tolerancing approach for the design of an efficient closed-loop supply chain network

S. Nukala, S. M. Gupta, Northeastern Univ.

Rapid technological developments and the growing desire of customers to acquire latest technology has led to a new environmental problem “waste”, comprising of both end-of-life products and used products that are disposed prematurely. As a result, both consumer and government concerns for the environment are driving many original equipment manufacturers (OEM) to engage in additional series of activities stemming from the reverse supply chain. The combination of forward/traditional supply chain and reverse supply chain forms the closed-loop supply chain. Contrary to a traditional/forward supply chain, a closed-loop supply chain involves more variability. In this paper, we explore the use of Motorola’s Six Sigma methodology to achieve better synchronization in a closed-loop supply chain network by tailoring the individual processes in the closed-loop supply chain in a way that maximizes the overall delivery performance. A numerical example is considered to illustrate the approach.

6385-12, Session 3

Supplier selection in a closed-loop supply chain network: an ANP-goal programming-based methodology

S. Nukala, S. M. Gupta, Northeastern Univ.

Traditionally, in supply chain literature, the supplier selection problem is treated as an optimization problem that requires formulating a single objective function. However, not all supplier selection criteria can be quantified, as a result of which, only a few quantitative criteria are included in the problem formulation. To this end, in this paper, we develop an integrated analytic network process (ANP) and preemptive goal programming (PGP) based multi-criteria decision making methodology to address the qualitative and quantitative criteria that influence the supplier selection problem in a closed-loop supply chain network (CLSC). While the ANP methodology aids in determining qualitatively the supply chain strategy by evaluating the suppliers with respect to several criteria, the PGP methodology uses the ANP ratings as inputs and aids in mathematically determining the optimal quantities to be ordered from the suppliers.

6385-13, Session 3

Total quality management (TQM) in a reverse supply chain

K. K. Pochampally, Southern New Hampshire Univ.; S. Nukala, S. M. Gupta, Northeastern Univ.

A reverse supply chain consists of a series of activities required to collect used products from consumers and reprocess them (used products) to recover their left-over market values or dispose them of. In the past decade, there has been an explosive growth (both in scope and scale) of reverse supply chains, because it has been realized that reprocessing of used products is essential for saving natural resources, energy, clean air and water, landfill space, and money. Besides these motivators, an important driver for companies to engage in reprocessing is the enforcement of environmental regulations by local governments.

Total Quality Management (TQM) is a customer-focused, strategic, and systematic approach to continuous performance improvement. It is aimed at embedding awareness of quality in all organizational processes. TQM has been widely used in manufacturing, education, government, and service industries.

This paper proposes a quantitative approach to evaluate a reverse supply chain's performance vis-à-vis' TQM. Special emphasis is given to six-sigma quality performance, while new formulae that are simpler than the conventional formulae for process capability are proposed and used in the approach.

6385-14, Session 3

Developing the reverse logistics network for product returns

N. Zaarour, E. Melachrinoudis, Northeastern Univ.; H. Min, Univ. of Louisville

In this day and age of internet shopping and catalogue buying, product returns have been an unavoidable cost of doing business, forfeiting any chance of cost savings. As cost pressures continue to mount in this era of economic downturns, a growing number of firms have begun to explore the possibility of managing product returns in a more cost efficient manner. However, few studies have addressed the problem of determining the number and location of initial collection points and the location/allocation of centralized return centers (i.e., reverse consolidation points) where returned products from retailers or end customers are collected, sorted, and consolidated into large shipments destined for manufacturers or distributors' repair facilities. To fill the void in such a line of research, we present a nonlinear integer programming model for the design of a reverse logistics network for product returns under capacity restrictions and service requirements. The objective function explicitly considers facilities costs, inventory carrying and handling costs and shipping costs with quantity discounts and distance penalties. The non-linear programming model is converted into a mixed-integer linear programming model, by introducing some additional variables, and is solved by readily available commercial software. An illustrative example is presented that validates the model and its solution approach.

6385-15, Session 4

Initiating a waste management and resource recovery network: a college, NGO, and corporate partnership

I. Dunmade, Mount Royal College (Canada)

The increasing awareness of sustainable development concept and its economic benefits are making environmentally proactive companies to consider how they can achieve eco-efficiency improvement through material exchange and by partnering with academic, governmental and non-governmental agencies. This paper reports the experiences and achievements of a tripartite partnership initiated by the author with a number of companies in Calgary and a Calgarian NGO. The network is a form of eco-industrial network that is being developed to benefit the participating companies and to develop industrial ecology students' skill in eco-industrial network modeling. The paper highlights the initial difficulties, how they were overcome and a conceptual model developed for assessing the sustainability of the material exchange loop. The preliminary results obtained revealed that the companies are enthusiastic in taking part if it will help them achieve waste management cost reduction, improvement in their corporate environmental performance and corporate goodwill, and protection of their proprietary information. It also reveals that such corporate exposure to students develop their skills in balancing their academic view with what works in the corporate world.

6385-16, Session 4

Designing for multi-lifecycles to promote industrial ecology philosophy

I. Dunmade, Mount Royal College (Canada)

This paper presents a design concept originally developed to suit the needs of agro-industrial sector in the developing economies. It also highlights how this concept fits into other green design paradigms and to the goals of industrial ecology.

The need to design for multi-lifecycles arose as there were lots of needs for durable easily maintained agro-processing machines in the developing economies. Most of the available machines are imported from countries of entirely difference technological, climatic and socio-cultural conditions. Many of the machinery become unmanageable after few years of use because of lack of technical know-how. Consequently, they become environmental problems and source of economic drains for the farmers, processors, regional and municipal authorities. There is therefore a need to develop a design concept that consider all prevalent local techno-economic and socio-cultural conditions as well as develop design features that promote multi-lifecycle use of such agro-industrial machinery.

This design concept incorporated DfX paradigms such as design for modularity; cost, assemblability; manufacturability; disassemblability; maintainability; reusability, and remanufacturability. The concept has been used to design and develop a cassava processing machine. The performance evaluation of the machine compares with the imported ones.

By incorporating all the aforementioned DfXs, this design concept promotes resource use optimization, pollution prevention and cost minimization which are among the goals of industrial ecology. It is believed that this design concept can be applied to other areas of needs in the industrial and agricultural sectors, and that using this design concept will go a long way in complementing various efforts aimed at reducing total environmental impact of our industrial activities.

6385-17, Session 4

Motivations and profits of the reverse logistics activities

B. Gonzalez-Torre, A. Díaz-Fernandez, M. Alvarez-Abella, P. Gonzalez-Torre, Univ. de Oviedo (Spain)

The growing social concern about the environment makes the reverse logistics activities to become the focus of numerous businesses opportunities. The present study tries to identify, using a structural equation model, which are the most important motivations and the profits obtained by the firms implementing reverse logistics activities. An empirical study was carried out in the Spanish auxiliary automotive industry obtaining that the profits could be classified into two big groups: economic and ecological. A 'green' image has become an important marketing element, and this issue has stimulated a number of companies to explore options for take-back and recovery of their products.

Overhauled products may be used as spares or sold on secondary markets while requiring only a small fraction of the original production costs for repair so this is and important economical profits. It has been used EQS as software tool in order to verify the considered hypothesis.

6385-18, Session 4

Strategic sustainability justification for reverse logistics

J. Sarkis, Clark Univ.

The strategic justification of most projects requires that integration of tangible and intangible factors be completed. Environmental programs and systems that need to be implemented in organizations require this strategic focus. In this presentation we shall introduce a broad-based

methodological approach and framework that allows for the strategic evaluation of reverse logistics from a sustainability perspective. Sustainability in this presentation focuses on the 'triple bottom-line' factors incorporating social, environmental, and economic dimensions. The methodology will focus on the characteristics and functions of reverse logistics and how an organization may go about justifying such a program from a strategic rather than just an economic perspective.

6385-19, Poster Session

Strategic and tactical planning of a closed-loop supply chain network under uncertainty

S. Nukala, S. M. Gupta, Northeastern Univ.

While the strategic planning of a supply chain, which is typically a long range planning, deals with the design aspect of the supply chain (what products should be processed/produced in what facilities etc), tactical planning is typically a medium-range planning that involves the optimization of flow of goods and services across the supply chain. In this paper, we present a multi-criteria optimization model for the strategic and tactical planning of a closed-loop supply chain under uncertainty, where the aspiration levels for various goals are more likely to be in the "approximately more/less than" and/or "more/less is better" form. We use fuzzy goal programming technique to solve the problem. When solved, the model identifies simultaneously the most economical used-product to re-process in the supply chain, the efficient production facilities and the right mix and quantity of goods to be transported across the supply chain. A numerical example is considered to illustrate the methodology.

6385-20, Poster Session

Effective marketing of a closed-loop supply chain network: a fuzzy QFD approach

S. Nukala, S. M. Gupta, Northeastern Univ.

Both consumer and government concerns for the environment are driving many original equipment manufacturers (OEM) to engage in additional series of activities stemming from the reverse supply chain. The combination of forward/traditional supply chain and reverse supply chain forms the closed-loop supply chain. Apart from its efficient design, the success of a closed-loop supply chain network depends on its marketing strategy as well. Hence, it is important that the planned marketing strategy be evaluated with respect to the drivers of public participation in the network. To this end, we identify the important drivers of public participation and propose a fuzzy Quality Function Deployment based methodology and method of total preferences to evaluate the marketing strategy of a closed-loop supply chain with respect to those drivers. A numerical example is considered to illustrate the methodology.

6385-21, Poster Session

Controlling disassembly line with multi-Kanban system

G. Udomsawat, S. M. Gupta, Northeastern Univ.

An adaptive way of employing pull system in a disassembly line is to use a multi-kanban model. The model employs several types of kanbans attached to both components and subassemblies. The heart of the system lies in the kanban routing mechanism which allows routing of kanbans in multi-directions based on real time conditions. This mechanism creates minimum amount of residual inventory while satisfying demand levels. It also helps regulate the requests for subassembly from upstream workstations when a breakdown occurs at a workstation in the middle. This helps reduce blockage and starvation of subassemblies at workstations other than the breakdown workstation. In this paper, we discuss the difficulties involved in utilizing the multi-kanban mechanism. We thoroughly investigate several scenarios of disassembly line setting including a scenario with common products, a scenario with component discriminating demand, a scenario with the presence of product with multiple precedence relationships, and a scenario with workstation breakdowns. These scenarios represent various disassembly environments that a facility may face when dealing with the disassembly of both single and multiple products on a single line. In each scenario, we examine effectiveness of the multi-kanban model with three performance measures, viz. the inventory level, the number of satisfied demand, and the customer waiting time. We compare the results with the ones generated from the same line that employs a traditional push system. Using simulation, we demonstrate that the overall performance of the disassembly line using multi-kanban mechanism outperforms the disassembly line with the traditional push system.

6385-22, Poster Session

Solving a disassembly-to-order system by using genetic algorithm and weighted fuzzy goal programming

P. Imtanavanich, S. M. Gupta, Northeastern Univ.

In this paper, Genetic Algorithm (GA) concept is applied in order to solve the disassembly-to-order (DTO) problem. DTO is a system where a variety of returned products are disassembled to fulfill the demand for specified numbers of components and materials. The main objective is to determine the optimal number of take-back EOL products for the DTO system which satisfy the desirable criteria of the system. GA, which has the capability to improve a set of solutions over evolutionary steps, is used to generate the presumably optimal number of take-back EOL products. We implement Weighted Fuzzy Goal Programming (WFGP) in order to calculate the fitness values in GA process. In addition, we consider product's deterioration which affects the product's yield rates (e.g., older products tend to have lower yield rates for usable components) and use heuristic procedure to transform the stochastic disassembly yields into their deterministic equivalents. A numerical example is also illustrated.

6385-23, Poster Session

Near optimum disassembly sequencing

A. J. D. Lambert, Technische Univ. Eindhoven (Netherlands); S. M. Gupta, Northeastern Univ.

This paper deals with disassembly sequencing problems subjected to sequence dependent disassembly costs. The currently available methods for dealing with such problems rely mainly on metaheuristic and heuristic methods. Because these methods intrinsically generate suboptimum solutions, it is desirable to have exact methods available that can be applied at least to medium sized problems in order to check whether the heuristically obtained solutions are reasonably good or not. The existing exact approaches, which are based on integer linear programming (ILP), become unmanageable, even for the cases of modest product complexity. To alleviate this problem, an iterative method is proposed. This method is based on repeatedly solving a binary integer linear programming (BILP) problem instead of an ILP problem. The method appears to converge sufficiently quickly to be valuable for dealing with medium sized problems. We then use the iterative method for the validation of a new heuristic method that is also proposed in this paper. Finally, both the heuristic and the iterative BILP methods are implemented on a cell phone from practice consisting of 25 components that are represented, according to a set of precedence relationships, via a disassembly precedence graph.

6385-24, Poster Session

Optimal inventory control with consideration for LCA

K. Nakashima, Osaka Institute of Technology (Japan); S. M. Gupta, Northeastern Univ.

This paper deals with an optimal inventory control problem with consideration for Life Cycle Assessment (LCA). In the traditional inventory models, there are lots of the previous works which focused on minimizing the average costs including holding, ordering and backlogged cost. Recently, Kyoto protocol has been issued, so that the companies have to consider CO2 emission in their businesses. In addition, environmentally conscious manufacturing is mainly driven by the escalating deterioration of the environment. It has become an obligation to the environment and to the society. Therefore, we should consider not only the economics but also the product life cycle for controlling the production systems. Here we propose a single item inventory control model including LCA effects based on CO2 penalty. We show the optimal control under some scenarios and discuss the properties.

Sunday 1 October 2006

Part of Proceedings of SPIE Vol. 6386A Optical Methods in Drug Discovery and Development II

6386A-01, Session 1

Biological applications of hyperspectral fluorescence imaging

D. D. Tuschel, A. Bangalore, ChemImage Corp.

Bioimaging based upon fluorescent molecular probes is generally performed using emission bandpass filters, thereby producing images of integrated fluorescence intensity without spectral information. One of the principal drawbacks to this approach is that it limits the number of molecular probes that can be used simultaneously because the emission spectra of the probes often overlap. Another shortcoming of bandpass based fluorescence imaging is that information about chemical interactions, which are revealed in the band structure of the emission spectra, cannot be obtained. The alternative to integrated fluorescence imaging is hyperspectral imaging through full field-of-view illumination and image capture using a wavelength tunable filter. Hyperspectral fluorescence images acquired using a wavelength tunable filter have a full emission spectrum associated with each individual pixel corresponding to that specific location on the sample. We will present and discuss hyperspectral fluorescence images of Muntjac skin fibroblast labeled with Alexa Fluor 488, Alexa Fluor 555, and TO-PRO-3 molecular probes. Principal component analysis has been used to differentiate probes with overlapping spectral signatures. Furthermore, we will discuss the use of fluorescence based pH indicator probes such as SNARF1 to image pH in biomaterials.

6386A-02, Session 1

New ultrafast laser system based on the chromium: Forsterite for multiphoton in vivo imaging

S. E. Egorov, C. C. Barnes, A. J. Carson, Del Mar Photonics, Inc.

Chromium-doped forsterite crystal (Cr:forsterite) is a solid state laser material that fluoresces in the near-infrared region centered around 1250 nm. Cr:forsterite has been successfully used as a gain medium in Kerr lens mode-locked (KLM) femtosecond lasers with cavity designs similar to the popular Ti:sapphire femtosecond laser systems. Cr:forsterite exhibits strong absorption in the near infrared and can be directly pumped with CW lasers operating at 1064 nm, offering a significant reduction in system cost compared to femtosecond lasers pumped in the 532 nm region. We present a design of compact femtosecond Cr:forsterite laser pumped by a 10-W ytterbium fiber laser, generating 60 - 80-fs pulses at 1230-1270 nm with output up to 300 mW. Wavelengths in the 1250 nm range are less damaging to biological samples than other ultrafast lasers making Cr:forsterite based femtosecond laser systems an ideal source of ultrashort pulses for biological and medical applications. This wavelength falls in the transparency window of most biological tissues, allowing deep tissue penetration with minimal photodamaging and making it a valuable alternative source for in vivo multiphoton imaging.

6386A-03, Session 1

Quantum dots imaging for observing mung beam seeding

S. Fu, T. Chia, L. C. Kwek, C. S. Lim, Nanyang Technological Univ. (Singapore)

Quantum dots (QDs) are nanocrystalline fluorophores which are used in fluorescent bioimaging applications. In this paper, two types of QDs were used. A commercially prepared QD, CdSe core with a ZnS shell, was dissolved in chloroform, a nonpolar hydrophobic solvent. It was not solubilised, whereas the other QD used, TiO2, was in the form of a water soluble nanogel. Comparison of the effects of the two types of QDs on mung bean (Vigna radiata) seedlings yielded different observations. Cross-sections of the root and shoot of the seedlings under the confocal scanning laser microscope showed no significant uptake of the CdSe/ZnS QDs (when the liquid was not used in excess). An expected result since the solution in chloroform was non-biocompatible. However, a simple and fast method of photostable fluorescent staining of cell nuclei was obtained by an in vitro immersion of the sample with CdSe/ZnS QDs in chloroform. This method could not be used in the case of a water-soluble gel like TiO2. For the TiO2 sol-gel, in vivo fluorescent imaging of cross-sections of the root and shoot of the seedlings showed a significant uptake in the regions of the epidermis and vascular cylinder. However, the laboratory produced TiO2 was not as brightly fluorescent as the CdSe/ZnS QDs in the excitation and emission ranges used. The studies also yielded observational foot-notes regarding the toxicity of the two types of QDs and the effects, if any, on the mung bean seedlings.

6386A-04, Session 1

Rapid analysis of drugs during clinical trials using saliva and disposable lab-on-a-chips

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A typical drug requires 12 years of research and development to bring it to market. A critical step in the latter stages of development is human clinical trials to study pharmacokinetics and efficacy. This step represents a significant barrier in that there is a limited number of willing test patients. Patients must not only endure multiple withdrawals of blood, but also run the risk of adverse side-effects, anemia and possible HIV contamination. Saliva analysis has long been considered an attractive alternative to blood, but current methods involving extensive sample extraction followed by gas chromatography and mass spectrometry, typically require 10-20 cc per analysis. In an effort to overcome this limitation we have been developing lab-on-a-chip devices to both separate drugs and their metabolites from saliva and generate surface-enhanced Raman spectra (SERS). We have incorporated standard chromatography materials to aid separation, as well as a porous material containing metal particles that generate SERS. Generally no more than a drop of sample is required and complete analysis can be performed in 5 minutes. The detailed molecular vibrational information allows chemical identification, while the increase in Raman scattering by six or more orders of magnitude allows detection of nanomolar concentrations. Measurements of basic drugs, drugs of abuse, and chemotherapy drugs will be presented.

6386A-05, Session 1

Laser application in assessing selected African herbal medicines

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The HIV/AIDs disease has sparked interest in African Herbal medicines for both researchers and patients. This interest will intensity with time given also, the rising cost of modern drugs that were developed to manage the HIV/AIDS disease. Associated with this development, is the urgent need for simple and cost-effective technologies for use in quality control and quality assurance. Against this background this paper discussses the application of laser light scattering technique as a tool for assessing African Herbal medicines. We have assessed selected African herbal medicines both in powdered and liquid form. We have restricted our study to those African Herbal medicine claimed to be useful in managing the HIV/AIDS diseases. Our experimental results indicate the potential usefulness of the laser light scattering technique as a simple and low-cost technique for assessing the quality of some of the herbs.

6386A-06, Session 1

FRET imaging by picosecond TCSPC laser scanning microscopy

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A new Time-Correlated Single Photon Counting (TCSPC) imaging technique in conjunction with a two-photon laser scanning microscope was used to obtain FRET lifetime data from living cells. Double exponential decay analysis separates the FRET fluorescence from the fluorescence of the unquenched donor molecules. By using the intensity ratio of the quenched and the unquenched donor fluorescence

images are created that show the size of the FRET in different regions of the cell.

6386A-07, Session 1

Investigation of the excited states dynamics in the Chl d- containing cyanobacterium Acaryochloris marina by time- and wavelength correlated single-photon counting

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Single photon counting with simultaneous time- and wavelength-resolution is a powerful tool for fast and non-invasive spectroscopic studies of fluorophores involved in dynamic processes. With our double correlated fluorometer system the fluorescence decay can be monitored with a temporal resolution of 50 ps in a large spectral range (200 nm) with high signal to noise ratio and short data acquisition times while using low excitation light intensities. In the present study we investigate fluorescence dynamics in the recently (1996) discovered cyanobacterium Acaryochloris marina, the only known oxygenic photosynthetic organism containing Chl d instead of Chl a or Chl b as the dominant light harvesting pigment. Additionally small amounts of Chl a and phycobiliproteins (PBP) are present. The Qy absorption band of Chl d is shifted towards longer wavelengths with respect to Chl a. This spectroscopic property raises important questions about the mechanism of excitation energy transfer between the antenna pigments. The results of the current work indicate a fast energy transfer from the PBP to Chl d, three times faster than in typical cyanobacteria containing more complex PBP aggregates. Cells of A. marina, which are stored at 0°C for several minutes show a decoupling between the membrane extrinsic PBP antenna and the intrinsic Chl d antenna, which is partially reversible when the cells are re-incubated at 25 °C.

6386A-08, Session 2

Cell transformation assays for drug carcinogenicity studies: a new structure-texture classifier of foci

C. Urani, G. F. Crosta, L. Fumarola, Univ. degli Studi di Milano-Bicocca (Italy)

Cell transformation assays are used as predictors of human carcinogenicity in drug discovery. Carcinogenesis is a multi-step process, which involves sequential genetic alterations, that can be monitored in vitro by foci formation in suitable cell lines (e.g. C3H10T1/2 mouse fibroblasts).

It is generally accepted that out of the three recognized types of foci, type II and III are classified as transformed. This classification is based on the visual evaluation of phenotypic alterations made by a human expert. However, the question of whether other foci types are potentially tumorigenic and should also be scored as transformants remains unanswered. Pattern recognition can play a role in properly addressing the classification problem and overcoming subjectivity of judgment. This paper describes the development and preliminary implementation of an automatic foci classifier which fuses morphological descriptors extracted from light microscope images by a variety of methods. The latter include “spectrum enhancement” which separates image structure from texture, fractal analysis (e.g. estimation of mass and contour fractal dimensions) and mathematical morphological operations. Descriptor fusion relies e.g. on multivariate statistics. Classification results include the quantitative estimate of the intrinsic morphological variability of the transformed phenotype.

This innovative approach will have repercussions on cell transformation assays used in mechanistic studies of carcinogenesis induced by drugs and in the screening of chemicals for potential chemo-preventive activities.

6386A-09, Session 2

Assessing drug-induced regeneration of demyelinated nerve fibers: an outbreak from quantitative morphology

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A class of cannabinoid CB1 receptor antagonist known to alleviate neuropathic pain, has been discovered to promote the nerve myelin repair. The assessment of damaged and repaired fibers usually relies on visual recognition and counting by a trained human expert.

This paper describes the development and implementation of an algorithm capable of quantifying damage and repair of nerve fibers from an animal model. Semithin sections of rat sciatic nerve were obtained by ultramicrotome cut and stained with toloudine-blue for light microscopy. Digital images were segmented by morphological operators for contour extraction and processed by the “spectrum enhancement” algorithm, which consists of FOURIER analysis followed by non linear filtering. As result a vector of features was associated to each image and passed on to a classifier. The latter was trained and validated, and applied to quantify the degree of damage after chronic constriction injury and recovery after drug treatment.

The approach is relevant to the development of drugs in neurodegenerative disease.

6386A-10, Session 2

Colony recognition and scoring in hematotoxicity assays by an image stack classifier

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In order to evaluate the potential hematotoxicity of xenobiotics, including candidate anti-cancer drugs, in vitro models of hematopoiesis are used, which involve clonogenic assays on CFU-GM (Colony Forming Unit-Granulocyte-Macrophage). These assays require live and unstained colonies to be counted. Most laboratories still rely on visual scoring, which is time consuming and error prone. As a consequence automated scoring is highly desired. A classification algorithm aimed at emulating the colony recognition and scoring capabilities of a human expert was designed and implemented and will be described herewith. CFU-GM assays were carried out on hematopoietic progenitors, among which human umbilical cord blood cells grown in methylcellulose. A three-dimensional (3-D) medium is essential for these assays to simulate the clonogenetic process which takes place in bone marrow. Stacks of images representing slices of a 3-D domain were acquired. Structure and texture information was extracted from each image. Classifier training was based on a 3-D colony model applied to the image stack. The number of scored colonies (assigned class) was required to match the count supplied by the human expert (class of belonging). The trained classifier was validated and applied to stacks containing colonies which partially overlapped. Scoring in distortion- and caustic-affected areas of the culture dish was also successfully demonstrated. Whereas the industry’s scoring methods all rely on image structure alone and process two-dimensional data, the classifier described herewith fuses 3-D data from a whole stack and is capable, in principle, of high-throughput screening.

6386A-11, Session 2

Optical speckle angular correlation and fractal property of a composite of cancer/normal cell layers with application for laboratory monitoring of drug efficacy

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Breast cancer cells and normal cells were grown on glass substrates and investigated via laser generated speckles. The optical speckle pattern of a layer was investigated via angular correlation and fractal dimension analysis. A porous silicate slab with various water contents was used as calibration. The angular correlation results were consistent with the cell sizes as measured by microscopy. The speckle intensity data can be treated as a random series and the Higuchi method was used to explore the fractal property of the random series. The fractal dimension results differentiated the cancer cells (fractal dimension about 1.4) from the normal cells (fractal dimension about 1.7). A composite of breast cancer/normal cell matrix was built with cancer cell layers embedded within normal cell layers. The optical speckle pattern of a composite was investigated and computer modeling was used to extract the embedded cancer cell angular correlation and fractal dimension information. The measurement of the efficacy of a drug was simulated with the monitoring of the effect of added chemicals in the growth media. Laboratory optical speckle

pattern monitoring of the effect of added chemicals was demonstrated. The extension for early cancer detection was also discussed.

6386A-12, Session 2

For our eyes only: challenges in realizing the promise of quantitative microscopy imaging

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The growing use of quantitative image analysis techniques holds the promise for significant improvements in extracting useful information from digital microscopy image data. This is especially significant in areas like automated high-throughput analysis and screening.

Currently, however we face a significant obstacle in realizing the promise of using quantitative image analysis (i.e. “machine vision”) to enhance, and possibly replace, qualitative visual analysis(i.e. “human vision”).

This problem is that current image acquisition technology is highly optimized for human visual analysis. That is, image acquisition technology is designed (quite appropriately) according to “visual image quality” metrics defined specifically for human perceptual performance.

While this problem is an issue for digital imaging in general, it is especially pronounced in digital microscopy imaging, since here image quality depends on a complex series of acquisition operations, that includes many not used in the traditional image acquisition (e.g. sample preparation and microscope settings).

Consequently, when we apply quantitative analysis methods to image data that were acquired for purposes of qualitative analysis, we can obtain no better than sub-optimal results.

In this talk,we discuss the pressing need in digital microscopy for replacing the traditional “visual image quality” metric with a “computational image quality” metric, and the implications that this has for the design and evaluation of image acquisition methods.

Monday-Tuesday 2-3 October 2006

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6386B-13, Session 3

Shockley-Reed-Hall and Auger recombination in 0.5-0.6 eV GaSb-based photonic devices

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There is a growing interest to In(Al)GaAsSb material system due to a unique combination of properties not available in other well-developed material systems for mid-infrared applications.

A number of GaSb-based optoelectronic devices have been demonstrated for the wavelength range of 2-2.5 microns including high-power diode lasers and diode laser arrays, light-emitting diodes, avalanche photodiodes, high-gain phototransistors. This range corresponds to the atmospheric transparency window with a minimum noise from the scattered solar radiation and thermal radiation of Earth so that it is attractive for free-space optical communications and remote gas trace sensing. For biomedical research and in-situ diagnostic applications this range allows for a deep penetration in tissue, it is suitable for noninvasive blood glucose monitoring.

Optimization of the device design and technology encourages study of carrier recombination in these materials. The achieved technology level demonstrates a microsecond-range minority carrier lifetime in undoped materials. The p-type materials can be obtained with large hole concentrations while achievement of large electronic concentrations is a challenge due to weak activation of Tellurium commonly used as a donor.

Our studies of the Te-doped InGaAsSb epitaxial layers showed abnormal dependence of the hole lifetime on excess carrier concentration indicating unusual character of Shockley-Reed-Hall recombination. These dependences were studied by optical modulation response to small-signal excitation. Auger recombination in p-type materials was studied with wavelength up-conversion method. Contributions of radiative and non-radiative processes were separated by measuring lifetime temperature dependences. Carrier recombination properties will be discussed in conjunction with parameters of optoelectronic devices.

6386B-14, Session 3

Mid-infrared electroluminescence from InAs quantum dots

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The past decade has seen the rapid development of the Quantum Cascade (QC) Laser, a robust, wavelength flexible, and powerful mid-Infrared light source, opening up a range of the optical spectrum in which reside numerous absorption resonances of trace gases of significant interest to the medical, environmental and homeland security research communities. The intersubband nature of the optical transition in QC lasers, however, also allows for short non-radiative scattering times between the states of interest, limiting the wall plug efficiency of such devices. Additionally, due to intersubband transition selection rules, emission from QC lasers is limited to the edges of QC devices, unless additional processing steps such as 2nd order diffraction gratings or photonic crystal cavities are applied.

To resolve these two challenges (wall plug efficiency and surface emission), there have been recent efforts to integrate into QC structures active regions which confine carriers in three dimensions. One such method utilizes self-assembled InAs quantum dots (QDs) as the active region in QC-like devices. Initial results have shown mid-IR electroluminescence from such devices [1]. More recent work has increased the output from such devices with improved bandstructure engineering, device processing, and output coupling. Additionally, recent devices have exhibited multiple wavelength emission [2]. The two emission peaks are orthogonally polarized within the growth plane, indicating photon emission from intersublevel electron transitions within anisotropically shaped quantums dots. This work suggests the feasibility of using quantum dot mid-infrared emission to study both the morphology of, and intersublevel transitions within, self-assembled quantum dots .

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6386B-15, Session 3

Silicon-on-lithium niobate waveguides for the mid-infrared

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While many sensing and spectroscopy applications use wavelengths in the mid-infrared, optical domain routing and filtering have been done with bulk optics to date. In this paper, we explore planar waveguide designs for the mid-infrared, by simulation and experimentally. Since the wavelengths are much larger than traditional telecom wavelengths, the challenge is to increase the mode confinement in midIR-transmissive materials to make planar waveguide integration attractive in this wavelength range. We explore designs and tradeoffs for silicon-on-lithium niobate to achieve higher mode confinement necessary for tighter bend radii and compact circuits. Additionally, this approach offers the capability to perform fast phase tuning or modulation in the mid-IR and the ability to expand the mode in a low-index-contrast waveguide for better matching to fibers or external focusing optics. The low-index-contrast guiding structure is a lithium niobate (LN) waveguide made by either titanium-indiffusion or proton-exchange. Deposited and patterned Si is overlayed on the LN waveguide. Tapers are utilized to couple the mode from the LN to the Si overlay. The mode is then tightly confined to make compact 180 degree bends that are impractical using traditional LN waveguides. Simulations have been performed for wavelengths from 2.5um to 4.5um. Over this range, the LN waveguide depth varies from 15 to 25um for singlemode operation while the deposited silicon thickness changes from 0.5 to 1um. The taper length varies between 200um and 2mm. The bend radius for 2.5um is under 1mm whereas it is under 1.5mm for 4.5um.

6386B-16, Session 3

Recent progress by mid-IR antimonide type-II “W” interband cascade lasers and LWIR detectors

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Interband cascade lasers (ICLs) with type-II “W” active regions are promising sources for the mid-IR (3-5 microns), since they have the potential to emit high cw powers with high efficiency. Our simulations show that it can be advantageous to employ fewer active stages than in most previous ICLs, since the heat dissipation is then significantly reduced as long as the gain is sufficient to overcome waveguide losses. A 10-stage interband cascade laser emitting at 3.3-3.6 microns exhibited a voltage drop only 4% above the theoretical minimum, and operated to room temperature in pulsed mode. Another device with 5 stages and coated facets had a maximum cw wallplug efficiency of 21% at 78 K, despite being mounted epitaxial-side-up. A sister device with a longer cavity produced up to 1.1 W of cw power. A distributed-feedback (DFB) grating was defined by electron-beam lithography and lift-off of Ge stripes on top of a 10-stage ICL with a thin InAs/AlSb top cladding. The 15-micron-wide DFB operated cw in a single mode near 3.42 microns, with a maximum single-mode output power of \> 3 mW. The instrument-limited linewidth was ~0.5 Å, and the wavelength was linearly tunable over a 4 nm range by varying the temperature from 110 K to 125 K (0.28 nm/K), or over 0.6 nm by varying the current from 60 mA to 83 mA (0.031 nm/mA).

NRL is also developing IR detectors that incorporate absorbers with a similar type-II “W” configuration. We recently demonstrated that dark currents associated with tunneling and generation-recombination processes were strongly suppressed in devices having a novel design

with a graded bandgap in the depletion layer. The median dynamic impedance-area product (R0A) of 216 Ohm-cm2 at 78K, for 33 devices with 10.5 μm cutoff, is comparable to that for state-of-the-art HgCdTe-based photodiodes. The sidewall resistivity of ~70 kΩ-cm for untreated mesas is also considerably higher than any reported previously for type-II LWIR detectors, apparently indicating self-passivation by the graded bandgap.

6386B-17, Session 4

Probing the electronic and optical properties of quantum cascade lasers under operating conditions

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Recent years have seen spectacular developments in the performance and functionality of mid and far-IR quantum cascade lasers (QCLs). There have, however, been relatively few spectroscopic studies of QCL device physics which could provide key information on important aspects such as the intersubband energy distribution of electrons in functioning devices. Here we present the details of a new intersubband transmission technique which is potentially very informative for such studies. In these experiments, the broadband thermal "globar" emission from the FTIR spectrometer was used as the incident light. This emission was precisely focused onto one facet of the QCL under investigation and only the light transmitted through the waveguide was collected from the other side of the laser ridge and detected with a cooled CMT detector. This novel technique allows spectroscopic study of light transmission through the waveguide of QCLs in a very broad spectral range (1.5-12 μm), limited only by the detector response and by the interband absorption of the materials used in the QCL core region. Waveguide transmittance spectra have been studied for both TE and TM polarization, for a range of InGaAs/InAlAs/InP and antimonide-based QCLs with different active region designs emitting from 4.5 to 10.3μm. The transmission measurements clearly show the depopulation of the lower laser levels as bias is increased, the onset and growth of optical amplification at the energy corresponding to the laser transitions as current is increased towards threshold, and the thermal filling of the second laser level and decrease of material gain at high temperatures. This technique also allows direct determination of key parameters such as the exact temperature of the laser core region under operating conditions, as well as the modal gain and waveguide loss coefficients.

6386B-18, Session 4

Spectral tuning and mode competition of quantum cascade lasers studied by time-resolved Fourier transform spectroscopy

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Over the past few years quantum cascade (QC) lasers have attracted much interest for sensing applications and infrared countermeasures. The sensing applications can be divided into two classes: (i) spectroscopy of trace gases, typically covering a small spectral range at high spectral resolution, (ii) spectroscopy of solids, liquids and complex systems needing a broad spectral tuning range. Due to larger width of characteristic absorption features in the latter case, Fabry-Perot (FP) lasers rather than more costly to fabricate DFB lasers should be sufficient for spectroscopic sensing. In the present paper, we present a study of the spectral characteristic of FP lasers applying a time resolution of 3 ns in combination with a spectral resolution of 0.02 1/cm. Pulse lengths ranging between 100 ns and several μs applying duty cycles between 0.01 % and 10 % were investigated. Depending on the current density and operation temperature, the lasers exhibit very complex spectral structures, which can be explained by mode competition. Typically, in the first 20 ns of the current injection the temperature change of the active layer is caused by adiabatic heating. On a time scale of some 100 ns the temperature of the active layer stabilizes. In thermal equilibrium an inhomogeneous temperature distribution in the layer structure is established, and a redistribution of the optical emission into higher lateral modes is observed. Since a change in the mode structure is associated with a change in the far field distribution, the implications for QC laser design and integration into optical measurement systems will be discussed.

6386B-19, Session 4

Modeling of room-temperature high-performance quantum cascade lasers

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High performance quantum cascade (QC) lasers are desired for applications such as trace gas sensing in an environment where cryogenic cooling is undesirable. Designing optimal waveguides and active regions present unique challenges due to temperature-dependent effects that degrade laser performance. In order to consistently and efficiently produce high performance lasers, more complete performance models are needed to aid the design process. We present a 3-dimensional computational model for determining QC laser performance at high temperatures by considering the influence of temperature on carrier lifetimes, linewidth broadening, "thermal backfilling" of the lower laser state, resistive heating in the cladding layers, core heat extraction ability, cladding material choice, waveguide geometry, and heat extraction method. From this model, temperature dependent pulsed and continuous wave performance characteristics such as threshold current density, power dissipation, maximum operating temperature, slope efficiency, and wall plug efficiency are predicted. The model is also compared with experimental data of high performance QC lasers grown on InP substrates with varying active region doping levels, waveguide geometries, top cladding material (InP or In0.52Al0.48As), growth method (MOCVD or MBE), and core heat extraction method (electroplated gold or InP regrowth). These results aid the design of high-performance QC lasers and have already shown how some optimized low-temperature designs may be suboptimal at higher temperatures.

6386B-20, Session 4

In-plane integration of quantum cascade lasers with resonant intersubband nonlinearities

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It has been recently demonstrated that active region of a quantum cascade (QC) laser can be integrated with a cascade of intersubband transitions designed for the nonlinear conversion of laser light into coherent radiation at other frequencies. In other words, the laser field serves as an intracavity optical pump for the desired nonlinear optical interaction. Integration has been implemented in the growth direction by vertically stacking the nonlinear region and active laser stages. While this approach is easy to realize, it has certain shortcomings including thicker structure, more complicated compound waveguide design, and limited ability to control current and voltage across the nonlinear region. Here we propose in-plane integration strategy, in which the laser is divided into two separately contacted and biased sections along the cavity length. One section operates as a laser active medium while another section serves as a nonlinear element. The sections obviously share the same layer structure but may have very different set of electron states depending on the applied biases. We show that such schemes turn out to be surprisingly flexible in implementing various optical nonlinearities. We consider specific designs when the nonlinear section serves as a Raman active region, a cascade for second-harmonic or difference-frequency generation, or saturable absorber for the main laser. In addition, this approach enables convenient tuning by applied voltage and can be used to enhance the tuning range of the laser.

6386B-21, Session 4

Intersubband nonlinearities in GaAs-based quantum cascade lasers

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Intracavity second harmonic generation (SHG) via intersubband nonlinearities in quantum cascade lasers (QCLs) has been first reported

for the InP-based material system [1,2]. In the case of GaAs based devices the nonlinear bulk susceptibility of (111) grown lasers was used so far for sum frequency mixing [3]. Recently we showed SHG due to intersubband nonlinearities in GaAs QCLs [4].

We investigated different active regions as well as different waveguide designs concerning their SH conversion efficiency and absolute output power. We also report on our results of the first single mode surface emitting SHG QCLs [6], where the vertical emission is solely SH. Typical SH optical power ranges are 100μW to 150 μW at 1W fundamental intensity. To improve the conversion efficiency we work towards modal phase-matching, as already demonstrated in the InP material system [5]. We intend to present detailed far field measurements (surface and edge emitters) which give information about the modal behavior depending on the waveguide design and dimensions. This gives us a more detailed understanding which will be used for the improvement of SHG and other nonlinear effects like difference frequency mixing for THz emission.

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6386B-22, Session 5

A new frontier: mid-infrared chemical sensors based on single-mode waveguides

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Optical chemical sensor technology in the mid-infrared (MIR) spectral range (3-20 μm) is gaining importance in process monitoring, environmental analysis and the biomedical field due to the increasing demand for versatile and robust sensor technology with inherent molecular specificity. Interfacing IR-transducers with continuous measurement or surveillance situations becomes increasingly feasible with the advent of appropriate waveguide technology, protective surface coatings, molecular recognition chemistries, and the availability of advanced light sources.

Using single-mode distributed feedback (DFB) quantum cascade lasers (QCLs) allows for the combination with wavelength-tailored waveguides matched to the laser emission frequency. This presentation will review a new generation of IR sensing platforms based on single-mode waveguide technology for ultra-sensitive gas phase and liquid phase analysis highlighting today's state-of-the-art in miniaturized IR sensor technology.

6386B-23, Session 5

Breath test for o.s.s. detection in humans compared to free radical analysis in blood

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The presence of a large amount of free radicals in human organism characterises a condition of the body known as oxidative stress (o.s.). Some of the free radicals, the reactive oxygen species (ROS), have been shown to be associated with a wide variety of pathological phenomena: Alzheimer disease, riperfusion injury, radiation injury, carcinogenesis. The free radical oxidant activity in human body becomes evident through the emission of low molecular weight volatile hydrocarbons (ethane, pentane, ethylene) in the exhaled breath in very low amounts (around 1 ppbv). The above mentioned exhaled hydrocarbons are known to be molecular markers of lipid peroxidation (LP), a chained chemical degradation of poli-unsaturated fatty acids in the living cells started by oxidant free radicals attack. High specificity sensitive methods are required for a successful detection of such a low amounts of volatile substances.

For monitoring the oxidative stress status (o.s.s.), we propose a breath test based on the detection of ethylene (one of the volatile markers of LP) by mean of laser photoacoustic spectroscopy technique. In the present paper we report some experiments supporting the correlation between the analysis of free radicals in blood and the amount of ethylene emission in exhaled breath. The oxidant activity in blood was analysed through a colorimetric method based on the Fenton reaction, while the breath ethylene was detected by a high resolution 10 W c.w. CO2 laser spectroscopy system developed in our Molecular Spectroscopy Laboratory at ENEA, in the Frascati Research Area. The experimental results are reported and discussed.

6386B-24, Session 5

Breath acetone detection

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Acetone is a good marker for metabolic stress as it is the most volatile and rapidly equilibrated of the ketone bodies produced by fat metabolism. Measurement of breath acetone concentration is a non-invasive probe appropriate for diabetes screening and determination of overall nutritional status provided a sufficiently sensitive and economic measurement method for acetone is available. A novel laser-based method for the quantification of acetone at concentrations appropriate for breath analysis will be described.

6386B-25, Session 5

Of wristwatches, organ-pipes, and insects: quartz-enhanced photoacoustic spectroscopy

A. A. Kosterev, Rice Univ.

Quartz-Enhanced Photoacoustic Spectroscopy (QEPAS) is a modification of conventional photoacoustic spectroscopy first reported in 2002. It is based on the use of a mass-produced frequency reference element, quartz tuning fork, as a sharply resonant acoustic transducer [1]. Being also spatially selective and operating at high 32.8 kHz frequency, such a transducer exhibits superior immunity to environmental acoustic noise and the analyzed gas flow noise. A spectrophone constructed from a wristwatch tuning fork and a piece of capillary tubing working as an organ-pipe type resonator performs on a par with conventional spectrophones in terms of sensitivity but requires a ~1000 times smaller gas sample. This unique property enables spectroscopic analysis of gases produced by biological objects such as insects or bacterial cultures. QEPAS is also considered as a means for creating miniature and low cost autonomous gas sensors that can be integrated into sensor networks.

Fundamental principles and practical implementation of QEPAS for trace gas sensing will be presented. Detection sensitivities achieved to date with QEPAS when it was used with different laser sources will be reported. The role of relaxation processes as both a sensitivity limiting factor and a means for enhanced chemical selectivity [2] will be considered. Ongoing and intended developments of QEPAS technology will be discussed.

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6386B-26, Session 6

A mid-IR ICL-based sensor for field measurements of ambient CH_4

D. M. Sonnenfroh, M. L. Silva, M. G. Allen, Physical Sciences Inc.

We are developing a prototype sensor for field measurements of ambient CH4. Our CH4 field sensor uses a Type II Quantum Cascade Laser (or Interband Cascade Laser, ICL) operating near 3.3 μm to monitor a well-isolated line in the υ3 fundamental band of CH4. The ICL operates in cw mode at cryogenic temperature. Output power is in the 10 mW range. Side mode suppression is \>19 dB. The sensor consists of two major components, the optical breadboard containing the laser, transfer optics, sample cell, and detectors, and the instrumentation module containing the power supplies and system control computer. The laser is mounted in a custom dewar. Light from the laser is collimated using a reflective microscope objective and transported to a multipass cell via a simple optics train. The multipass

cell is a spherical Herriott configuration with a re-entrant design. The optical path is ~7 meters using an 0.25 m base path. The cell is stabilized at 35 C and 50 mTorr. The spectrometer uses TE-cooled InAs detectors along with our Balanced Ratiometric Detection. Our measured precision for CH4 in air at ambient temperature is 40 ppbv for a 15 sec integration time. We will report on additional sensor characterization and the results of field testing the sensor at two facilities maintained by the University of New Hampshire.

6386B-27, Session 6

Quartz-enhanced photoacoustic spectroscopy based formaldehyde sensor using a mid-IR interband cascade laser

Y. A. Bakhirkin, A. A. Kosterev, T. Ajtai, Rice Univ.; R. Q. Yang, Jet Propulsion Lab.; F. K. Tittel, Rice Univ.

Formaldehyde (H2CO) detection and quantification at ppbv concentration levels is important in a number of applications such as environmental monitoring and atmospheric chemistry. A quartz-enhanced photoacoustic spectroscopy (QEPAS) based sensor [1] was developed to determine trace concentrations of formaldehyde. A liquid nitrogen cooled 3.57-micron continuous wave distributed feedback interband cascade laser was used as the excitation source to target a H2CO absorption line at 2804.9 cm-1 delivering 8 mW of optical power to the QEPAS absorption detection module. Improvements made to the original H2CO sensor architecture [2] resulted in an enhancement of the noise-equivalent sensitivity by a factor of 4.5. With a data acquisition time of 5 minutes a noise equivalent formaldehyde concentration level of ~ 25 ppbv was obtained. This sensitivity is sufficient for the monitoring of the air quality in spacecraft habitats in compliance with the established safe maximum allowed concentration levels of H2CO. The influence of the sampled air humidity on formaldehyde molecule V-T relaxation rate as well as further improvements of the detection sensitivity will also be discussed.

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6386B-28, Session 6

Gas phase photoacoustic spectroscopy in the mid-wave infrared using quartz tuning

M. D. Wojcik, Pacific Northwest National Lab.

We demonstrate the performance of a novel mid-infrared photoacoustic laser absorbance spectrometer for gas-phase species using an amplitude modulated (AM) quantum cascade (QC) laser and a quartz tuning fork microphone. Photoacoustic signal was generated by focusing the output of a Fabry-Perot QC laser operating at 8.41 μm between the legs of a quartz tuning fork which served as a transducer for the transient acoustic pressure wave. The QC laser was modulated at the resonant frequency of the tuning fork (32.8 kHz). This spectrometer was calibrated using Freon-134a as an infrared absober gas by performing a simultaneous absorption measurement using a 35 cm absorption cell. The NEAS of this instrument was determined to be 2 x 10-8 W cm-1 Hz-1/2. A corresponding theoretical analysis of the instrument sensitivity is presented and is capable of quantitatively reproducing the experimental NEAS, indicating that the fundamental sensitivity of this technique is limited by the noise floor of the tuning fork itself.

6386B-29, Session 6

Tunable THz source based on frequency conversion in quasi-phase-matched GaAs

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We demonstrate an efficient room-temperature diffraction-limited source of narrow-bandwidth frequency-tunable (0.5-3.5 THz) terahertz radiation based on parametric down-conversion in quasi-phase-matched orientation-patterned GaAs (OP-GaAs). The OP-GaAs samples were grown by a combination of photolithography, molecular beam epitaxy and hydride vapor epitaxy with different orientation-reversal periods ranging from 504 to 1277 * m. We produced micro-Watts of average THz power when the OP-GaAs crystal was pumped, in a single-pass geometry, by ~100-femtosecond pulses from either a high-repetition rate (100MHz), high average power (3W) Tm-fiber laser at 2 * m, or, alternatively, by a low-repetition rate (1KHz) Ti:Sapphire-laser-pumped OPA/DFG system with the energy-per-pulse of 2-3 * J operating in the wavelength range of 2-4.4 * m. In both cases, THz radiation was produced by quasi-phase-matched optical rectification and the THz tuning was achieved by varying either the orientation-reversal period of the OP-GaAs, or the pump wavelength. In the case of the OPA/DFG pump, the optical-to-terahertz photon conversion efficiency exceeded 5%. Our best results however were achieved when we used intracavity THz generation. In this case, the OP-GaAs crystal was placed inside a cavity of a near-degenerate (* ~ 2.13 * m) synchronously pumped picosecond (6-7ps) OPO system. The OPO ‘signal’ and the ‘idler’ pulses were mixed in the OP-GaAs to produce THz radiation through difference frequency generation. Up to 1mW of average THz power was produced in this setup. Such new GaAs-based THz sources would be suitable for many applications including real-time imaging and spectroscopy.

6386B-30, Session 7

Linear and non-linear optical microscopy and spectroscopy of human papilloma virus transfected cells

I. Georgakondi, J. M. Levitt, A. Baldwin, C. Mujat, C. A. Greiner, L. A. Stucenski, Tufts Univ.; K. Münger, Harvard Medical School

The overall goal of this project is to identify intrinsic fluorescent and light scattering signatures that allow us to differentiate normal and human papilloma virus (HPV)-transfected epithelial cells. Over 95% of cervical cancers and more than 25% of oral lesions are attributed to HPV infection. In addition, the results of our studies comparing normal and HPV-transfected cells may be applicable more generally to the detection of early pre-cancerous changes in epithelial tissues. We acquired and compared images and spectra of unstained normal and HPV-transfected human foreskin keratinocytes (HFKs). Biochemical characterization of these cells was based on fluorescence microscopic imaging and spectroscopy of endogenous chromophores, such as tryptophan, NAD(P)H and FAD. We performed both single-photon and two-photon excited fluorescence (TPEF) imaging. TPEF imaging was also used to compare three dimensional engineered epithelial tissues with normal and HPV-transfected cells to examine the relevance of our monolayer studies to more realistic epithelial tissue constructs. Light scattering spectroscopy was used to characterize the morphological/structural properties of these cells. We found that significant differences exist in the tryptophan content and localization and the fluorescence redox ratio (FAD/(FAD+NAD(P)H)) of normal and HPV-tranfected cells. These changes are consistent with observations in three-dimensional engineered tissues (rafts). In addition, TPEF studies with normal and HPV-transfected rafts allow us to examine in a more detailed manner effects of other processes, such as differentiation, on intrinsic tissue fluorescence and light scattering signals.

6386B-31, Session 7

Interstitial Doppler OCT monitoring of microvascular shutdown during photodynamic therapy in a Dunning prostate model: fluence rate dependences

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Microcirculatory changes inducing vascular shutdown may be a predictor to the therapeutic efficacy of photodynamic therapy (PDT). The aim of this study was to measure the tumor vascular response of varying dose rates during PDT deep within prostate tumor xerograft via interstitial Doppler optical coherence tomography (DOCT).

DOCT provides micron-scale spatial resolution allowing visualization of structures near histological levels and yields flow velocity resolution of

~17 μm/s. Current in vivo DOCT imaging probes are limited to intraluminal and near-surface sites. To improve the accessibility of DOCT to anatomically relevant sites deep within the body (e.g., prostate), an interstitial (IS) needle (~700μm diameter) probe was developed for minimally invasive monitoring of the microvascular response to PDT within tumor tissue. Rats were given a light sensitizing drug, Photofrin, and 20-24 h later the tumors were exposed to light (635nm) with a fluence rate of 8-133 mW/cm2 for 25 minutes to a total of 12-200 J/cm2. Results illustrated different rates of vascular shutdown within the tumor as imaged by IS-DOCT, related to the administered PDT fluence rate and light dose. Controls (tumor + light) showed no significant microvascular changes.

IS-DOCT was able to detect and monitor microvascular changes during PDT. Microvascular shutdown occurred at different rates and showed correlation with PDT light dose and fluence rate. These dependencies may play an important role in PDT treatment planning, feedback control for treatment optimization, and post treatment assessment.

6386B-32, Session 7

Diffusion approximation model of photon migration in the human lung

Z. Sikorski, M. Furmanczyk, CFD Research Corp.

The application of the near infrared spectroscopy (NIRS) to diagnosis of the human lung injury challenges many elements of these techniques. These include the NIRS instrument performance (light penetration depth, SNR) and accurate models of light transport in the heterogeneous thorax tissue. The thorax tissue not only consists of different media (chest wall with ribs, lungs) but its optical properties also vary with time due to respiration and the thorax geometry changes with contusion (e.g. pleural cavity filled with air - pneumothorax or blood - hemothorax).

We have developed the Finite Volume solver to model photon migration in the diffusion approximation in heterogeneous complex 3D tissues. The code applies boundary conditions that account for the Fresnel reflections. We proposed an effective diffusion coefficient for the void volumes (pneumothorax) based on the assumption of the Lambertian diffusion of photons entering the pleural cavity and accounting for the local pleural cavity thickness. The code has been validated using the MCML Monte Carlo code as a benchmark. The code environment enables a semi-automatic preparation of 3D computational geometry from medical images and its rapid automatic meshing.

We will present application of the code to optimization of the NIRS technique. The code effectiveness (3D complex case computation takes 1 second) enables its use to quantitatively relate detected light signal to absorption and reduced scattering coefficients that are indicators of the pulmonary physiologic state (hemoglobin concentration and oxygenation).

6386B-33, Session 7

Time-domain in vivo near-infrared brain imaging in adult humans

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Non-invasive optical imaging of the adult brain is performed by mapping diffuse reflectance of near-infrared light. The spatial resolution of diffuse optical imaging methods is far lower than with, e.g., magnetic resonance imaging (MRI) or computed tomography (CT). However, optical methods are expected to be less expensive and can be implemented as a bedside technique due to their compactness and portability. At wavelengths between 650 nm and 900 nm light can penetrate a few cm deep into tissue. Moreover, in this range the spectra of oxy- and deoxyhemoglobin are significantly different enabling the quantification of their concentration changes, e.g. during brain activation. Time-resolved recording of diffuse reflectance offers the opportunity of depth localization of absorption changes. In particular, cerebral and extracerebral absorption changes can be discriminated. This depth selectivity is important since, in particular, functional stimulation of the brain is often accompanied by systemic physiological changes that influence the absorption of extracerebral tissue thus contaminating cerebral optical signals. We present our recently developed time-domain optical brain imager that relies on picosecond diode lasers emitting at various wavelengths, an optical fiber switch and multi-channel time-correlated single photon counting. In-vivo applications include various functional stimulation experiments as well as perfusion assessment based on bolus tracking of the contrast agent indocyanine green. We show how cerebral (deep) and systemic (superficial) contributions to the signal can be separated by analyzing integral, mean time of flight and variance of measured time-of-flight distributions of diffusely reflected photons.

6386B-34, Session 8

Solid state microelectronic terahertz receivers and transceivers

M. Lee, M. C. Wanke, E. A. Shaner, J. L. Reno, Sandia National Labs.; S. J. Allen, Univ. of California/Santa Barbara

The terahertz (THz) electromagnetic spectrum between microwaves and infrared offers several unique advantages in chemical and biological sensing relevant to environmental and health monitoring applications. While THz spectroscopy and sensing have been demonstrated in the laboratory, a technological infrastructure that is compact and robust enough to move THz technology out of the laboratory and into common field use remains elusive. The primary obstacles to THz applications are: power, compactness, and reliability. Reasonable estimates suggest that many practical sensing applications require a coherent THz source that delivers 10 mW or more average power with low noise and good stability. Particularly in the 1 to 5 THz range, existing THz sources capable of such power are large, high-maintenance, lab-based instruments such as molecular gas and free-electron lasers. We believe that widespread acceptance of fieldable THz systems awaits a microelectronics-based semiconductor technology analogous to what exists for microwave electronics and infrared photonics. In this talk we will describe our research to develop all-solid-state microelectronic THz receivers and transceivers based on high-mobility III-V semiconductor heterostructures and bandgap engineered multilayers. These THz microelectronic sensor components rely on THz quantum cascade lasers (QCLs) to act as illumination source in direct detection and as local oscillator for heterodyne detection. We will also present results on THz detectors ranging from relatively simple but very high speed bolometric detectors to electronically tunable resonant THz detectors based on plasmon rather than electron excitations. The compatibility and integration of THz QCLs with direct such detectors and mixers will be discussed.

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

6386B-35, Session 8

Vertically emitting quantum cascade lasers based on photonic crystal resonators

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The quantum cascade laser is a mid or far-infrared semiconductor emitter based on electron subband transitions in multilayered semiconductor heterostructures. The large wavelength versatility of this laser has been combined in this work with the flexibility of the photonic crystal, in order to realize a vertically emitting semiconductor laser in the terahertz window of the electromagnetic spectrum. The active layers are based on the so-called bound-to-continuum design applied to the GaAs/AlGaAs material system, and are processed in a double metal plasmonic waveguide configuration by means of Au/Au thermo-compression wafer fusion. The photonic lattice based cavity is realized either by opening holes in the top metallic contact layer or by dry etching deep holes through the whole active region. In both cases a photonic crystal triangular symmetry is chosen.

Lasing emission from the top surface of the sample is observed for

some particular values of the photonic crystal parameters, with threshold current densities of about 300 A/cm^2 in optimized devices. These performances represent a significant improvement with respect to what obtained with the same active layer in the standard ridge waveguide configuration. The optical feedback is the result of a first order Bragg condition obtained along the Gamma-K direction of the photonic crystal as shown by the simulations realized both with plane wave expansion and finite difference time domain methods.

The tuning of the emission wavelength with the photonic lattice parameters as well as the far field patterns of the lasing structures will be presented. Moreover, a systematic comparison of the measurements with the numerical simulations will also be discussed.

6386B-36, Session 8

Terahertz pulsed imaging and spectroscopy of breast tumors

V. P. Wallace, A. Fitzgerald, E. Pickwell, TeraView Ltd. (United Kingdom)

We have developed a portable terahertz pulsed imaging system (TPIscan) for use in a clinical environment. The system uses photoconduction to generate and detect terahertz radiation with frequency content from 0.1 - 4 THz. Here, we report on a study using TPI for imaging breast tumours ex vivo. Several breast samples were imaged and parameters from the time domain impulse functions were used to provide contrast. The size and shape of tumor regions in the terahertz images were compared with the corresponding histology section. Good correlation was found for area and shape of tumor in the THz images compared to that of histology. In addition, we have also performed spectroscopy study comparing the terahertz properties (absorption coefficient and refractive index) of excised normal breast skin and breast tumor. Both the absorption coefficient and refractive index were higher for normal tissue that contained tumor. These changes are consistent with higher water content and structural changes, like increased cell and protein density. This study demonstrates the potential of TPI to image both invasive breast carcinomas and ductal carcinoma in situ using THz and encourages further studies.

6386B-37, Session 8

Device and application of quantum well photodetectors for terahertz region

H. Luo, H. C. Liu, C. Song, Z. R. Wasilewski, A. J. Springthorpe, National Research Council Canada (Canada)

We report on the progress of devices and applications of quantum-well photodetectors (QWIP) for the terahertz (~ 1-10 THz) spectrum region. We discuss device design and show that the device dark current can by effectively reduced by employing wider quantum barriers. We demonstrate several GaAs/AlGaAs QWIPs for different peak wavelength with background limited infrared performance (BLIP). We report experimental results on intersubband absorption spectra, measured using multi-pass waveguide geometry. We show that the experimentally measured intersubband energy levels agree excellently with the theoretical simulations, provided that many-body effects are taken into consideration, including exchange-correlation and depopulation effects. We report the results of QWIP photo-current spectra and detector responsivity. We discuss the high frequency capability of THz-QWIP and present experimental results of device time response measured using microwave rectification technique. We discuss its application in free space terahertz communication in combination with a terahertz quantum cascade laser (QCL). We discuss the terahertz to near infrared (THz-to-NIR) optical upconversion using a monolithic integration of THz GaAs/AlGaAs QWIP and NIR GaAs/AlGaAs LED, and its potential applications in terahertz imaging.

Monday-Tuesday 2-3 October 2006

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6387-01, Session 1

Per-packet reservation MAC protocols

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Recent and future communications networks have to provide QoS (Quality of Service) guarantees for a rapidly growing number of various telecommunications services. Therefore, various communications systems, such as wireless and fixed access networks, apply reservation MAC protocols, providing a good network utilization, which is particularly important access networks with typically limited data rates, and ensuring realization of different QoS guarantees for various telecommunications services. This is important because of a hard competition among communications technologies (DSL, WLL, CATV, PLC) applied in the access area. Furthermore, the reservation protocols are suitable for application in centralized communications structures, which are particularly typical for the access area, where multiple network stations are connected via a wireless or a wired shared medium to a central unit, so-called base station, which ensures communications with the wide area network.

The considered MAC protocol applies a per-packet reservation method to avoid the transmission gaps caused by per-burst reservation, and accordingly to achieve a better network utilization. However, the per-packet reservation increases the network load caused by the signaling, which calls for an efficient resource sharing strategy in the signaling channel. There are two basic solutions for capacity sharing in the signaling channel: random access, usually using slotted ALOHA, and dedicated access, realized by a polling method. Performance improvement of basic protocols can be carried out in different ways; by protocol extensions (e.g. piggybacking), a combination of different protocol solutions (hybrid protocols), and the application of adaptive protocols providing a change of access parameters according to the current network status (e.g. depending on network load). The performance of various protocol variants has to be investigated under near to realistic network conditions taking into consideration different traffic and disturbance models.

To find a protocol which performs well under different network conditions, the basic protocols has to be improved; e.g. by usage of free data channels for signaling, piggybacking, adaptive backoff mechanism, and hybrid protocols. Comparison of extended reservation protocols shows the advantage of the polling based access, which always achieves a near to full network utilization and generally, shorter signaling delays. In the case of advanced polling protocols, the signaling delay can be additionally reduced by active polling and dynamic association of network stations, as well as by application of two-step reservation protocol. Together with efficient traffic scheduling strategies, the two-step protocol allows realization of QoS guarantees for various telecommunications services, ensuriing fairness and stabile operation in a hard noise envoronment. Thanks to the high efficiency of the two-step protocols, the QoS guarantees can be provided for the services with hard time-critical requirements, too.

6387-02, Session 1

A decentralized load balancer for grid networks

O. A. Abu-Rahmeh, P. Johnson, A. Taleb-Bendiab, Liverpool John Moores Univ. (United Kingdom)

Grid is a type of parallel and distributed network that enables the sharing, selection, and aggregation of geographically distributed “autonomous” resources dynamically at runtime depending on their availability, capability, performance, cost, and users’ quality-of-service (QoS) requirements.

As the popularity of Grid network has increased, there is a need for an effective load-balancing paradigm for the distributed resources accessible on the Grid. So, when one node is overloaded, it can utilize the unused computing power of other nodes in the network.

Therefore, implementing an effective load balancing paradigm that would be integrated with Grid systems for efficient resource discovery and load distribution across virtual organizations (VOs) will have an important role in designing self-configuring and self-optimizing Grid networks.

In this paper, we present a distributed algorithm based on statistical mechanics that provides a load-balancing paradigm without any centralized monitoring. Thus, instead of monitoring resources and their availability via a static network, a dynamic overlay network is created that provides both a measure of instantaneous load distribution, and dynamics for job allocation and resource update. The resulting load-balancer would be integrated with Grid systems to increase the efficiency and utilization of the Grid computing.

Furthermore, we study the cases where services require a certain QoS constrains (such as distance-sensitive services which require a geographical awareness, and time-bounded services), and where jobs are dependent on the completion of other preceding jobs. Finally, analytical and simulation results are used to evaluate and validate the proposed load-balancing paradigm.

6387-03, Session 1

Evaluation of reliable solutions for on-chip and off-chip embedded interconnect architectures

M. Gillet, Nokia (Finland)

The networks-on-chip (NoC), multiprocessor systemc-on-chip (MP-SoC) and off-chip communication network platforms are emerging as an important trend for multi-chips systems. Each of these platforms has a different set of requirements and constraints, which can be ranked in terms of their relative importance. In most cases the main system characteristics can be described by the following parameters: power consumption, development and manufacture cost, architectural complexity, end-to-end traffic latency, network throughput, modularity, bit error rate, reuse, etc.

Recently a number of modular and scaleable communication-centric interconnect specific solutions for each field of application is proposed. Among them we specifically stress our attention on SPIN, Xpipes, BLACK-BUS and Aethereal solutions that are tailored for networks-on-chip based on bus transactions, which requires special care to achieve low latency. We also studied SpaceWire and MIPI UniPro solutions for off-chip network with transactions similar to message passing. Moreover, PCI-Express and RapidIO are also solutions for off-chip network but based on bus transactions.

For all on-chip and off-chip platforms reusability is a key requirement. However, from a device integrator perspective it is not sufficient if reusability in an embedded system is limited to the on-chip or off-chip solution and it also has to be extended respectively to off-chip or on-chip level, which would effectively merge both fields of application. Since requirements vary strongly for an on-chip versus off-chip environment, all attempts to simply extend the range of applicability of the existing systems leads to the creation of inefficient solutions. The reliability of network communications is another key aspect of any design. Generally the reliability can be achieved by use of a number of underlying technologies, such as point-to-point versus end-to-end flow control, point-to-point versus end-to-end data retransmission scheme, etc. The paper discusses an impact of applying different reliability schemes.

This paper makes a first attempt to approach a communication-centric interconnect solution that is specifically optimized for covering in a joined fashion on-chip and off-chip networks use scenario. The paper presents a few key points that help to identify the design trade-offs and aspects leading to the definition of an optimum solution. Moreover we identify a number of criteria to define what are the cases where a given set of underlying techniques is optimal. Also we specifically focus on issues encountered for a reliable on-chip to off-chip network systems.

6387-04, Session 1

Parallel hierarchical networks in communications

O. V. Malinochka, Kiev Univ. of Economy and Transport Technology (Ukraine)

The given work offers new approach to the creation of computing medium - of parallel-hierarchical (PH) networks, being investigated in

the form of model of neurolike scheme of data processing. The approach has a number of advantages as compared with other methods of formation of neurolike media (for example, already known methods of formation of artificial neural networks). The main advantage of the approach is the usage of dynamics of multilevel parallel interaction of information signals at different hierarchy levels of computer networks, that enables to use such known natural features of organization of computations in cortex as: topographic nature of mapping, simultaneity (parallelism) of signals operation, inlaid cortex, structure, rough hierarchy of the cortex, spatially correlated in time mechanism of perception and training. The formation of multi-stage PH networks assumes the process of sequential transformation of correlated and formation of decorrelated in time elements of neural networks at its transition from one stable state into another. The key feature of the offered approach is analysis of dynamics of spatially correlated mechanism of transformation of current and formation of resultant elements of neural networks. Such mechanism allows presenting in a new way the processing in neural networks as the process of parallel-sequential transformation of various components of image and account of time responses of transformation. Physical contents of input elements of neural networks, which participate in correlation - decorrelation, such as, for example, the amplitude or frequency, phase or energy of signals, cohesion or texture of images, is determined by the type of transformation being used, the selection of which depends on the class of problems being solved.

6387-05, Session 1

Reliability evaluation model for multi-states WDM networks

H. Fan, X. Sun, Southeast Univ. (China)

With optical networks evolving to the next generation optical networks, various services are intended to be carried over a single optical network infrastructure. This contributes to the phenomenon that different services with different QoS requirements may survive in a set of degradative network working-states. Thus during the study of optical network reliability, it is insufficient to regard optical networks as having only binary working-states according to their network connectivity. We proposes here a new reliability evaluation model for WDM networks, which regard the network as a system having multiple working-states with reference to their route (s-t) capacity and maximum hop number constraints. Additionally, considering that there exist in WDM networks some elements whose failures affect neither the nodes nor the entire links but only certain wavelength channels in the links, a new kind of network element is added to the traditional element types (nodes and links) of network reliability evaluation model, namely wavelength channel related elements. The model was used to simulate the reliability of WC (wavelength continuous), PWC (partial wavelength conversion) and NWC (non-wavelength continuous) WDM networks with CERNET topology by way of Monte-Carlo method. Simulation results indicate that different working-state requirements may lead to different reliability evaluation results, and the differences will enlarge very quickly with the increasing of network element failure rates. This implies that the study of WDM network reliability should be performed under multiple working-states assumption, especially for multi-service networks, and the addition of the new network element kind - a wavelength channel-related element is necessary.

6387-06, Session 2

A cooperation mechanism of pure P2P file-sharing networks to improve application-level QoS

N. Wakamiya, J. Konishi, M. Murata, Osaka Univ. (Japan)

To provide application-oriented network services, a variety of overlay networks are deployed over physical IP networks. Since they share and compete for the same physical network resources, their selfish behaviors affect each other and, as a result, their performance deteriorates. Our research group considers a model of overlay network symbiosis, where coexisting overlay networks cooperate with each other to improve their application-level quality of service (QoS) while sustaining influences from the physical network and other overlay networks. In this paper, we especially focus on Peer-to-Peer (P2P) networks among various overlay networks. We propose a mechanism for pure P2P networks of file-sharing applications to cooperate with each other. In our proposal, a cooperative peer first finds another P2P network and establishes a logical link to a cooperative peer in the found network. Both ends of the logical link decide whether they cooperate or not from a viewpoint of the mutualism. When they consider they benefit from the cooperation, messages and files are exchanged among cooperative P2P networks through the logical link. For an efficient and effective cooperation, we also propose an algorithm for the selection of cooperative peers and a caching mechanism to avoid putting too much load on cooperative peers and cooperating networks. Simulation results showed that the number of discovered providing peers and the ratio of search hits increased about twice, while the load by the cooperation among P2P networks was reduced about half by caching.

6387-07, Session 2

Survivable passive access network SPAN

M. U. Wasim, S. M. H. Zaidi, National Univ. of Science and Technology (Pakistan); M. Y. Raja, Univ. of North Carolina at Charlotte; N. Ghani, Tennessee Technological Univ.; R. Ahmad, National Univ. of Science and Technology (Pakistan)

Wavelength Division Multiplexed based Passive Optical Networks (WDM-PON) are subjected to wide variety of unintentional failures caused by natural disasters, wear out, overload, software bugs, and human errors. Many such failures occur at optical layer: like fiber cuts resulting from digging works, failure of an individual transmitter or receiver, and failure of complete optical node. Under such conditions it is preferred in optical networks to provide fault management (survivability) at optical layer. In this paper our objective is to determine the factors, which can increase the scope of survivability at optical layer, that are not provided in previous research and on the basis of that we have proposed a cost effective recovery mechanism, called “survivable passive access network” (SPAN). SPAN is cost effective multi-level protection scheme that is proved to be highly efficient and scalable. It provide protection against single link, multi link, single node (single remote node), and multi node (multiple remote nodes) failures in access domain. It is independent of devices (ONU and OLT), which are used to deploy WDM-PON, this make our proposed architecture to be cost effective, and easily scalable. SPAN is independent of transmitter used in WDM-PON architecture, these transmitters includes: Wavelength-specified source, multiple-wavelength source, wavelength selection free source, and shared resources. SPAN works on notion of recovery class and provide protection to users who are registered for services that highly depend on recovery skills of network infrastructure, this make SPAN to be market oriented protection scheme. SPAN, provides efficient paths for protection that keep factor of “additive latency” under affordable level. SPAN uses 1:1 protection scheme for distribution/collection, feeder fiber and node failure, which is more efficient then 1+1 protection, which lead to better resources utilization.

6387-08, Session 2

Information gathering system based on combination of random and selective accesses for ubiquitous environments

Y. Hirano, M. Sasabe, H. Nakano, Osaka Univ. (Japan)

In this paper, we focus on an information gathering system where a reader continuously collects information from mobile nodes in its access area, such as environmental information cameras and sensors. We assume that a mobile node is relatively tiny and does not have a high-precision antenna to sense carriers emitted by other nodes.

Although a random access method like ALOHA can be easily used, it has disadvantages of transmission efficiency and energy consumption.

To tackle these problems, we propose a novel method that is a combination of random and selective accesses. At first, a reader sends an ID request to all nodes. Then, each node replies its ID to the reader at a response probability involved in the request. Finally, the reader selectively gathers information from nodes according to the obtained ID lists.

In our method, non-registered nodes and non-deleted nodes affect the system performance. The non-registered node is a node that is in the access area but its ID is not registered to the reader. The non-deleted node is a node that leaves the area but its ID is still registered to the reader. In this paper, we first derive their numbers by an analysis using the Inversion Formula of Palm Calculus. Then, we conduct simulation

experiments to verify the analysis. Simulation results show that our method can achieve 70% of transmission efficiency while ALOHA and Slotted ALOHA attain 18% and 36%, respectively when node mobility is relatively small.

6387-14, Session 3

Performance evaluation of reactive and proactive routing protocol in IEEE 802.11 ad hoc network

S. Hamma, J. V. Guédon, E. Cizeron, H. Issaka, Univ. de Nantes (France)

Wireless technology based on the IEEE 802.11 standard is widely deployed. This technology is used to support multiple types of communication services (data, voice, image) with different QoS requirements.

MANET (Mobile Adhoc NETwork) does not require a fixed infrastructure. Mobile nodes communicate through multihop paths. The wireless communications medium has variable and unpredictable characteristics. Furthermore, node mobility creates a continuously changing communication topology in which paths break and new ones form dynamically.

All routers in adhoc networks must keep routing tables up-to-date. MANET uses distance vector or link state algorithms which insure that the route to every host is always known. However, this approach must take into account the adhoc networks specific characteristics: dynamic topologies, limited bandwidth, energy constraints, limited physical security, ...

Two main routing protocol categories are studied in this paper: proactive protocols (e.g. Optimised Link State Routing - OLSR) and reactive protocols (e.g. Ad hoc On Demand Distance Vector - AODV, Dynamic Source Routing - DSR).

The proactive protocols are based on periodic exchanges that update the routing tables to all possible destinations, even if no traffic goes through. The reactive protocols are based on on-demand route discoveries that update routing tables only for the destinations that have traffic going through.

The present paper focuses on study and performance evaluation of these categories using NS2 simulations. We have considered qualitative and quantitative criteria. The first one concerns distributed operation, loop-freedom, security and sleep period operation. The second is used to assess performance of different routing protocols presented in this paper. We can list end-to-end data delay, jitter, packet loss rate, control packet load and optimal path discovery.

A comparative study will be presented with a number of networking context considerations and a pertinent routing protocol classification will be presented in this paper: the results show the appropriate routing protocol for multiple types of communication services (data, voice, image) with different QoS requirements.

6387-15, Session 3

INFOCUS: information corroboration from UAV sensors

M. L. Talbert, Air Force Research Lab.; P. D. Baldwin, United States Strategic Command

This research demonstrates a foundation for modeling the quantification of sensor coverage for a sensor web comprising swarmed Unmanned Aerial Vehicles (UAVs). Areas of interest (AOI)s are analyzed from a multi-phenomenal sensor swarm geo-location perspective to determine the quantity of coverage afforded by a swarm of multiple sensor-laden UAVs. This work investigates the coverage of AOIs as determined by the number of visits the swarm gives to sectors of the AOI over designated times, the swarm density, and swarm topology. By comparing the coverage of several different swarm configurations, we gain an understanding of how varying swarm sizes and configurations affect coverage. We exploit spatio-temporal coverage estimates to enable efficient and precise information extraction from each sensor platform's on-board volatile memory.

6387-16, Session 3

A novel FBG sensor network with high survivability

P. Wei, X. Sun, Southeast Univ. (China)

Fiber Bragg grating (FBG) sensors have been identified as one of most hopeful sensing elements. In this letter, a self-healing architecture for FBG sensor network is proposed in detail, including remote nodes, main node which is responsible for sending the light from the source to the sensor network and FBG sensors which are arrayed in series, parallel and ring architecture in order to further enhance the survivability of the sensor network. The sensor network, called sector sub-network, has high survivability which checks the breakpoints and reconfigures the sensor network with different route if any link fails. According to the different applications, the network can offer higher survivability without reducing the performances of the network too much which can tolerate more than one breakpoints in the network in which the route reconfigured and the remote nodes made using optical switches and couplers are redesigned. The results are approved by the simulation.

The sensor network can be expanded to large scale by the means of combining two or more sector sub-network in which the routes become a little more complicated. Remote nodes of different kinds are also redesigned using optical switches, couplers and circulators to help finding a new route when certain links fail. To enhance the performance of the large scale sensor network if more than three sub-networks are combined, route is carefully redesigned. The improved performances are also verified by the simulation. The proposed architecture can facilitate a reliable sensor network of large scale and multipoint smart structure.

6387-09, Poster Session

A role-based global trust model for peer-to-peer systems

J. Zhang, Z. Zhao, Tianjin Univ. (China); M. Ma, Nanyang Technological Univ. (Singapore)

P2P systems are usually used for information exchange between peers in recent years. However, the open and anonymous nature of a P2P network makes it an ideal medium for malicious peers. There is a lack of efficient mechanism for existing P2P softwares to avoid from free riding, whitewashing, collusion and malicious attackers.

In this paper, we describe a role-base global trust model for Chord like decentralized unstructured P2P systems. First, we give object criterias to track each peer's contribution in the system which stored locally. Second, we introduce a metric to compute global trust value. Third, we divide all the peers into 3 parts according to their trust value: backbone peers, anonymous peers, malicious peers. Each of the 3 roles is binded with different rights and obligations. Finally, we discuss how our trust model allows peer to revoke relationships with untrusted peers.

We present a concrete method to validate the proposed trust model and report the set of simulation-based experiments, showing the feasibility and benefit of this model.

6387-10, Poster Session

Decentralized session initiation protocol solution in ad hoc networks

L. Han, Z. Jin, Y. Shu, Tianjin University (China)

Decentralized Session Initiation Protocol Solution in AD HOC Networks: With the fast development of ad hoc networks, SIP has attracted more and more attention in multimedia service. This paper proposes a new architecture to provide SIP service for ad hoc users, although there is no centralized SIP server deployed.In this solution, we provide the SIP service by the introduction of two nodes: Designated SIP Server (DS) and its Backup Server (BDS).The nodes of ad hoc network designate DS and BDS when they join the session nodes set and when some pre-defined events occur. A new sip message type called REGISTRAR is presented so nodes can send others REGISTRAR message to declare they want to be DS. According to the IP information taken in the message, an algorithm works like the election of DR and BDR in OSPF protocol is used to vote DS and BDS SIP servers. Naturally, the DS will be replaced by BDS when the DS is down for predicable or unpredictable reasons. To facilitate this, the DS should register to the BDS and transfer a backup of the SIP users' database. Considering the

possibility DS or BDS may abruptly go down, a special policy is given. When there is no DS and BDS, a new election procedure is triggered just like the startup phase. The paper also describes how SIP works normally in the decentralized model as well as the evaluation of its performance. All sessions based on SIP in ad hoc such as DS voting have been tested in the simulation with ns2 within a 1000mÅ~1000m square area where 10 to 40 random nodes are placed.

6387-11, Poster Session

Wireless network traffic modeling based on extreme value theory

C. Liu, Y. Shu, Tianjin Univ. (China); O. W. W. Yang, Univ. of Ottawa (Canada); J. Liu, Y. Xu, Tianjin Univ. (China)

With the rapid development of computer and wireless communication technologies, the wireless networks are receiving an increasing amount of attention due to its deployment and administration flexibilities. It is very desirable to research on different transport techniques for wireless networks. Congestion control and bandwidth assignment are some examples that have been researched widely. As a foundation of these research fields, it is the most essential to build a model that can accurately characterize wireless network traffic, which can indicate the network congestion degree. In turn this knowledge can be used for network design and management, and even applied to network control design. In the conventional analysis of network traffic, traffic data was usually assumed to meet some specified distribution. But in the real world, it is difficult to determine the distribution of wireless traffic.

This paper introduced the extreme value theory (EVT) for analysis of network traffic. The role of EVT is statistically rational to estimate the extreme behavior of random processes. It is not necessary to assume the distribution function of traffic, and only extreme events were considered. A procedure based on EVT using points over threshold method was proposed to wireless traffic modeling and prediction. Then some experiments were performed using S-Plus software to study the feasibility of our proposed method.

Our experiments showed that the EVT could be applied to analyze wireless network traffic and it had a good foreground in traffic modeling and prediction. Furthermore, since only the data greater than the threshold is processed, the computation overhead is reduced greatly. Compared with other prediction models, the prediction results are more consistent with real trace, meaning we can reap the benefits of using EVT without losing much accuracy in the process. It indicates that EVT is effective in analyzing the wireless network traffic.

6387-12, Poster Session

Application of MAC delay in TCP fairness improvement in ad hoc wireless networks

L. Dong, Y. Shu, T. Guan, Tianjin Univ. (China)

Significant TCP unfairness in ad hoc wireless networks has been reported during the past several years. Dr. Xu et al in UCLA and we proposed a Neighborhood RED (NRED) scheme to enhance TCP fairness in ad hoc wireless networks. NRED adopt a passive measurement technique to detect the early congestion of a neighborhood. But the measurement and account for the channel utilization are hardly to implement because it needs to modify the hardware of lower layer. As it is known, packet delay increases when the wireless channel is very busy and the overall traffic load exceeds the capacity of the channel. Thus the packet delay can reflect whether or not the channel is busy. Nodes that share the same wireless channel have different average packet delay due to the fact that they have different number of competitors. For each packet's transmission, the more delay, the more severe congestion and competition. We believed that the delay of data can reflect the congestion of shared link promptly.

In this paper, we analyze the TCP fairness problem and identify the main causes leading to unfairness. Every node monitors its packet delay separately. If the delay exceeds the given threshold, this node translates the delay into queue size and broadcasts the packet drop probability to its neighbors. The neighbors will adjust it transmission rate. We analysis the average packet delay on IEEE 802.11 DCF which is represented exactly by a Markov model. Based on the relationship between the MAC delay and number of competitors, whether there exist severe competition can be found. The one-hop delay can be converted into a queue length, and NRED can be implemented in testbed. We have done extensive simulation and test-bed experiments to validate our analysis. The analytic and experimental results shown that the TCP fairness can be greatly improved with very small overhead.

6387-17, Poster Session

HASN: a power saving and reliable communication paradigm for sensor networks

Q. Zhang, Z. Zhao, Tianjin Univ. (China)

HASN is a hierarchical and asymmetric sensor network, optimized via cross-layer designs. It does not need global addresses for sensors. There are two kinds of nodes in HASN: normal sensor and header node that has more powerful battery and higher performance antenna. Every header and sensors in its radio transmitting range compose a group. The header takes charge of data collection and data aggregation in its group. In a group, the communication is asymmetric. From a header to sensors is directly reachable, but from sensors to their header needs multi-hop. We use three methods to save sensors' energy. (1) The header selects relay nodes for every sensor with different priorities according to the principles of minimum hops and maximum available energy. (2) The header assigns different time for relay nodes to be active. (3) For many sensors may report the same event, the header depresses it by broadcast. We design a routing protocol for packets relay between headers. The main points are: (1) The data sink send short interest packets along with a unique label and locations of itself and interest area. (2) Headers randomly contend the forwarding right with different priorities according to its location and available energy. The winners forward the packet and record the label. (3) Headers in the interest area send data along with the label. (4) The headers who recorded the label will forward the data packets. We simulate HASN in NS-2. It shows that HASN save much energy than Directed Diffusion.

6387-18, Poster Session

Implementation of an effective video transmission scheme over ad hoc networks

L. Liu, Z. Jin, Y. Shu, Tianjin Univ. (China)

Real-time video transmission over ad hoc networks faces many challenges including low bandwidth, long end-to-end delay, high packet loss rate, frequently changing topology and limited-powered mobile nodes. This paper presents an effective real-time video transmission scheme and improves implementation of DSR (Dynamic Source Routing) protocol. We set up a test-bed by using DSR routing in the IP layer, and an application transmitting video stream over UDP protocol. We get a continuous JPEG image stream from a ZC0301p web camera and split each image into small blocks according to the MCU (Minimum Coding Unit) borderline. The strong point of splitting JPEG image is that IP layer fragmentation can be avoided so we can determine which part of data in the frame gets lost to do loss recovery at the receiver. By using JPEG image stream, the video encoding complexity is reduced, which can save computing power of mobile nodes compared with MPEG and other Multiple Description Coding (MDC) methods. We also improve implementation of DSR to make it suitable to transfer real-time multimedia data. First different priorities are given to different traffic classes in DSR routing. Second the route maintenance scheme is modified to decrease overhead and link failure misjudgments. We carry out two experiments both indoors and outdoors using six mobile nodes. The first is to transmit continuous JPEG images using our former DSR implementation according to DSR draft. The second is that we split JPEG images into blocks and then transmit them using improved DSR implementation. Results show the latter gives better video stream fluency and higher image quality.

6387-19, Poster Session

Agent-based web services gateway

N. Park, Electronics and Telecommunications Research Institute (South Korea)

Web services enable the integration of applications in a web environment. Due to an increased automation of web service interoperation, intelligent web services are recommended, such as Semantic Web Services. In this paper, we first introduce web services

and the concept of intelligent web services. We then propose an agent-based web service gateway. We focus on the intelligent web services platform with existing standards instead of proposing other standards. In particular, we present an agent approach to dynamic web services, which invokes access points of UDDI registry automatically and returns execution results for web services. The proposed approach is used to build experimental solutions involving intelligent web service systems. Finally, we'll give an example to illustrate a typical scenario in which consumers search web services using our web services gateway.

6387-21, Poster Session

High-speed readout method of ID information on a large amount of electronic tags

W. Nagate, M. Sasabe, H. Nakano, Osaka Univ. (Japan)

An electronic tag such as RFID is expected to create new services that cannot be achieved by the traditional bar code. Specifically, in a distribution system, simultaneous readout method of a large amount of electronic tags embedded in products is required to reduce costs and time. In this paper, we propose novel methods to accomplish this requirement.

In our system, a reader firstly sends an ID request to electronic tags in its access area. It successes reading information on a tag only if other tags do not respond. To improve the readout efficiency, the reader appropriately controls the response probability in accordance with the number of tags.

However, this approach cannot entirely avoid a collision of multiple responses. When a collision occurs, ID information is lost. To reduce the amount of lost data, we divide the ID into two parts and first gather only the former part (temporal ID) according to the above method. After obtaining temporal IDs from all tags, we sequentially collect the latter part of ID based on the list of temporal IDs. Note that we determine the number of bits of a temporal ID in accordance with the number of tags in the access area so that each tag can be distinguishable.

Through simulation experiments, we evaluate our proposed methods in terms of the readout efficiency. Simulation results show that our proposed methods can accomplish about 0.9 of readout efficiency in a condition where there are a thousand of electronic tags whose IDs are 128 bits.

6387-22, Poster Session

Dynamic coordination rules in peer-to-peer database

Z. Zhao, Z. Zheng, Tianjin Univ. (China)

In existing peer-to-peer database framework designs, coordination rules are assumed already present and never changed during the whole course of operation. This paper investigates how coordination rules are created and changed, hence helping ease the procedure. Local database can be on and off dynamically, but this feature of P2P database is inconsistent with fixed coordination rules, for dependency path will be broken when an intermediate peer is absent. A restoration mechanism is designed in this scenario to realize dynamic coordination rule. To achieve this, coordination rules on the same dependency path have to be available after the path is broken, and combined together to form a new dependency path and bypass the absent peer. To backup rules before host is down they can be published as resource advertisement to remote peers by underlying P2P platform facility. Actually since coordination rules are no longer bounded with their host, they can be viewed independent from the database system to form a coordination rule P2P network, with some peers having no database and purely as rule cache. The protocols about rule cache, combination and new rule creation request in such network are discussed Rules float along dependency paths across network and combine to form a new rule where necessary. A peer wanting to create new coordination rules can publish query and if there is a rule on another peer which can be combined with the existing one, a new rule is created and send back. This dependency path discovery process can be similar to route discovery process.

6387-23, Poster Session

A new wavelength assignment scheme for supporting QoS in optical burst switching networks

Z. Zhang, L. Li, Chongqing Univ. of Posts and Telecommunications (China)

A novel wavelength assignment scheme for supporting Quality of Service (QoS) in Optical Burst Switching (OBS) networks is proposed. At each OBS node, we set the range of the wavelengths for every class of priority according to the corresponding ratio of its throughput to the whole traffics' throughput. Bursts with QoS requirement can only be assigned their predefined wavelengths if there is no contention. In order to guarantee the performance of high priority in the case of contention, bursts with high priority can preempt the wavelengths that are originally arranged for low priority. However, low priority bursts cannot be assigned wavelengths that are predefined for high priority bursts. Although bursts with low priority have less opportunities to be assigned wavelengths than those with high priority, their priority will be gradually increased in case that contention make them stored in the buffers, i.e., bursts with low priority in this condition can even be assigned an idle wavelength that is not predefined for them. In the paper, we give the detailed means to increase the priority of the buffed low priority bursts and show it is especially beneficial to improve networks average throughput than that of offset-time-based scheme. Theoretic analysis and simulation results demonstrate that by using our scheme (1) large end-to-end delay due to the extra offset time in the offset-time-based scheme can be avoided, (2) the limitation of low priority burst dropping directly mechanism can be remedied and the performance of OBS networks can be improved.

6387-24, Poster Session

Throughput analysis of IEEE 802.11-based ad hoc networks in presence of selfish node

C. Liu, Y. Shu, S. Wang, Tianjin Univ. (China)

Mobile devices and Ad Hoc networks based on the IEEE 802.11 technologies are becoming more and more popular. 802.11 protocol relies on the random deferment of packet transmissions. Like most other protocols, 802.11 protocol was designed with the assumption that the nodes would play by the rules. This is important, since the nodes themselves control their random deferment. However, with the higher programmability of the network adapters, the temptation to tamper with the software or firmware is likely to grow; in this way, a selfish node could obtain a much larger share of the available bandwidth at the expense of other users.

This paper investigates saturation and finite load throughputs of DCF (distributed coordinated function) as specified IEEE 802.11 wireless network protocol in presence of selfish node. To study throughput of IEEE DCF with selfish node, we used Markov model of DCF. A general analytical solution was derived for DCF that may be used to find throughput under various traffic loads. To validate our analytic results, we have done extensive simulation using Qualnet.

The analytic and the simulation results matched well, which revealed two interesting insights: 1) In the situation of a single selfish node, the throughput of selfish node is much more than that of the well-behaved nodes under different traffic load. With the increasing of initial contention window size of selfish node, the throughput obtained by selfish node decreases. On the contrary, the throughput of well behaved nodes increases. 2) In the situation of more selfish nodes, the throughput of all nodes is lower than that in one selfish situation. When the network load is finite, the throughput decreases rapidly with the increase of initial contention window size of selfish nodes. Even the network may collapse in this situation when traffic load is saturation.

6387-25, Poster Session

Fixed-rate layered multicast congestion control

B. Zhang, Z. Liu, B. Yuan, Xidian Univ. (China)

It is widely accepted that one of the key factors inhibiting the usage of IP multicast on the Internet is the lack of good, deployable, well-tested multicast congestion control mechanisms. While a number of single rate multicast congestion control protocols have been proposed, they cannot scale to large or heterogeneous audiences. Multi-rate congestion control protocols have the advantage of scalability, but

existing multi-rate protocols are less mature than single rate protocols and are complex in their implementations. In this paper, we propose a new fixed-rate layered multicast congestion control protocol called FLMCC, which is a window based multi-rate multicast congestion control algorithm. The sender of a multicast session transmits data packets at fixed rate on each layer, while receivers each obtain different throughput by cumulatively subscribing to deferent number of layers based on their expected rates. In order to provide TCP-friendliness and estimate the expected rate accurately, a window-based mechanism implemented at receivers is presented. To achieve this, each receiver maintains a congestion window on each layer, adjusts it based on the GAIMD algorithm, and from the congestion window an expected rate is calculated. To measure RTT, a new method is presented which combines an accurate measurement with a rough estimation. A feedback suppression based on a random timer mechanism is given to avoid feedback implosions during the accurate measurement. The protocol is simple in its implementation. Simulations indicate that FLMCC shows good TCP-friendliness, responsiveness as well as intra-protocol fairness, and provides high link utilizations.

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6388-01, Session 2

Nation-wide GMPLS/OXC networking experiments over JGN II test bed

Y. Sameshima, National Institute of Information and Communications Technology (Japan)

We present GMPLS/OXC networking experiments in JGN II. JGN II is a nation-wide open testbed network established by NICT (National Institute of Information and Communications Technology) for promoting R&D activities of advanced networking technologies and network-related applications.

In JGN II, we have carried out some experiments. In our presentation, some experimental results are introduced, which include the interworking between MPLS and GMPLS, the improvement of controllability of OXCs using interfaces with rapid wavelength tunable lasers, the customer controllable functions based on NMS, some transport results of high traffic volume applications and so on. We have confirmed GMPLS/OXC feasibility and applicability through these experiments.

6388-03, Session 3

Management of nonlinearity in modern optical fiber transmission

X. Liu, Lucent Technologies/Bell Labs.

Optical fiber transport networks have been evolving rapidly to meet the demands of today's telecommunications such as unprecedented transmission capacity and reach. Fiber nonlinearity becomes an important issue as the transmission capacity and reach increase, and appropriate management of fiber nonlinearity is necessary. We review the progresses on some novel techniques for managing fiber nonlinearity in modern optical transmission systems. Advanced optical modulation techniques that allow optical signals to have high tolerance to both inter-channel and intra-channel nonlinear effects will be discussed. In particular, differential phase-shift keying (DPSK) and its impact in high-speed dense wavelength-division-multiplexing (DWDM) systems will be described. Novel dispersion management methods that suppress nonlinear effects will also be reviewed, particularly in the context of scalable and transparent optical transport networks having mixed 10 Gb/s and 40 Gb/s DWDM channels and optical add/drop multipliers (OADM).

6388-04, Session 3

Suppression of intrachannel nonlinear effects in high-speed WDM systems

I. B. Djordjevic, B. V. Vasic, The Univ. of Arizona

High-speed optical transmission systems operating at 40 Gb/s or higher are severely limited by intrachannel nonlinearities such as intrachannel four-wave mixing (IFWM) and intrachannel cross-phase modulation (IXPM). Approaches to deal with intrachannel nonlinearities may be classified into three broad categories: modulation formats, constrained (or line) coding, and equalization techniques. The IFWM is a phase-sensitive effect, and the aim of the first approach is to remove the phase short-term coherence of the pulses emitted in a given neighborhood. The role of constrained coding is to avoid those waveforms in the transmitted signal that are most likely to be received incorrectly.

In this paper we describe two alternative techniques for suppression of intrachannel nolinearities: (i) constrained coding techniques, and (ii) combined nonlinear ISI cancellation and error control. Three different constrained coding techniques will be presented: (a) the use of constrained encoding itself, (b) combined constrained and error control coding and (c) deliberate error insertion. The nonlinear ISI cancellation scheme employs the maximum a posteriori probability (MAP) symbol decoding based on Bahl-Cocke-Jelinek-Raviv (BCJR) algorithm, while the forward error correction is based on low-density parity-check (LDPC) codes. The nonlinear ISI channel is modeled by a finite state machine (FSM) whose transition and output functions describe the dependency of the channel statistics and the ISI on transmitted patterns. The BCJR algorithm operates on a trellis of the corresponding FSM, and creates the soft information (detected bit likelihoods) used in the iterative decoder. The main feature of these schemes is that they can operate in the regime of very strong intrachannel nonlinearities where FEC schemes such as turbo or LDPC codes are not designed to operate.

6388-05, Session 3

Parametric processing of optical signals

C. J. McKinstrie, Lucent Technologies/Bell Labs.

Parametric devices based on four-wave mixing in fibers provide many functions that are required by optical communication systems. When operated in the linear regime, parametric devices provide amplification, frequency conversion and phase conjugation, all with high gain levels and broad bandwidths. They can also be used to monitor and switch signals. When operated in the nonlinear regime, parametric devices regenerate optical signals. In this talk the current status of re-search on parametric devices will be reviewed briefly, and some promising directions for future research will be indicated.

6388-06, Session 4

Future integrated broadband fiber, wireless, and satellite networks

V. W. S. Chan, Massachusetts Institute of Technology

With the increasing technical maturity in fiber, wireless and satellite communication technologies, new horizons are becoming feasible for future broadband networks, providing economically data rates well in excess of Gbps for stationary and mobile users as well as novel applications these advanced network services will permit. This talk explores the future architecture possibilities of such a network using new and radical technology building blocks such as: free space laser communications, multiple access multi-beam data satellite communications, novel all-optical network transport/switching and analog transmission and processing over optical carriers that support coherent distributed platform sensing and communications. We will articulate why we have to design this new network across layers from the Physical Layer to the Network and Transport Layers (even the Application Layer). Not only can the future network performance and cost undergo quantum-leap improvements; such a network can have profound transforming effects on space and terrestrial system architectures for sensing, healthcare, early warning systems, disaster relief, research collaborations and other new commercial applications.

6388-07, Session 4

Advances and challenges of IP plus photonic networks

K. Sato, Nagoya Univ. (Japan)

Recent advances in photonic network technologies and in access technologies, and the emergence of IP-based control protocols such as MPLS and GMPLS, provide powerful tools for creating the next generation networks that support IP convergence. Those new technologies combined with the emergence of new regulatory environments have spurred the divergence in technologies and architectures adopted. This allows us to develop optimized networks that match each country's or region's or carrier's situation. This tutorial will give an overview of recent advances in IP plus photonic network technologies and discuss the next steps to proceed in the development of future networks.

6388-08, Session 5

Optical networking: status update

T. S. El-Bawab, Jackson State Univ.

Optical Cross-Connects (OXCs) is considered a cornerstone of the optical layer and next generation transport networks. By the end of the 20th century, optical networking was in a period of high growth. Large

investments were pouring into research and development of optical technologies, components and networks. Progress in optical switching, in particular, was remarkable. Many vendors, established and startups alike, proposed OXCs and a number of field trials were carried out in carriers' networks. The downturn of the telecommunications industry has put this progress on hold. Today, OXCs are starting to penetrate national and international research/education networking initiatives. Nevertheless, progress in these scientific initiatives has not been matched yet by commercial deployment in carrier networks.

This paper discusses the present and future of optical cross-connects. We explore progress made in their technologies, applications, and deployment, both in cutting-edge scientific initiatives and in carriers' networks.

6388-09, Session 5

Representing structural conflicts in provisioning optical protection switching

J. B. Kroculick, Winifred Associates; C. Hood, Illinois Institute of Technology

There are an increasing number of ways optical network devices and IP routers

can interact with each other during a network fault. To provide continuity of service, the interactions between each component in a network must be cooperative. Consequently, the effect of recovery processes cooperating are the network configurations that have certain structural relationships, which can be elaborated. A conflict detector can prove that service will be restored during a fault scenario by checking whether these structural properties hold.

We are using simulation as a method to study the coordination of recovery strategies and whether different coordination strategies will achieve recovery goals attached to a network service. The network service carries a traffic stream, which is injected into and extracted from a network. For multilayer recovery to complete, the cumulative effect of device actions during a failure must be (1) a connected path between the endpoints of a service and (2) a flow traffic delivered to a destination at a quality that matches a service level agreement.

We represent Optical and Multiprotocol Label Switching (MPLS) recovery actions as graph-maintenance operations that change the state of a digraph. For example, the actions of forwarding traffic between an access port and a trunk port and selecting traffic from a new trunk port and forwarding it to an access port can be modeled as a sequence of edge additions and deletions. The state of the digraph represents the current configuration of a multilayer network as actions of recovery are performed. In this paper, we define some structural properties that can be observed during a simulation as the network evolves to a final state from an initial state before a failure occurs.

6388-10, Session 5

Optical switch architectures for hierarchical optical path networks

S. Kakehashi, H. Hasegawa, K. Sato, Nagoya Univ. (Japan)

Broadband access is being rapidly adopted throughout the world and as a result traffic is continually increasing. Further traffic expansion will occur in the near future with the introduction of new broadband services including IP video and HDTV, which will warrants the introduction of hierarchical optical path cross-connect (HOXC). Regarding hierarchical OXC networks, studies have been done on the possible reduction of OXC port count achieved with utilizing HOXCs compared to utilizing single granularity OXCs. This paper proposes new HOXC node architectures that allow graceful expansion of the node throughput in response to the traffic growth. They allow incremental increase in the numbers of fiber ports, wavebands, and optical paths per waveband, which allows cost-effective introduction of the HOXC system even at the outset when traffic volume is not so large. The paper also discusses necessary scales of the switch in terms of the number of switch cross-points, and proposes new switch configurations that can effectively reduce the number of cross-points. The effectiveness of the proposed switch architectures is demonstrated compared with the single-layer OXCs where parameters such as number of fiber ports, optical paths per waveband and the ratio of optical paths that need to be groomed at a node are changed. The results will provide us useful criteria for the introduction of HOXCs compared to conventional OXCs.

6388-11, Session 6

ROADM technology review: why, when, what, where, and how

W. I. Way, OpVista, Inc.

Reconfigurable optical add-drop multiplexer (ROADM) is now considered essential equipment in a next-generation dense wavelength division multiplexing (DWDM) transport network. It provides flexible wavelength add drop, similar to the flexible frame add-drop of a SONET/SDH ADM, yet with a much higher capacity. However, at this early stage of deployment, service providers are presented with a variety of ROADM technology alternatives, and often faced with difficult decision-making criteria. This talk presents a practical guide to ROADM selection criteria and deployment considerations.

6388-12, Session 6

ROADM expansion and its cross-layer applications

M. Cvijetic, NEC America, Inc.; S. Nakamura, NEC Corp. (Japan)

In today's converged network environment, a rapid transition to unified packet-based core/edge network architecture is occurring. Core architecture becomes a two-layer network structure based on IP/MPLS transport over DWDM bandwidth pipes, which is the most effective way of providing sharing network capacities, enabling efficient protection schemes, and delivering guaranteed end-to-end performance. The edge network is recognized as a place for an intense manipulation of both data streams and services, through traffic grooming, exchange, and service convergence. Three major groups of the end-to-end services are voice, data, and video. Today's reality is that current network structure is in transitional phase, where a number of legacy services, delivering voice and data, are still in place, while packet based services are being rapidly introduced. Optical ROADM handles the wavelength bandwidth pipes and provides flexible handling of wavelength paths (amplification, add/drop, and wavelength switching). In-service upgrade should be achievable at any particular location, which means that in line-amplifier site can be converted to ROADM site. In addition, the ROADM site should be upgradeable to full wavelength crossconnect functionality, which is required in a number of application scenarios. The ROADM functionality is not limited to wavelength related functions, but rather handles the key functions related to multiservice environment by accommodating Layer 1&2 features from a blade. Herewith, we will analyze the role of ROADM, its functions, and expansion over cross-layer applications, and present a structure that is the most appropriate to multiservice packetized environment

6388-13, Session 6

Hybrid burst/packet switching architectures from IP NOBEL

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The proliferation of bursty IP services has fuelled intensive research on the design of flexible, fast reconfigurable optical networks, since transferring such traffic over SDH necessitates wasteful over-provisioning. In an effort to adjust the IP paradigm to optical core networks, the Optical Burst Switching architecture has emerged. Optical Burst Switching is a core architecture designed to reconcile the available optical technology with the increasing burstiness of traffic. However, this expensive solution suffers high packet loss and/or low system utilization. In the framework of the NOBEL Integrated Project, solutions that alleviate these drawbacks have been pursued. Moreover, fixed-size frame switching architectures have been proposed as short term solutions that allow for a graceful migration. To eliminate losses, the network is partitioned into a number of geographically limited domains where two-way reservations are feasible. The cluster nodes form a ring and a reservation protocol is employed to guide the nodes emit contiguous optical slots to create longer bursts towards a destination cluster. The reservation mechanism responds to actual fluctuating demand at the required small timescales by only fast laser control obviating expensive fast optical switching. The collision-free aggregation of traffic from several core nodes allows the use of cost-

effective, bufferless, all-optical transport among the domains, while at the same time, the system offers multiplexing gain. The performance of the architecture has been evaluated using computer simulations which have also shown that delay bounds can be guaranteed.

6388-14, Session 6

Performance evaluation of wavelength contention minimization strategies for optical burst-switched networks

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Optical Burst Switching (OBS) has been proposed as an optical networking architecture to efficiently support Internet Protocol (IP) packets over the Wavelength Division Multiplexing (WDM) layer. In OBS networks, IP packets are assembled into bursts, at the ingress node, and the bandwidth for burst transmission is reserved using a one-way resource reservation mechanism. Since this mechanism allocates wavelengths on a link by link basis, ignoring the wavelengths availability in the downstream links of the burst route, wavelength contention occurs whenever two or more bursts, overlapping in time, arrive at a transit node on the same wavelength and are directed to the same output link. Most of the studies regarding OBS networks have assumed that wavelength contention is solved using wavelength converters. However, all-optical wavelength converters are still undergoing research and development, and hence are relatively immature and expensive. Thus, the future prospects of OBS networks would greatly benefit, in terms of ease of implementation and cost, if the number of wavelength converters used at the network nodes is reduced, or even eliminated.

This work proposes and evaluates the performance of a new strategy for minimizing wavelength contention in OBS networks without wavelength conversion capabilities. This strategy preferably selects wavelengths for burst transmission, at the ingress nodes, in such way that the probability of wavelength contention at transit nodes is minimized. This is achieved using inputs such as network topology, routing paths, and long-term traffic pattern in order to isolate, as much as possible, the traffic of overlapping routes on different wavelengths. The performance evaluation results show that, under certain network conditions, it is possible to avoid the use of wavelength converters while maintaining reasonable network performance. Moreover, it is shown that the wavelength contention minimization strategy proposed by the authors outperforms previously proposed strategies, in some cases by several orders of magnitude, in terms of average burst blocking probability.

6388-16, Session 7

TUTORIAL: Forward error correction for advanced optical transmission

B. V. Vasic, I. B. Djordjevic, The Univ. of Arizona

The state-of-the-art fiber-optics communication systems standardized by the ITU employ concatenated BCH/RS codes. Several classes of concatenation codes are listed in ITU-T G975.1. In recent years, iteratively decodable codes, like turbo codes, and low-density parity-check (LDPC) codes, have generated significant research attention.

In this tutorial, we compare performance of several classes of forward error correction schemes suitable for advanced optical transmission. The first class is based on the concatenation of two RS codes, and concatenation of convolutional and RS codes. The second class is the class of turbo product codes with BCH codes as component codes. The third class is the low-density parity-check (LDPC) codes that have attracted much attention over the past decade. Finally, the fourth class of codes to be presented is generalization of both turbo product and LDPC codes, known as generalized LDPC (GDLPC) codes. We will present enhanced decoding algorithms for turbo product codes and LDPC codes that use probability density function of output sequences instead of calculating initial likelihood ratios assuming (inaccurate) Gaussian or chi-square approximation. We will also present error floors results obtained by analyzing decoding failures of hard-decision iterative decoders.

6388-17, Session 7

Hard decision error correcting scheme based on LDPC codes for long-haul optical transmission

M. Ivkovic, I. B. Djordjevic, B. V. Vasic, The Univ. of Arizona

Soft decision belief propagation decoding algorithms for low-density parity-check (LDPC) codes provide excellent coding gains in systems heavily degraded by nonlinear intersymbol interference due to fiber nonlinearities and chromatic and polarization mode dispersion. However, the implementation of soft decision LDPC decoders at high-speeds (40 Gb/s and above) is a very difficult task for today available electronics.

In this paper we investigate performance of an error correcting scheme based on the maximum likelihood sequence detection-Viterbi algorithm and a hard decision “Gallager B” decoding algorithm for LDPC codes. We compare the performance of this scheme to conventional Reed-Solomon codes, as well as to soft-decision error correcting schemes for LDPC codes.

6388-19, Session 7

Comparison and optimization of the transmission performances of various advanced modulation formats in high bit rate systems

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As is well known, chromatic dispersion (CD) and nonlinear effects such as self-phase modulation (SPM), cross-phase-modulation (XPM), and four-wave-mixing (FWM), as well as their impairments interaction with each other are recognized as a limiting impairment for a high bit rates optical systems. With the advent of the 40 Gb/s, it is necessary to study transmission performance, which clearly depends on the modulation format and the system design.

In this paper, we will describe and optimize different schemes of dispersion management for transmission systems composed of standard monomode fibers (SMF) and dispersion compensating fibers, afterwards a numerical comparison of non-return-to-zero (NRZ), return-to-zero (RZ) and differential phase shift keying (DPSK) formats is made at a bit rate of 40 Gb/s for single-channel and WDM systems with different compensation method in attempt to find the optimum modulation format taking into account the CD, the nonlinear effects and attenuation.

The transmitter under consideration used a DFB-laser externally modulated by a Mach-Zehnder modulator (MZM) modulator with modulation format (NRZ, RZ, DPSK), a stream of 64 bits. At the receiver end an optical filtering using gaussian, fabry-perot and rectangular filter is used, to study the influence of the Bandwidth of the optical filter. Between the compensation method the symmetrical design leaves the best results in comparison to pre- and post-compensation.

6388-20, Session 7

An efficient modulation technique for suppressing of intrachannel FWM in 40Gb/s optical transmission systems

H. G. Batshon, I. B. Djordjevic, B. V. Vasic, The Univ. of Arizona

In high bit-rate return-to-zero (RZ) on-off keying (OOK) systems operating at 40Gb/s and beyond, it is widely accepted that the ghost pulse induced by intrachannel four-wave mixing (IFWM), and intrachannel cross-phase modulation (IXPM) are dominant limiting factors affecting the performance of a high-speed optical transmission system. As the creation of ghost pulses is a phase sensitive effect, the common approach to deal with IFWM is to remove short-term phase coherence by employing a proper modulation format. Another approach, known as constrained or line coding, is to identify the most troublesome sequences is to forbid them during encoding process.

This paper presents an efficient modulation technique of countering the effects of IFWM by choosing the initial pulses phases properly so that different contributors to the ghost pulse creation cancel each other in bit being in “resonance”. This can be achieved at the code rate above 0.9 so that after application of FEC the code rate is kept above 0.8, the limitation determined by commercially available high-speed electronics. Significant Q-factor improvement of up to 7.5dB (depending on the

number of spans and the phase sequence implemented) over the uncoded RZ-OOK is demonstrated. The proposed phase modulation technique is combined with an advanced FEC scheme based on low-density parity-check (LDPC) codes, and an excellent coding gain is found. Finally, this phase modulation technique is less complicated to implement than any the other data-dependent modulation, and yet it is very efficient in extending the non-linearity tolerance and enhancing the performance of a high-speed optical transmission system.

6388-27, Poster Session

Performance limitations of an optical IM-DD transmission system due to polarization mode dispersion

S. M. Islam, Bangladesh Univ. of Engineering and Technology (Bangladesh)

Polarization mode dispersion (PMD) constitutes one of the main limiting factors for reliable optical fiber system performance in high speed transmission. An analytical approach is presented to evaluate the impact of PMD on the average bit error rate (BER) performance of a intensity modulated direct detection (IM-DD) optical transmission system considering Maxwellian distribution for the differential group delay (DGD). The results show that the performance of an IM-DD system suffers power penalty of 0.27 dB, 0.45 dB and 2.4 dB corresponding to mean DGD of 20 ps, 35 ps and 40 ps respectively at a BER of 10-9 operating at a bit rate of 10 Gb/s. Furthermore, at increased values of the mean DGD there occur BER floors above 10-9 which can not be lowered by further increasing the signal power. It is noticed that BER floors occur at about 2x10-9, 10-7 and 10-5 corresponding to mean DGD of 45 ps, 50 ps and 60 ps respectively at 10Gb/s. The effect of PMD is found to be more detrimental at higher bit rates.

6388-21, Session 8

Managing dispersion in optical networks

K. Roberts, Nortel Networks Ltd. (Canada)

Digital methods, implemented in CMOS, mitigate the effects of analog degradations on 10 Gb/s optical signals. Experimental results, across 320, 1280, and 5280 km of standard single-mode fiber (G.652), without any optical compensators, show complete compensation for the dispersion and substantial elimination of the SPM.

6388-22, Session 8

Scalability limitations of optical access and metro networks due to the polarization-dependent gain of semiconductor optical amplifiers

I. Roudas, Univ. of Patras (Greece)

Polarization-mode dispersion (PMD) and polarization-dependent loss (PDL) may limit the capacity of future transparent optical networks using deployed optical fibers and operating at ultra-high data rates (e.g., 40 Gb/s per channel and beyond). The current paper examines the impact of polarization effects on the performance of optical metropolitan area networks, where the fiber nonlinearities are typically of minor importance. Emphasis is given on the accurate performance evaluation by modeling and simulation of various topologies of optical metropolitan area networks employing either circuit or packet switching in the optical transport layer. Several optical and electronic adaptive polarization compensator schemes will be reviewed.

6388-23, Session 8

Modeling the time-variant channel of a PMD-affected WDM transmission system in respect to the temperature activity of dispersion compensating modules

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The most common model used for PMD simulations visualizes the fiber as a concatenation of a large number of birefringent elements. This systems differential group delay (DGD) has the same Maxwellian probability density function (PDF) for each frequency. By measurement of certain links it is shown that the PDF of the DGD is not equal for all of the frequency bands. This behavior could be traced back to the fact that fiber links consist of a certain number of stable buried sections, with nearly no PMD changes over weeks and months. These sections are connected by sections exposed to strong temperature variations, acting as polarization rotators. This new model of a fiber link is known as the “Hinge Model”. To characterize these “hinges”, the temperature dependent behavior of several DCM and patch cord commonly used in WDM systems had to be investigated. Measurements showed that DCM are the most active “hinges”. They produce approximately a full rotation in Stokes space when heated 1°C. This rotation is both reproducible and reversible. An novel model of the analyzed DCM is developed, which is able to reproduce the described measured behavior in simulations. The frequency dependency of the DGDs PDF leads from overall systems outage probability to frequency selective outage probability. That means instead of having a system outage at a certain outage probability, outage probabilities are connected to a number of outage channels. The correlation between the systems number of “hinges” and the outage number of channels is investigated.

6388-25, Session 8

Methods for in-service measurement of polarization mode dispersion

S. Boehm, K. Schumacher, P. M. Meissner, Technische Univ. Darmstadt (Germany)

Polarization mode dispersion (PMD) is one of the major limitations for optical transmission systems at 10 GBit/s and beyond. While first- or second order PMD compensators (PMDC) can be driven with a feedback signal, more complex broadband PMDCs have to be set feed forward. An exact knowledge of the fiber’s PMD characteristics - e.g. the PMD vector - is needed for the feed forward setting. Since PMD chances with time, real-time PMD measurement without data traffic interruption is necessary. Some recently published frequency domain methods and a novel time domain method meet these conditions.

In this publication we are going to examine and compare different on-line measurement methods. Using numerical simulations, the performance of the measurement methods is assessed in terms of the accuracy of the PMD vector measurement and the qualification as feed forward control signal for setting a PMDC.

The measurements exhibit an inherent inaccuracy if the signal is launched close to one of the principal states of polarization (PSP). Although these combinations of PSP and signal polarization result in inaccurate PMD vector measurements, the transmitted signal is not degraded by first order PMD. Consequently, the accuracy of the PMD vector measurement is a bad figure of merit for the performance of a system including a feed-forward set PMDC. Furthermore, due to the averaging over the signal bandwidth, the measured PMD vector is a better control variable for a PMDC than the analytically calculated PMD vector if second order PMD is considered.

6388-26, Session 8

Basics, implementation and performance evaluation of digital equalization approach based on maximum likelihood sequence estimation (MLSE)

W. Kaiser, CoreOptics GmbH (Germany)

Several options for electronic signal equalizations are in discussion for high-speed optical transmission systems, ranging from multi-tap feed forward filters, decision feedback structures, combinations of both options and also digital based equalization methods involving high-speed analog to digital conversion. Main goal of all these ap-proaches is to provide adaptive signal processing capability at a potential low cost margin.

Digital Equalization with the implementation of the Maximum Likelihood Sequence Estimation (MLSE) is rated as the most advanced scheme. This solution realized in high-end signal processing chips is available today for use in high-speed optical transmission systems at a data rate of 10Gb/s. Field deployed systems show the readiness of this electronic equalization approach.

Theoretical background, implementation approach and receiver architecture of this digital equalization technique are shown and discussed in detail. In addition, application examples and experimental

performance results with this MLSE based equalization solution in combination with different modulation formats are presented.

6388-30, Session 8

Upgrade of optical WDM transport systems introducing linerates at 40 Gbit/s per channel

M. Schneiders, S. Vorbeck, R. Leppla, W. Weiershausen, T-Systems International GmbH (Germany)

Driven by high growth rates of internet traffic the question of upgrading existing optical metro-, regio- and long haul transport networks introducing 40 Gbit/s per channel is one of the most important questions today and in the near future. Current WDM Systems in photonic networks are commonly operated at linerates of 2.5 and 10 Gbit/s per channel. Induced by market analyses and the historical development of transport systems some work has already been carried out to evaluate update scenarios from 10 to 40 Gbit/s channel data rates. Due to the inherent quadruplication of the bandwidth per channel, limitations due to linear and non-linear transmission impairments become stronger resulting in a highly increased complexity of link engineering, potentially increasing the capital and operational expenditures. A lot of work is therefore in progress, which targets at the relaxation of constraints for 40 Gbit/s transmission to find the most efficient upgrade strategies. One approach towards an increased robustness against signal distortions is the introduction of more advanced modulation formats. Different modulation schemes show strongly different optical WDM transmission characteristics. The choice of the appropriate format does not only depend on the technical requirements, but also on economical considerations as an increased transmitter- and receiver-complexity will drive the transponder price.

This article presents investigations on different modulation formats for the upgrade of existing metro-/ regio and long haul transport networks. Tolerances and robustness against the main degrading effects dispersion, noise and nonlinearities are considered together with mitigation strategies like the adaptation of dispersion maps. Results from numerical simulations are provided for some of the most promising modulation formats like NRZ, RZ, CS-RZ, Optical Duobinary and DPSK.

6388-31, Session 8

Investigation of 40Gb/s WDM multi-casting using a hybrid integrated Mach-Zehnder interferometer

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All-optical multi-casting permits the establishment of high-quality, high-bandwidth point-to-multipoint applications in metropolitan area networks by diffusing an incoming data carrying wavelength onto a number of outgoing wavelengths. With the proliferation of hybrid Wavelength Division Multiplex (WDM)/Optical Time Division Multiplex (OTDM) networks, the ability to perform high-speed broadcasting of OTDM signals at multiple wavelengths will prove an efficient method in the dissemination of information over WDM.

Current approaches to WDM multi-casting involve the execution of multiple cycles of optical-electronic-optical conversion, thus necessitating the use of costly high-speed electronics and optoelectronics. All-optical multi-casting would therefore remove such constraints while concurrently providing for a higher level of network transparency thereby improving network management and performance. To date, the issue has most promisingly been addressed through the manipulation of nonlinear phenomena within semiconductor optical amplifiers (SOA). The demonstrations so far however, have exhibited either low conversion efficiency or operating speed constraint, or a complicated setup.

All-optical Mach-Zehnder interferometer (MZI) approaches are therefore particularly attractive as they are not limited by the aforementioned constraints, while still offering a low switching power requirement at high-speed and a high level of integratability. Using such a device we have already demonstrated the MZI's applicability as a 10Gb/s and 40Gb/s all-optical WDM multi-caster when operating under push-pull operation.

In this paper we present a highly detailed model of our 40Gb/s experimental setup in order to investigate the operational limit of the MZI when employed in WDM multi-casting. Through simulation we examine the factors determining the constraints imposed on the maximum number of output multi-cast channels that can be achieved using such a device and establish its suitability as a next-generation all-optical multi-caster.

6388-28, Session 9

TUTORIAL: Application of telecom technologies to optical instrumentation

C. Xu, Cornell Univ.

In this tutorial, we will show several novel optical instruments using optical phase modulation, which is a common technique in fiber optic communications (for example, phase shift keying, chirped RZ transmission, etc.). We will cover the concept of space-time duality, time-lens for jitter compensation and pulse compression, time-prism for ultrafast tunable optical delay line, and generation of effective negative nonlinear refractive index using electro-optic phase modulation. These device concepts are inspired by the rapid technological development in telecom, and demonstrate the great potential of applying telecom technologies to optical instrumentation.

6388-29, Session 9

Diffractive imaging micro-spectrometer

I. Avrutsky, I. F. Salakhutdinov, K. Chaganti, Wayne State Univ.

Optical multiplexers/demultiplexers developed for the telecommunication industry, at the level of the basic principles, perform essentially the same functions as general-use optical spectrometers. The spectrometer design inspired by the telecom devices would be an extremely compact device compatible with the manufacturing procedures in integrated optoelectronics and micro-optics. We report a miniature optical spectrometer based on a diffractive optical element integrated with a planar optical waveguide designed to provide spectral resolution of at least 2nm in the entire visible spectral range from 450nm-700nm, and simultaneously resolve spectra from up to 35 independent optical inputs. The optical part of the spectrometer fits volume below 10mm^3. The spectrometer is designed for on-chip diagnostic systems, in particular for fluorescence detection of hazardous materials. Prototypes with diffractive optical elements fabricated using focused ion beam milling and electron beam lithography are manufactured and tested.

6388-32, Session 9

Optical feedback dependence of anticorrelation polarization dynamics in vertical-cavity surface-emitting lasers

K. A. Shore, Y. Hong, Prifysgol Cymru Bangor (United Kingdom)

In this paper, we report an experimental study of the effect of optical feedback on the magnitude of polarization dynamics anticorrelation in VCSELs operating at a number of bias currents relative to the polarization switching current. The correlations are considered in the time domain and in the spectral domain. The dynamics of the slow fluctuations between the X- and Y-polarizations show strong anticorrelation, which is considered to be induced by gain competition between the X- and Y- polarizations. The fast dynamical fluctuations between X- and Y- polarization are poorly correlated which is conjectured as coherence collapse dynamics by optical feedback. For the unstable polarization dynamics of solitary VCSEL, weak optical feedback increases the polarization dynamics anticorrelation. For higher optical feedback, the magnitude of the anticorrelation decreases with increasing optical feedback ratio. For stable dynamics of solitary VCSEL subject to parallel polarization feedback, the anticorrelation between the X- and Y-polarizations is small within the experimentally accessible optical feedback range because the parallel polarization feedback has a weaker effect on the gain competition between X- and Y-polarizations. For polarization-preserved or orthogonally polarized feedback, weak optical feedback induces weak anticorrelation. With increased feedback, the magnitude of the anticorrelation increases sharply and then decreases with the feedback ratio.

6388-33, Session 9

Like and cross polarized reflections and transmission matrices for propagation across a chiral slab

E. Bahar, Univ. of Nebraska/Lincoln

It has been determined experimentally that only the eight (quasi) off diagonal elements of the Mueller matrix for the reflected waves are impacted by the chiral properties of the material. In this paper analytical expressions are obtained for the waves reflected off and transmitted through a slab that possess chiral properties. The analytical expression derived for the cross polarized reflection and transmission coefficients for the linearly (vertical or parallel and horizontal or perpendicular) polarized waves due to the chiral properties of the slab are shown to have simple and revealing physical interpretations.

The assumed constitutive relations between the electric and magnetic flux density vectors and the electric and magnetic fields are presented. The relationship between the reflection and transmission matrices for circularly and linearly polarized waves are formulated. Chirality impacts only on the diagonal terms of the reflection matrix for circularly polarized waves at a free space-chiral interface. These diagonal terms are shown to be proportional to the off diagonal terms for the linearly polarized reflection matrix. The analytical expressions for the linear cross polarized terms are proportional to the chiral parameter and a product of the vertically and horizontally polarized Fresnel transmission coefficients for waves propagation in both directions across the interface. The diagonal terms of the reflection matrix are independent of the chiral parameter while the off diagonal terms are proportional to the chiral parameter, consistent with experimental results. Cross polarization is not due to surface roughness or inhomogenity of the medium above and below the interface.

The corresponding expressions for the transmission matrix are obtained and it is shown that the diagonal terms are not impacted by chirality while the off diagonal-cross polarized terms are proportionally to the chiral parameter. The expressions are shown to satisfy duality relationships in electromagnetic theory. The composite reflection and transmission matrices for chiral slabs (surrounded by free space) are also derived. The continuity relationships for the electric and magnetic fields in and perpendicular to the plane of incidence are presented for both vertically and horizontally polarized incident waves. These relationships are consistent with energy conservation.

The application of these results to detection and identification of chiral materials and for the design of novel devices made from melamaterials possessing chirality are considered.

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6389-01, Session 1

Recent progress on optical fiber amplifiers and their applications

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I review recent progress on optical fiber amplifiers and their applications in fiber-optic communication systems. This study focuses on rare-earth doped fiber amplifiers (RDFAs) and fiber Raman amplifiers (FRAs). There are three types of RDFA, namely erbium, thulium, and praseodymium doped fiber amplifiers (EDFAs, TDFAs, and PDFAs, respectively) and EDFAs have been widely deployed in trunk networks for about a decade. EDFAs have wideband, low noise, and high pumping efficiency characteristics, and are key components of high-capacity and cost-effective wavelength-division-multiplexing transmission systems in the low loss 1.5 micrometer band. In contrast, distributed Raman amplification (DRA) has been recognized as a powerful and practical technology in long-haul trunk networks in recent years. DRA/EDFA or DRA/lumped FRA hybrid-amplification systems yield significantly higher signal-to-noise ratios than lumped optical amplification systems that use EDFAs or FRAs. The latter are hybrid systems called all-Raman systems. As regards the bandwidth enhancement of optical fiber amplifiers, which is indispensable for cost-effectively realizing a rapid increase in communication traffic, silica Raman amplifiers have seamless single band bandwidths (BW) up to ~100 nm wider than those of RDFAs (~ 30 to ~80 nm). Further bandwidth enhancement can be achieved by using tellurite-based Raman amplifiers with BW up to ~160 nm or multi-band amplifiers. Each multi-band amplifier uses plural single-band RDFAs and/or FRAs in the parallel configuration in the low loss wavelength region (1.3- to 1.6-micrometer band) of silica transmission fibers.

6389-02, Session 1

Bismuth-doped silicate glass fiber for ultra-broadband amplification media

T. Haruna, M. Onishi, Sumitomo Electric Industries, Ltd. (Japan)

Bismuth (Bi) -doped silicate glass for future photonics applications was proposed by Fujimoto et al. in 2001. and its broadband fluorescence characteristic at 1.3um band was demonstrated for the first time. From this report, several studies such as clarifying the fluorescence mechanism, surveying the optical properties of Bi-doped glass with various host glass materials and so on have been done.

However, there was no report on fabricating Bi-doped silicate glass fiber (BiDF) for the demonstration of optical amplification and laser oscillation.

In 2005, Haruna et al. succeeded in fabricating the BiDF by Modified Chemical Vapor Deposition (MCVD) method for the first time, and evaluated its absorption and fluorescent characteristics. In this report, the absorption bands around 0.5um, 0.7um, 0.8um and 1.0um were shown, and the very wide fluorescence band with a FWHM of 192nm centered at 1.06um was also indicated. The background loss of the fiber was as low as <0.05dB/m at 1.55um because of the MCVD method which is well established method for the conventional optical fibers.

Furthermore, the 1.3um band amplification using the BiDF prepared by the similar MCVD method was reported by V. V. Dvoyrin et al. in 2005, and the laser oscillation by this fiber was also demonstrated in 2006.

In this paper, a current research progress on the Bi-doped glasses and fibers is reviewed. By looking at the optical properties such as fluorescence characteristics, future possible applications are explained and its fluorescence mechanism is also discussed.

6389-03, Session 1

Recent development on silicon-based Raman lasers and amplifiers

H. Rong, M. J. Paniccia, Intel Corp.

Silicon photonics has recently attracted a great deal of attention since it offers an opportunity for low-cost optoelectronic solutions for applications ranging from telecommunications down to chip-to-chip interconnects as well as potential applications in new emerging areas such as optical sensing and bio-medical applications. This talk will give an overview of research being done at Intel in silicon photonics, and present some of the recent results in the area of Raman amplification and CW lasing in silicon.

6389-04, Session 1

Advances in planar waveguide integration

S. V. Frolov, Inplane Photonics, Inc.

Starting with a waveguide amplifier as a crucial building block among many others, we demonstrate a library of optical elements that can be seamlessly integrated on a single silica-on-silicon chip and produce complex integrated optical circuits. This new level of planar waveguide integration is made possible by recent advances in our waveguide manufacturing technology capable of combining up to three different core materials on the same wafer. We discuss in details the performance and applications of these elements as well as new circuits, such as an amplified reconfigurable add-drop module.

6389-05, Session 1

Raman scattering characteristics of WO3 and P2O5 doped TBSN glasses: a new gain medium for broadband fiber Raman amplifiers

Y. Ohishi, R. Jose, Toyota Technological Institute (Japan)

Fiber Raman amplifiers are key devices for wavelength division multiplexing systems. The Raman amplification performance depends on Raman active modes of a glass system. We can potentially control the Raman scattering characteristics of a glass by using suitable dopants. We developed a new TeO2-BaO-SrO-Nb2O5 (TBSN) glass system characterized by broader Raman spectra and higher scattering cross-sections compared to conventional tellurite glasses. We noted that TeO2-WO3 and TeO2-P2O5 glasses held Raman modes in the higher wave numbers than that of TBSN glass. Therefore, doping of WO3 and P2O5 in tellurite glasses has a potential to yield glasses with broader Raman spectra. We systematically doped WO3 and P2O5 in TBSN glass and examined Raman scattering characteristics for the new tellurite glasses. When these oxides were co-doped in TBSN, both intensity and full width at half maximum (FWHM) of the main Raman bands were increased. The Raman spectra were deconvoluted into Gaussian functions and discussed in connection with the enhancement of intensity and FWHM. We identified glass compositions in this system with FWHM ~400 cm-1 and Raman gain coefficient ~9.3 10-12 m/W. The new glasses are expected to be promising candidates for ultra-broadband Raman amplifiers.

6389-06, Session 2

Multicore fibers for amplifiers and lasers

S. Jiang, NP Photonics, Inc.

Our current progress in multicore fibers for fiber amplifiers and lasers will be described.

6389-07, Session 2

Ultra-broadband amplification through nanotechnology

J. R. DiMaio, J. M. Ballato, B. Kokuoz, Clemson Univ.

As demands for bandwidth continue to increase, telecommunication networks would greatly benefit from the development of broader-band amplifiers. The currently erbium doped fiber amplifiers are limited to amplification of approximately 100 nm bandwidth window. One method to increase the bandwidth of the fiber amplifier would be to incorporate multiple rare earths (REs) into a single fiber which exhibit emissions from ~1000-1800 nm. Unfortunately, energy transfer between rare earth ions typically results in quenching all but selected emissions negating this approach to potential ultra-broadband amplification. It would be ideal if one could take the individual spectra of an ion and place that

ion into a host with no regard to other lanthanides that also are present in the host.

This problem can be solved by using a composite material that utilizes nanoparticles to constrain different REs to individual particles thereby controlling or preventing energy transfer. In order to control energy transfer, RE doped LaF3 nanocrystals were grown in an aqueous solution using a core/shell technique to constrain different rare earth into separate shells within a single particle. Using these techniques, we show that energy transfer can be controlled to allow for some energy transfer from a donor ion to an acceptor ion but still maintain some percentage of the emission of the donor ion. This allows for a common excitation source for two or more rare earth ions while maintaining the emissions of all dopant ions. RE dopants used in this work include Dy3+, Er3+, Nd3+, Pr3+, and Tm3+.

6389-08, Session 2

Opportunities in high-power fiber lasers

J. K. Sahu, J. Kim, S. Yoo, A. Webb, C. Codemard, P. Dupriez, Y. Jeong, J. Nilsson, D. J. Richardson, D. N. Payne, Univ. of Southampton (United Kingdom)

Fiber lasers and amplifiers offer unique characteristics that derive from the use of a waveguide and the properties of rare-earth doped glass. Their capability for high output powers is demonstrated by the recent surge in output power from high brightness Yb-coped fiber lasers at wavelengths around 1100 nm. It has increased from ~100 W to over 2 kW in four years. Other wavelengths can be reached with Er-doping (1500 - 1600 nm), Tm-doping (1800 - 2100 nm), and nonlinear conversion such as stimulated Raman scattering (any wavelengths within the transparency range of the material). The development of these sources tracks the rapid rate of progress of Yb-doped fiber sources, but at lower powers. Advances in high-power multimode diode and fiber technology, and the inherent power-scalability of cladding-pumped fibers, lie behind this surge.

In master oscillator - power amplifier (MOPA) configurations, active fibers can combine high power and accurate control, e.g., in terms of complex temporal and spectral characteristics. MOPAs promise to make a drastic difference in a range of new applications. However to make the most of these attractions, it is necessary to develop high-power components, that enable all-fiber optical paths. Standardization will spur the development of needed components and building blocks with which more advanced, versatile and highly functional, robust and reliable, high-power systems can be constructed.

6389-09, Session 3

Recent development of polymer optical waveguides towards next generation FTTH applications

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Polymer optical waveguides (POW) are of special interest because of their simple fabrication process and low cost. For the next generation fiber to the home (FTTH) applications, their use in conjunction with plastic optical fibers (POF) is expected. For that , multi-mode transmission of optical signals is innevitable. In this presentation, several types of POW fabrication methods will be introduced and simple measurement method of waveguide optical loss will be discussed. Light-induces self-written waveguide fabrication method is effective to have packaged structure of waveguides. Using the softlithography method based on silicone molds, low loss and highly reliable POW can be fabricated. For optical loss measurements, 45 degree cut waveguides are effectively applied and their loss values are almost the same as that measured by cut-back method. Control of the modes of input power to the waveguides are criutical for the measurement.

6389-10, Session 3

Precisely positioned light-induced self-written (LISW) polymeric optical waveguide for optical transceiver module fabrication

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Plastic optical fibers (POFs) are beginning to replace electrical wiring in many automotive and home applications. In view of this, we have reported the inexpensive wavelength-division-multiplexing (WDM) device for POF system using the LISW waveguide. The LISW waveguides are an attractive and a low-cost process for realizing self alignment between a POF and a waveguide. In this study, we have investigated about the method for precisely aligned LISW polymeric optical waveguides by using an “optical solder” effect. The “optical solder” effect makes it possible to realize a waveguide connection between two faced optical fibers by radiating from both sides even if a significant gap and a small degree of misalignment exist. When we utilize POFs with core diameters of 700* m, waveguides are combinable on the condition that an offset is 700* m or less and a gap is from 6mm to 13mm. By applying this effect, we fabricated precisely positioned LISW waveguides for optical devices. The fiber ends were set at certain mounting positions with respect to the LEDs and PDs. And we evaluated the positioning accuracy. The resulting positional accuracy at the extremities of the optical waveguides is less than one-tenth of the optical fiber core diameter. This value is sufficiently accurate to realize passive alignment. And this result creates new possibilities for boosting the yield of optical modules in mass-production.

6389-11, Session 3

Laser direct writing of inorganic-organic hybrid polymeric optical waveguide for optical integrated circuits

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Optical waveguide is one of the fundamental components in optical integrated circuits. Polymer based optical waveguide is extremely attractive. Because polymeric materials may be deposited on a variety of substrates, and they can be readily and inexpensively deposited in the thin film form at low temperatures, polymers, therefore, exhibit inherent compatibility with Si integrated circuit devices. In this paper, the focused 375 nm laser diode module is used to directly write optical channel waveguides on silicon wafers using commercially available inorganic-organic hybrid polymers - Ormocore and Ormoclad. Laser direct writing is a maskless, single-step channel waveguide formation process, therefore reduces the turn-around time for device development. The methodology is especially useful for custom design and rapid and inexpensive prototype fabrications. Ormocore/Ormoclad has been reported for waveguide fabrications with photolithography technology. We report here the maskless approach for waveguide fabrication. Ormoclad is used as the cladding layer, while the mixture of the Ormoclad and Ormocore is used as waveguide channel layer. By mixing two polymers in different ratios the index of refraction of the mixture can be precisely tuned to achieve the desired index contrast, making large cross-section single-mode channel waveguide possible. The dependency of the waveguide physical dimensions (thickness and width) on the laser spot dwell time for different laser powers are studied. Single-mode channel waveguides with smooth side-wall are fabricated and characterized. The losses, measured using cutback loss measurement method, are typically less than 1 dB/cm. The polymers are highly clear at 1550nm, making them ideal for telecommunications applications.

6389-12, Session 3

Highly functional PLC devices for advanced photonic networks

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This presentation describes recent advances in functional photonic devices fabricated by silica planar lightwave circuit (PLC) technology, which we are developing for advanced photonic networks. First, the fabrication, properties, and progress of the PLCs are briefly summarized. The PLCs are fabricated with silica waveguides on silicon wafers, and can provide waveguides that have a low loss of better than 0.01 dB/cm with a uniform refractive index and core geometry throughout a large wafer. Next, the presentation reviews recent progress on the integrated dynamic photonic devices required for high-speed wavelength division multiplexing transmission that are designed to compensate for undesirable fiber characteristics. These dynamic devices include adaptive chromatic dispersion (CD) and polarization-mode dispersion (PMD) compensators that are constructed with a lattice-form optical circuit configuration. With the revival of research and development on 40 Gbit/s transmission, CD and PMD are again

becoming important factors for consideration. Then, optical signal processing devices are described for next generation photonic networks. Optical label processing may become one of the key technologies for photonic routing networks, where each router has to provide an ultra-high throughput that exceeds the electrical speed limit. Label processing devices are presented that include encoder/decoders for time-spreading/wavelength-hopping (two-dimensional) optical code division multiple access. The encoder/decoders comprise monolithically integrated arrayed-waveguide gratings and an array of variable delay lines. A pulse waveform synthesizer is also presented that can tune complex spectral components of pulses and manipulate their temporal waveforms without using active components for high-speed transmission. As an example, temporal waveform shaping is demonstrated that generates square (flat-top) pulses with a 40 GHz repetition rate and various pulse widths for optical gating and metrology.

6389-13, Session 4

Fabrication and optical properties of the multilayered waveguide made by photobleaching process

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In the field of optical interconnect technology, many works are in progress for polymer material that is more inexpensive in terms of material and processes than conventional quartz optical waveguides. We had developed a novel type of material for optical waveguides consisting polysilane, silicone and photosensitizer. This material named “GlasiaWG(tm)” can decrease its refractive index by UV irradiation. Using this photobleaching phenomenon, we can fabricate optical waveguides that have flat surfaces by simple process without chemical etching. In this work, we have developed multilayered optical waveguides that enable to make two-dimensional multichannel connectors for multimode optical interconnects.

To fabricate multilayered optical waveguides, we prepare glass substrates whose thickness are 150μm and two kinds of GlasiaWG(tm) having different refractive indexes respectively. At first GlasiaWG(tm) having a higher refractive index is coated on the glass substrate, and then the coated film is irradiated by UV-light with a photomask to create core and side cladding parts. After baking the core layer at 250ºC another GlasiaWG(tm) with a lower refractive index is coated on the core layer and baked at 250ºC. One-layer optical waveguide is completed for one unit. After accuracy alignment, four units of optical waveguides are laminated by heating at 80ºC and pressing with 50kg/cm2, and diced to proper size pieces. Eventually four-layered optical waveguides are fabricated. Flat surfaces made by photobleachig process and adhesive properties with glass enable to fabricate multilayered optical waveguides. This fabrication is a feature of GlasiaWG(tm).

The multilayered optical waveguide made from GlasiaWG(tm) has resistance to severe environmental conditions. After storage test at high temperature (85ºC), at high humidity (60ºC /95%) or in the heat cycling (-40ºC /75ºC) condition for two weeks, difference of insertion loss (waveguide length:1cm) is less than 0.2dB.

6389-14, Session 4

A 3D wide-angle beam propagation method for optical waveguide devices

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Many 2-D wide-angle beam propagation methods (BPMs) have been developed to improve the accuracy of simulations of wide-angle beam propagation, but only a few methods have been developed explicitly for 3-D structures. For real devices such as multi-level planar lightwave circuits and tapered waveguides, 3-D algorithms need to be developed in order to accurately model beam propagation. In this article, we propose a simple and practical 3-D BPM using Hoekstra’s scheme. The linear matrix equation will be explicitly formulated. This matrix equation is no longer tri-diagonal and cannot be solved in the usual way using the Thomas method, but can be solved using an iterative method such as one employing bi-conjugate gradients. Simulations using our new method will be compared to the analytical results to assure its effectiveness and applicability. We will also discuss the convergence of the method.

6389-15, Session 4

Bend loss in plastic optical fiber and its applications

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Plastic Optical Fibre (POF) is increasingly used as a physical layer for data communications in automobiles, linking together a variety of entertainment and other sub-systems. Other applications, involving communications over a short range are being actively developed for home networking and other areas.

Bend loss is a phenomenon in POF that has been investigated by a number of authors. The primary effort has been in the predication and modeling of bend loss in silica optical fibres with a view toward reducing the bend loss. Recently the wavelength dependence of bend loss in silica optical fiber has been studied with the objective of utilising bend loss within an optical edge filter for use within optical wavelength measurement systems for communications and optical sensing.

In this paper we present a study of bend loss in POF with a novel focus on its application rather than on its elimination or reduction. A comparison is initially undertaken of the wavelength dependence of bend loss from published models with experimental results for both graded index POF and step index POF. Furthermore the use of POF within an optical edge filter is examined. The influence on bend radius and bend length on the baseline attenuation and the discrimination attenuation of a POF based edge filter over a specific wavelength range is examined. The influence of the fiber layers outside of the cladding on the wavelength loss characteristic is examined to determine if the random fluctuations present for silica fibers are present for POF. Finally overall conclusions regarding the application of POF based edge filters in wavelength measurement systems are discussed.

6389-16, Session 4

Passive integrated circuits utilizing slow light in photonic crystal waveguides

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Photonic crystal waveguides (PCWs) are known for providing large group index dispersion together with very low values for the group velocity. Today, the utilization of the slow-light regime in PCWs is a hot research topic. This regime is interesting because modes with group velocities significantly smaller than the phase velocity in the bulk material are involved in enhanced light-matter interactions. Group velocities several hundreds times lower than the light speed in vacuum have recently been reported. Such enhancements might compensate the rather high losses observed so far in PCWs by shortening the physical length of the devices. Thus, the interest in utilizing slow light properties has constantly been on the rise. However there are certain problems in the exploitation of slow light. The mode profile is quite different from the ubiquitous case, so impedance mismatch causes severe reductions in the light transmission especially after sharp bends and the in and out coupling to a PCW.

We report thorough investigations of the mode properties in the slow light regime. We find that the transmission and the group index are oscillating in phase in close analogy with the 1D photonic crystal behavior. The finite number of periods in the investigated systems is addressed to explain the spiky character of both the spectra. We also find that the profile of the slow-light modes is stretched out into the first and second rows of the holes closest to the waveguide channel. One of our strategies to ameliorate the PCW designs is to engineer the radii of these holes. The results of the numerical simulations and the optical characterization of fabricated devices such as straight waveguides, bends and couplers are presented. A fine match is found between theory and experiment.

6389-17, Session 4

Replicated polymer optical waveguides and the application

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The spread of the optical elements, for example, lenses and optical disks, has been promoted greatly by the fabrication based on the replication technology with polymer material. The replication technology is known as the attractive technology to realize low cost production method. And we expect the same possibility with optical

waveguides if their cost and productivity has been improved. Therefore, our efforts have been given to develop a new replication technology for optical waveguides, compared to the conventional semiconductor fabrication process based technology. This new replication technology is called, SPICA (Stacked Polymer optical IC/ Advanced).

There are two main directions on the development of optical aveguides with SPICA: a single-mode and multi-mode.

For the single-mode, the SPICA has achieved low cost optical coupler modules with practical characteristics and high reliability for Passive Optical Network (PON) system. For the fabrication of the coupler, the V-groove integration technology is also applied. The V-groove which hold the optical fiber is integrated on the optical waveguide by the replication technology. The integration realizes the self-alignment of the optical fiber and the reduction of the coupler's cost.

For the multi-mode, highly bendable film optical waveguide is currently under development. This waveguide realizes high speed data transaction with free layout of the lines in narrow space like mobile device's body. Today, the waveguide has the propagation loss of 0.07dB/cm at 850nm and the bending excess loss of <0.2dB at bending radius 1 mm. With these performances, the waveguide has reached to the practical level.

In this paper, the technology of SPICA and the applications are presented.

6389-28, Poster Session

InGaAs/InAlAs multi-quantum well light modulator and detector

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Multi-Quantum Well (MQW) modulators have been demonstrated with a high contrast ratio of of 5:1 in an InGaAs/InAlAs p-i-n structure at 1.55 microns. Additionally, it was found that modulators that exploit the optical properties of resonant cavities can achieve contrast ratios at least three times larger than those that don't. The devices fabricated were measured to have modulation rates of greater than 30 MHz. Lastly, quantum efficiencies and responsivity measurements show that modulator would be able to detect incident light and coupled with electronics would "know" when to modulate.

6389-32, Poster Session

Transmission properties of tapered air-core photonic bandgap fibers

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Fiber tapers have found a wide range of important applications in communication and sensing, including narrow-band filters, mode-matching between waveguides, evanescent mode-coupling and fused couplers. Applying these taper-based technologies to air-core photonic bandgap fibers (PBFs) is very appealing because it would enable creating these same components directly in air-core fibers. Although there have been several studies of tapers in solid-core microstructured fibers, the transmission properties of tapered air-core photonic-bandgap fibers have not yet been studied. In this work, we report on the fabrication and testing of tapered air-core photonic-bandgap fibers. Our motivation in this work was to study the basic transmission properties of PBF bitapers in the bandgap region, and in particular, to see how the overall transmission was impacted by the taper, e.g., whether the taper induced resonant coupling to one or more cladding modes. Our experimental results indicate that air-core PBFs are highly sensitive to tapering, and unlike conventional single-mode telecommunication fibers, even a small tapering ratio results in significant modal interference in the transmission spectrum. Furthermore, we found out that the mechanical silica support surrounding the holey region of the PBF contributes as a lossy Fabry-Perot resonator to the observed transmission properties.

6389-33, Poster Session

Design optimization of high-speed electro-optic modulators

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Optical modulators are key components for today's optical communications systems. High-speed modulators predominantly exploit fast electro-optic effects and are mostly constructed in GaAs, InP, LiNbO3 or polymer materials. In the development of low-voltage modulators, the key design parameter is the product of the half-wave voltage and the device length, VpL. To reduce this parameter, the highest electro-optic coeffeicents, rij, need to be exploited by using the correct crystal orientation and by enhancing the overlap between the optical and modulating fields.

The bandwidth of a high-speed optical modulator with a travelling-wave electrode is primarily limited by the velocity mismatch between the optical carrier wave and the modulating microwave signal. For high-speed modulators, when phase velocity matching is achieved, the next limiting factor is the overall microwave propagation loss. At lower operating frequencies, the electrode conduction loss, ac, dominates; however, as the operating frequency is extended beyond 40 GHz, increasingly dielectric loss, ad, is expected to play an important role in the bandwidth calculation of the devices. In practical applications, if the characteristic impedance of the electrode, Zc, is not matched to the external source impedance, the performance of a high-speed modulator will also be affected. Finite element-based numerical methods have been developed to analyse both microwave [1] and optical wave [2] propagation characteristics and to calculate the key design parameters such as the VpL and the bandwidth of the optical modulators.

In the development of a high-speed modulator, directional coupler-based designs [3] can be used, but Mach-Zehnder-based [1] devices are more efficient. In the Mach-Zehnder-based design, the optical power spliiter can be implemented by using a half-length directional coupler or a Y-branch splitter; however, more recently a more compact design based on the MMI principle is increasingly being considered. The design of compact bends to reduce the overall chip size or the incorporation of a spot-size converter to reduce the insersion loss are also key issues for modulator systems. Rigorous numerical methods are required to design both the optical and micorwave properties of such guides, besides the design of compact bends, power splitters and spot-size converters.

Powerful, versatile, accurate and numerically efficient finite element-based computer programs have been developed [1-4] by the authors to study the effects of various fabrication parameters, such as the waveguide height, waveguide width, buffer thickness, metal electrode thickness, electrode width and the separation between the guides, on the optical parameters, such as VpL and the optical bandwidth. Data on these parameters are presented for deep-etched GaAs, etched LiNbO3 and rib-type polymer electro-optic modulators.

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6389-35, Poster Session

Second-order nonlinear thin film characterization using logarithmic Hilbert transform

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A new technique based on logarithmic Hilbert transform processing of Maker-fringe (MF) curves to characterize second-order optical nonlinear depth profile of thin films is described. Such characterization methods are important for several fields, for example to characterize

the nonlinear coefficient profile of poled glass samples, which hold an important potential for fiber based nonlinear devices in telecommunication links. In the classical MF measurement system, a laser beam is focused onto the nonlinear film and the generated second-harmonic power is recorded vs. the laser incidence angle. The resulting MF curve is proportional to the square of the magnitude of the Fourier transform of the spatial profile d(z) of the nonlinear coefficient, where z is perpendicular to the film surface. Our new analytical method requires only the measurement of the MF curve of the nonlinear sample alone. It is based on the computation of the logarithmic Hilbert transform of the measured MF curve of the sample. Being analytical, this approach provides speed advantage over its iterative alternative. This new technique is verified experimentally with two germanosilicate-Infrasil structures, thermally poled at ~5 kV and 280 C in air. This choice of material was primarily made because germanosilicate films form excellent waveguides with a refractive index close to that of silica, which makes them compatible with fiber-optic technology. This is the first time that a Hilbert transform based analytical tool has been applied to uniquely characterize nonlinear thin films.

6389-36, Poster Session

All-optical signal processing using mode-locked semiconductor laser diode

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We describe ultrafast optical signal processing schemes utilizing mode-locked semiconductor laser diode (MLLD) for OTDM transmission over 100 Gbit/s. New polarization-insensitive all-optical clock recovery scheme of optical-electrical hybrid optical phase-lock loop (PLL) operating at 160 Gbit/s is presented.

Due to the high frequency operation and short pulse generation capabilities, the MLLDs show promising features as optical clock source for OTDM systems. So far we have demonstrated all-optical clock extraction by means of optical injection, which showed strong polarization dependence due to its TE-mode lasing nature. For the hybrid PLL described here the MLLD is operated as a voltage controlled oscillator, to which the error signal is fed back by forming a closed loop with a semiconductor optical amplifier (SOA) as a phase comparator and a low-frequency component as a loop filter. Cross-gain modulation in the SOA allows for high frequency PLL operation at 160 Gbit/s. Also the bulk active layer with small polarization dependency is the origin of polarization insensitive clock-extraction operation. By combining the PLL and all-optical gate, we have successfully demonstrated all-optical demultiplexing of 40Gbit/s signal from 160Gbit/s OTDM signals. To demonstrate operation capabilities in real systems, we have examined all-optical clock extraction on the OTDM transmission test bed of 254 km field-Installed fibres (Dojima-Keihanna, 63.5 km, and 4 spans) at 160 Gbit/s. The measured root-mean-square (RMS) timing jitters of the recovered clock signal is as low as 240 fs which showed the feasibility of the clock extraction scheme for practical use in OTDM systems over 100 Gbit/s.

6389-37, Poster Session

High efficient coupling between wedged-shaped fiber and planar lightwave circuit chip using gradient refractive-index media

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Planar lightwave circuit chips (PLCs) based on III-V semiconductor MQW rib waveguide promise to be not only a solution to information access, but also direct the issues of bandwidth, pincount, reliability and complexity. Nanopositioning and precision alignment addresses vital importance in high-efficient connectivity between PLC chips and fiber arrays. Refractive-index mismatching between fused silica and III-V compound is one of the most serious problem which remains unsolved on one hand as well as mode field mismatching which can be mitigated in other hand through gradient geometry structure such as tapered spot size converter (SSC) and specialty fibers such as wedge-shaped fiber (WSF). Axial gradient refractive-index (GRIN) media whose refractive-index varied from 1.5 to 3.4 intervened between WSF and MQW rib waveguide was put forward. The GRIN media virtually eliminated the reflection losses associated with the fused silica-air interface and III-V semiconductor-air interface. The beam spot emitted from WSF was observed by PC camera and the fundamental mode of MQW rib waveguide was calculated out. Lightwave propagation and mode field evolution in the WSF-GRIN-PLC-GRIN-WSF system were simulated by FDTD method, which showed coupling loss approximating to 6-7dB. 1.55μm signal laser was injected into WSF, transmitted along GRIN media and PLC waveguide and output vice versa. Optical power meter-based measurement was performed, verifying the whole system coupling loss to be consistent with the numeric estimation. The approach provided experimental prototype for coupling and packaging technique of integrated photonic devices, hence supplying foundation for photonic network.

6389-38, Poster Session

FSR-tunable Fabry-Perot filter with superimposed FBG

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There is a continuous growth of interest in passive fiber optic components for telecommunication, as well as for nontelecommunication applications. Fabry-Perot Filter (FPF) as an important basic passive component, have attracted considerable attention in recent years. In this paper, a novel free spectral range (FSR) tunable FPF based on a superimposed uniform fiber Bragg grating (FBG) is proposed. The uniform FBG is chirped by a novel technique to introduce large linear chirp with fixed center wavelength. And the tuning principle is based on a cantilever beam-based chirp tuning method. It is achieved by gluing the FBG in a slanted direction onto a side face of a simple supported cantilever beam-based tuning setup. When the beam is bent, the strain gradient is formed along the length of the FBG and forms a linear variation in the grating pitch. If the central point of the FBG is located at the centre layer of the cantilever beam, half of the FBG is under a varying compression and the other half is under a varying tension, there will be no strain effect at the centre of the grating. Hence, the centre wavelength will be fixed during the tuning process. Finally, we obtain a wide tunable range of 0.1-0.5nm.

6389-40, Poster Session

Spectroscopic properties of Tb^{3+}-Yb^{3+}-codoped borosilicate glasses

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The visible fiber lasers and amplifiers have potential applications in the fields of optical data storage, spectroscopy, biomedical technology, and optical LANs in automobiles. In the present study, a spectroscopic analysis was performed on Tb3+ and Yb3+ codoped in a borosilicate glass to assess this material as a green laser and amplifier medium. The rare-earth ion concentration effect on thermal, absorption, and emission properties of the glasses were investigated using differential scanning calorimetry, UV/VIS/NIR absorption, and luminescence measurements, respectively. Theses glasses were found to have good glass-forming ability, and show a high thermal stability indicating the potential to facilitate the low-loss fiber fabrication. Judd-Oflet analysis was performed for Tb3+ doped in the borosilicate glasses. The radiative lifetime of the 5D4 level was found to be 2.6 msec, and was almost constant in 0.5~15wt.% concentration range. The peak cross section for stimulated emission by the 5D4→7F5 transition was found to be 0.8Å~10-21 cm2 at λ=542 nm. In the Tb3+-Yb3+-codoped glasses, the green emission occurred by the cooperative energy transfer between doped ions was observed under infrared excitation (λex=0.98 μm). This upconversion emission increased with doped ion concentrations. These results suggested that the Tb3+-Yb3+-codoped borosilicate glass is a promising candidate for an all-solid-state upconversion green laser and amplifier.

6389-41, Poster Session

Arbitrary femtosecond optical pulse shaping with a liquid crystal spatial light modulator

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Free space optical (FSO) communications technology has potential applications in the military sector to provide a secure, high speed communication channel, and in the civilian sector as a ‘last mile’ carrier solution. It has been proposed that a multi-rate communication system

that utilizes Meyer wavelets would achieve the greatest bandwidth and highest reliability possible for an FSO system. In order to generate Meyer wavelets in a high bandwidth system, femtosecond pulses must be filtered optically to produce the desired pulse shape. One of the simplest ways to produce and arbitrary pulse shape from a laser pulse is with a tunable liquid-crystal spatial light modulator (LC-SLM) in a 4-F, zero-dispersion pulse compression system. The simplest approach to determine the correct mask pattern for an LC-SLM is to utilize adaptive, global optimization methods. Since it takes several milliseconds to adjust an LC-SLM and there are typically over one-thousand pixels, it is important to determine the fastest algorithm for determining the optimum mask pattern. Several global optimization methods were characterized in terms of convergence rate and accuracy for an LC-SLM with discrete transmission and phase levels. It was found that exhaustive search can be used to form waveforms with negligible inaccuracies at rates of about 5 times faster than simulated annealing and about 3 times faster than random search, but that simulated annealing provides the highest accuracy. However, the difference in accuracy between all of these algorithms is less than 10-4.

6389-42, Poster Session

Michelson interferometer-based interleaver design algorithm based on IIR filter model

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Michelson interferometer based interleaver has been widely used in optical communication systems, and several researchers have proposed different Michelson interferometer based interleaver structures. The Michelson interferometer can be considered as a special type of infinite impulse response (IIR) filter consisting of two all-pass filters. The corresponding output spectrum is the result of the phase difference and sum of its two all-pass filter components. Using the IIR filter to model the Michelson interferometer can provide a different point of view and shed more insights into the Michelson interferometer nature. Moreover, numerous IIR filter design techniques developed by digital signal processing researchers can be easily adapted for Michelson interferometer based interleaver design. Therefore, signal processing has been considered as an enabling technology for optical device design by many researchers. In this article, we proposed a Michelson interferometer based interleaver design algorithm based on all-pass filter phase approximation. We demonstrate that, with the proposed algorithm, different Michelson interferometer based interleaver designs can be easily generated with respect to different specifications such as bandwidth utilization ratio, passband attenuation, stopband isolation, etc. The proposed algorithm can greatly increase productivity of optical engineers. Several interleaver designs based on different specifications are presented to demonstrate the usefulness of the proposed algorithm. Besides, the Michelson interferometer based interleaver designs generated with the proposed algorithm will also be compared with other designs available in literature proposed by other researchers.

6389-43, Poster Session

Broadband near-infrared emission properties from Bi-doped silicate glasses as new laser and optical amplification media

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Broadband amplifiers and tunable lasers are key devices for the development of ultra-broadband wavelength-division-multiplexing network systems. Many efforts have been made on broadening and flattening of gain spectra of rare-earth-doped optical fiber amplifiers and fiber Raman amplifiers. However, these amplifiers have complex system structure and require high power consumption. Recent years, an ultra-broadband near-infrared emission from Bi-doped glasses has been extensively studied. However, the optical characteristics of Bi-doped glasses have not been clarified in detail.

We have found for the first time to our knowledge that the peak positions and the width of a broad near-infrared emission from Bi-doped lithium alumino silicate (LAS) glass could be drastically controlled by the excitation wavelength. Furthermore, we have found that the emission was broadened to as much as about 500 nm by selecting the excitation wavelength.

The emission spectrum became the broadest bandwidth more than 500 nm under 900 nm excitation. The emission consists of two Gaussian peaks and the stimulated emission cross sections at the peaks were calculated as 7.3Å~10-21 and 2.3Å~10-20 cm2. The lifetime was 550 * sec at 5 K and almost temperature independent up to 350 K. These large stimulated emission cross section and lifetime give large the * * products of 4.0Å~10-24 and 6.1Å~10-24cm2•sec. In this paper, we show the spectroscopic properties of Bi-doped LAS glasses and a potential of the glasses as new laser and ultra-broadband gain media for optical communications.

6389-44, Poster Session

Reconfigurable optical add/drop multiplexer with 8.0 dB net gain using double pass amplified scheme

S. Liaw, National Taiwan Univ. of Science and Technology (Taiwan); C. Chiang, National Taiwan Normal Univ. (Taiwan)

Recently, many significant efforts have been devoted to the design of high-capacity, flexible, reliable and transparent multi-wavelength optical networks. Optical add-drop multiplexer (OADM) is one of the fundamental building blocks in multi-wavelength optical network, as well as in dense wavelength-division- multiplexing (WDM) system. Also the presence of OADM is particular essential in a reconfigurable ring topology. OADMs allow the network nodes to access a subset of wavelengths in the optical networks, reducing the hardware requirements and processing load in intermediate nodes by handling only pass-through traffic. A reconfigurable OADM (ROADM) is usually constructed by adding space division switches in between the DMUX/MUX pair. It is able to access all wavelengths from and to the WDM optical networks, provides the flexibility to satisfy the reconfiguration requirement and to enhance network survivability. However, the extra insertion lose are induced by optical switches (OSWs), optical attenuators and other optical components. These issues must be overcome before ROADM is vast utilized.

In this paper, we proposed N-channel power compensated and reconfigurable optical add/drop multiplexer (ROADM) based on the utilization of fiber Bragg gratings (FBGs). Both tunable and fixed fiber Bragg gratings are used in this ROADM. By using the dual-pass amplification scheme, an 8.0 dB optical net gain is achieved with gain variation under ¡Ó0.5 dB for each add/drop/pass-through channel. System demonstration bit error rate performance with only 1.2 dB of power penalty in a 10 Gb/sx 4 Ch, 100-km lightwave transmission.

6389-45, Poster Session

Comparison of wavelength conversion in SOA and EDFA fiber ring systems

A. Siahmakoun, Y. Tang, S. C. Granieri, N. Hoghooghi, S. Teferra, Rose-Hulman Institute of Technology; M. Sayeh, Southern Illinois Univ.

We report on two types of wavelength conversion techniques that are based on gain saturation effect in semiconductor optical amplifier (SOA) and erbium doped fiber amplifier (EDFA). In these amplifiers the gain saturation occurs when the optical density at the gain medium is high enough to result in depletion of the population inversion by stimulated emission. In each case, the fiber ring laser is assembled using a variable fiber coupler, a narrowband optical filter and the gain medium. For external input power values higher than the determined threshold value of the ring resonator, the gain will be saturated. Because the wavelength of the external laser is different from the oscillating wavelength of the ring resonator, the optical power at the output of the resonator is drastically decreased (low-state). On the other hand, when the input of the external laser is below the threshold value, the output power of the resonator increases (high-state). In our experiment the operating wavelengths of the ring resonators are 1314 nm and 1553 nm for the SOA and EDFA respectively. The input signal is modulated around the threshold value for frequencies of 20 MHz and 1 MHz and resonator lengths of around 8 m and 16 m for the SOA and EDFA cases respectively. Both systems exhibit high contrast modulation of 41 dB and 33 dB at the output port for the low/high states of the SOA and EDFA ring lasers respectively.

6389-46, Poster Session

Measurement of intensity noise correlation between lines of spatially distributed multi-wavelength fiber lasers

G. Brochu, S. LaRochelle, Univ. Laval (Canada); J. Poëtte, P. Besnard, J. Simon, Ecole Nationale Supérieure des Sciences Appliquées et de Technologie (France)

Photoinscription of superstructured Bragg gratings in Er-Yb codoped fiber is a promising and cost-effective approach to produce high-quality multi-wavelength fiber lasers for various applications like radio-over-fiber systems, fiber-optic sensors or low-cost WDM testing source. However, a good understanding of the noise properties of the laser source is required before these applications can be addressed. Previous modeling has shown that these devices are similar to compact cascades of single wavelength DFB fiber lasers in which the modes at each wavelength are almost non-overlapping along the fiber. In this paper, we further examine the independence of each channel by performing relative intensity noise (RIN) measurements on a multi-wavelength fiber laser, a dual-polarization fiber laser and a dual-wavelength fiber laser. In each case, we estimate the correlation between the laser lines.

From RIN measurements performed on each channel of a multi-wavlength laser, as well as on the full spectrum, we compute an average degree of correlation between the RIN of neighboring lines and observed no correlation. Moreover, each channel displays a single relaxation frequency, function of its effective pumping rate and coupling loss, which is different from those of the other channels. On the other hand, we observed strong partition noise, with negative correlation, between polarization modes of a single wavelength fiber laser. Finally, we measured the RIN of the two modes of a dual-wavelength fiber laser with modes having a greater overlap than the multi-wavelength laser. The results show that the lines share two common relaxation frequencies, an indication of a dynamic link between them.

6389-47, Poster Session

Impact of XPM on the performance of optical switching with NOLM

M. Yuan, X. Sun, Southeast Univ. (China)

The nonlinear optical loop mirror (NOLM) can make up of many optical signal processing units with simple and convenient controllable structures. The deterioration of switching performances of NOLM and the waveform distortion of signals are caused by the cross-phase modulation (XPM) which is induced by the overlap between the counter-propagating optical fields in the fiber loop or the crosstalk of signal wavelengths. Apparently, XPM should be one of the most important factors inducing the performance deterioration of NOLM. Now, the researches on the impact of XPM in the single-mode fiber (SMF) links are comparatively in-depth. But, so far as we know, comprehensive analyses for the impact of XPM on NOLM in the digital optical communication system and the analog microwave photonic communication system have not been reported.

The impact of the cross-phase modulation (XPM) on the performance of NOLM with the single-wavelength channel or WDM channels in the digital optical communication system and the analog microwave photonic communication system is studied by using the split-step Fourier method (SSFM). The simulation results show that XPM passivates the switching performance of NOLM and the passivation effect is aggravated by the XPM induced nonreciprocity when the splitting ratio of the NOLM coupler $f \neq 0.5$. And the impact of XPM would be more serious with the increase of the working speed or the modulation bandwidth. Furthermore, the crosstalk of XPM between wavelengths is far more than that of XPM between the counter-propagating optical fields in the WDM channels. Pedestals leaked from the main lobe appear and the pedestals of the middle wavelengths are larger than those of the edge wavelengths.

6389-50, Poster Session

Performance analysis of EDFA physical model in optical fiber communication systems

S. Singh, R. S. Kaler, H. K. Sidhu, Thapar Institute of Engineering & Technology (India)

To amplify a signal after a few kilometers need an optical amplifier in optical communication systems. In this paper OSNR as a function of length of EDFA for physical model of EDFA is observed. Also measured the receive power for custom designed length at different wavelength and optimize the length of EDF (Erbium doped fiber). It is observed that at 980nm, EDFA with length 20 to 40m has highest OSNR and satisfactory power available. Similar results are found at wavelength 1550nm.

6389-51, Poster Session

Optimization of crosstalk and power penalty in semiconductor optical amplifiers for 10Å~80 Gb/s WDM over long transmission using soliton RZ-DPSK format

R. S. Kaler, Sant Longowal Institute of Engineering and Technology (India); H. K. Sidhu, Thapar Institute of Engineering & Technology (India)

We investigated twenty channels at 80 Gb/s wavelength division multiplexing (WDM) transmission over 910 km single mode fiber & dispersion compensating fiber using cascaded in-line semiconductor optical amplifiers at span of 70 km for soliton RZ-DPSK (return zero differential phase shift keying) modulation format. The spectral efficiency is approaching to 0.4 bit/s/Hz for this transmission distance with SOA. For this, we optimize the SOA parameters to obtained SOA model with low saturation power 20.89 mW and achieve high optical gain 37 dB. To achieve this, multi channel crosstalk and power penalty are optimized to reduce the cross gain saturation of SOA. With the narrow channel spacing i.e. 200 GHz, we obtained quality more than 15dB of the received signals after covering 910 km transmission distance without any power drop. We optimize the SOA model for in-line amplifier having low cross talk in multi channel WDM systems at zero power penalty with sufficient gain. We show that for the differential gain 200 atto cm2 and length 750 mm of SOA has minimum SOA induced crosstalk.

The impact of optical power received and Q factor at different differential gain, carrier lifetime and length has been illustrated. It is found that for transmission distance 700 km, as we decrease the channel spacing, there is increase in crosstalk among channels hence quality of signal goes on decreasing. We show clear eye diagram and good optical spectrum is observed at the transmission distance 910 km in soliton RZ-DPSK system.

6389-52, Poster Session

40 Gb/s optical wavelength converter for NRZ-DPSK signal based on four wave mixing in semiconductor optical amplifier

R. S. Kaler, Sant Longowal Institute of Engineering and Technology (India); H. K. Sidhu, Thapar Institute of Engineering & Technology (India)

We have demonstrated 40 Gb/s wavelength converter for non-return to zero differential phase shift keying (NRZ-DPSK) signal using four wave mixing in semiconductor optical amplifier (SOA) and also optimize the signal-to-pump ratio for the same. The optimum signal-to-pump ratio is 12 dB & 10 dB with Q-factor penalty of 0.685 dB & 0.663 dB. The dependence of four wave mixing efficiency and converted signal power with signal input power as been studied and it is found that four wave mixing efficiency decrease with increase in input power. The impact of pump power, signal-to-pump ratio, SOA parameters with Q-factor penalty for 40 Gb/s has been illustrated. We show that converted signal power increases up to saturation power of semiconductor optical amplifier and then decreases. It has been shown that for optimum pump power, OSNR varies small with signal input power. It observed that for higher bit rates, the choice of pump power is wide. So this wavelength converter leads to increase the cascadeability of optical networks for increasing the capacity of future broadcast networks. Finally the transmission of signal using normal dispersion shift fiber after wavelength conversion is demonstrated. We observe that for wavelength converted signal at 40 Gb/s is transmitted up to 40 km with quality factor of 15 dB without using any in-line amplifier. Quality of wavelength converted signal at higher bit rates can be improved by further optimizing the SOA model.

6389-53, Poster Session

Mode-locked phenomena of hybrid soliton pulse source

N. Dogru, Gaziantep Univ. (Turkey)

In recent years, several examples of short optical pulse sources using active mode-locking have been proposed. This method provides low timing jitter picosecond pulses, locked to an external electrical reference frequency, for high-speed optical communications systems. Fibers grating external cavity lasers have been experimentally demonstrated in the mode-locking regime at 2.5 GHz and 10 GHz. Hybrid soliton pulse source (HSPS) is one such device, developed as a pulse source for soliton transmission system. A practical soliton transmission system may be required to operate at the 2.488 GHz with a pulsewidth of around 50 ps giving a time-bandwidth product range of 0.3 to 0.5. An interesting feature of these devices is the extremely wide operating frequency range, which can be enhanced by using chirped gratings, as reported. Calculated and measured results showed that transform-limited pulses are generated over a frequency range of 850 MHz using linearly chirped Gaussian apodized fiber Bragg grating (FBG). However, in this paper, it is shown that proper mode-locking range is rises up to 1.3 GHz utilizing linearly chirped raised-cosine flat top FBG, which is very unusual in mode-locked laser system. Also, it produces a shorter pulsewidth than that of linearly chirped Gaussian apodized FBG.

In conclusion, with the use of linearly chirped raised-cosine flat top FBG instead of linearly chirped Gausssian apodized FBG, proper mode-locking range where transform-limited pulses are generated rises to 1.3 GHz.

6389-54, Poster Session

Tunable spectral switching and far-field spectral behavior of chirped Cosh-Gaussian pulses

S. Jana, S. Konar, Birla Institute of Technology & Science (India)

In this paper we have presented far-field spectral behaviour of a chirped cosh- Gaussian pulse, diffracted through a rectangular aperture. Employing Fourier transformation method and far field approximation we have derived an analytical expression for the far field power spectrum of the pulse in 3D. It has been found that the on-axis far field power spectrum is blue shifted. This shifting increases with the increase in Coshyperbolic parameter Ω for chirped pulses and decreases in case of unchirped one. For off-axis case, at some particular angle of diffraction, referred as critical angle, the diffraction-induced far field power spectrum is split into two equal lines. At an angle larger than the critical angle the far field power spectrum is blue shifted whereas for a smaller angle the spectrum is red shifted i.e. spectral switching occurs. For chirped pulse the critical angle for switching significantly increases with the increase in Ω. On the other hand Ω has marginal effect on critical angle in case of unchirped one. For same chirp, truncation parameter and pulse duration cosh-Gaussian pulse shows spectral switching at larger angle of diffraction in comparison to the case of a Gaussian pulse. The most noteworthy finding is that the switching frequency, blue shift frequency and red shift frequency can be tuned by varying Ω. For chirped pulses they decrease with increase in Ω. The effect of aperture width is also investigated. Spectral switching may be useed in fabricating optical interconnects, optical communication systems particularly for space communication.

6389-55, Poster Session

Isolator-free DFB laser diode operating in feedback regime V

A. Mokhtar, L. MacEachern, S. A. Mahmoud, Carleton Univ. (Canada)

A DFB laser diode is forced to operate in feedback Regime V by omitting the laser isolator and using an extended cavity mode. The DFB laser diode is coupled to a Fiber Bragg Grating (FBG) that has a reflectivity based on parameters extracted from optical back-reflection measurements. A stable wavelength, narrow linewidth and low relative intensity noise (RIN) were obtained using the proposed configuration. A DFB diode laser coupled to the FBG achieved a RIN level of - 158.5 dB/Hz at a 1GHz frequency offset, comparable to results obtained for a DFB diode laser with an isolator (-157.9 dB/Hz), for the same average optical power (5.1 dBm) at 1310 nm.

6389-18, Session 5

Generation and applications of ultrashort optical pulses from semiconductor lasers

H. Yokoyama, Tohoku Univ. (Japan)

I n this presentation, we describe a couple of basic technologies for ultrashort optical pulse generation from semiconductor diode lasers. Subsequently, novel potential applications of these optical pulses are shown.

Modelocking is a straightforward and beautiful method of ultrashort optical pulse generation from a semiconductor diode laser. If a saturable absorber (SA)
section is monolithically involved in the laser diode (LD), this device can generate picosecond (and sometimes sub-picosecond) duration optical pulses by passive modelocking. A single chip modelocked laser diode (MLLD) can generate optical pulses at a repetition frequency range from several tens of gigahertz to over a terahertz depending on the device length and the position of the SA section. For optical communication application point of view, electric synchronization by current modulation is required, and thus a pulse repetition frequency of less than 40-GHz is preferable. Furthermore, for the purpose of frequency and wavelength tuning, an external cavity configuration is often employed. Even with an external cavity configuration, with a compact module assembly, very stable turn-key operation was achieved. We also demonstrated the generation of optical pulses of less than 5-ps duration by gain-switching method with a combination of a high-speed LD and an electric pulser that can generate 100-ps electric pulse at flexible repetition frequencies up to 1 GHz. This configuration may provide ultrashort optical pulse sources much simpler than MLLDs, and may enable many practical applications for high-speed optical measurements.

As for the aspect of applications, we recently produced a few kilowatts peak power optical pulses by a novel optical amplification technique. Consequently, highly efficient second harmonic generation (SHG) of over 50% was achieved. Using these high peak power SHG optical pulses, more than an octave supercontinuum light generation including visible and ultraviolet regions was observed. Furthermore, a very successful application for two-photon fluorescence bioimaging was also demonstrated.

6389-19, Session 5

Development of femtosecond optical frequency combs for optical frequency standards in NICT

S. Nagano, H. Ito, Y. Li, K. Matsubara, M. Hosokawa, National Institute of Information and Communications Technology (Japan)

Recently, atomic frequency standards in optical region are being developed worldwide to lead a new definition of the unit of time. They have potentially higher accuracy and stability compared with the microwave atomic clocks. The optical frequency standard consists of three major components: a clock laser pre-stabilized to narrow the laser linewidth, a stable reference based on an atomic optical transition to control the laser frequency and a frequency counter to directly determine number of optical cycles.

National Institute of Information and Communications Technology (NICT), responsible for the national frequency and time standards, is developing an optical frequency standard with the frequency uncertainty of 10^-16. The clock laser is stabilized to a high finesse optical cavity for reduction of the linewidth down to 53Hz. Trapped single calcium ion whose clock transition linewidth is 0.13Hz has been prepared to serve as an ultimate reference of the clock laser. Cold neutral atoms trapped in the optical lattice is also projected as another reference. Precise optical frequency counters are indispensable for these complete systems.

We are developing broadband optical frequency combs for counting the frequency of the clock lasers. The femotosecond mode-locked lasers emitting a broadband continuum are employed. They allow the self-referencing technique without a microstructure fiber broadening the laser spectrum. These systems have no degradation of the performance due to the noise caused by the fiber. Consequently, our frequency combs have the potential for long-term operation and reliability in addition to the measurement precision required.

6389-20, Session 5

Optical logic operations

N. K. Dutta, Univ. of Connecticut

All optical XOR, OR and NOR functionality has been demonstrated experimentally using integrated semiconductor optical amplifier (SOA) - based Mach-Zehnder interferometer (SOA-MZI) devices at 40 and 80 Gb/s. The performance characteristics have been analyzed by solving the rate equation of the SOA numerically. The high-speed operation is limited by the carrier lifetime in the SOA. A relationship between the phase recovery time and the speed of operation has been derived. Performance improvement using quantum dot SOAs is described.

6389-21, Session 5

Ultra-low timing-jitter passively mode-locked fiber lasers for long-distance timing synchronization

F. O. Ilday, Bilkent Univ. (Turkey)

One of the key challenges for the next-generation light sources such as X-FELs is to implement a timing stabilization and distribution system to enable ~10 fs synchronization of the different RF and laser sources distributed in such facilities with distances up to a few kilometers. These requirements appear to be beyond the capability of traditional RF distribution systems based on temperature-stabilized coaxial cables. A promising alternative is to use an optical transmission system: A train of pulses generated from a laser with low timing jitter is distributed over length-stabilized fiber links to remote locations. The repetition frequency of the pulse train and its higher harmonics contain the synchronization information. At the remote locations, RF signals are extracted simply by using a photodiode and a suitable bandpass filter to pick the desired harmonic of the laser repetition rate.

Passively mode-locked Er-doped fiber lasers provide excellent long-term stability. The laser must have extremely low timing jitter, particularly at high frequencies (\>1 kHz). Ultimately, the timing jitter is limited by quantum fluctuations in the number of photons making up the pulse and the incoherent photons added in the cavity due to spontaneous emission. The amplitude and phase noise of a home-built laser, generating 100-fs, 1-nJ pulses, was characterized. The measured phase noise (timing jitter) is sub-10 fs, from 1 kHz to Nyquist frequency. In addition to synchronization of accelerators, the ultra-low timing jitter pulse source can find applications in next-generation telecommunication systems.

6389-22, Session 5

TUTORIAL: Ultrafast optical code division multiplexing and its enabling components

H. Sotobayashi, National Institute of Information and Communications Technology (Japan)

Ultrafast optical code division multiplexing (OCDM) and its enabling components are reviewed. Principle operation of OCDM and enabling components for OCDM are discussed. The demonstrated applications of OCDM are as followings; 1) high spectral efficiency transport system (1.6 bit/s/Hz, 6.4 Tbit/s QPSK-OCDM/WDM transmission experiment), 2) optical path networks (transparent virtual optical code/wavelength path network with optical code and wavelength convertible nodes), 3) photonic routing (optical code correlation based ultrafast photonic routing).

6389-23, Session 5

Semiconductor lasers for optical clock recovery and optical regeneration

P. B. Gallion, J. Renaudier, Ecole Nationale Supérieure des Télécommunications (France); G. Duan, Alcatel Research & Innovation (France)

Phase correlation leading to self-pulsation (SP) in semiconductor distributed Bragg reflector (DBR) lasers is investigated experimentally and theoretically.Self-Pulsation at 45 GHz repetition frequency has been demonstrated in 1.5- μm monolithic single-section quantum dots Fabry-Perot semiconductor lasers without saturable absorber. The mode-beating exhibits a narrow linewidth below 100 kHz, emonstrating high phase correlation between these modes.We demonstrate for the first time to our knowledge, that such a quantum-dots (QD) laser enables a high frequency jitter suppression that meets the ITU-T recommendation G825.1 requirements thanks to its intrinsic narrow free running spectral linewidth, as compared with lasers made on bulk or quantum wells.

6389-24, Session 5

Growth of antimonide compound semiconductor on Si(001) substrate

K. Akahane, N. Yamamoto, S. Gozu, A. Ueta, N. Ohtani, M. Tsuchiya, National Institute of Information and Communications Technology (Japan)

We investigated the heteroepitaxial growth of GaSb on Si(001) substrates. High-quality GaSb films can be grown on the Si substrate by introducing an AlSb initiation layer. When small AlSb islands were formed on the Si substrate before the growth of GaSb, two-dimensional GaSb growth occurred. In contrast, without the growth of AlSb small islands, large GaSb islands were formed on the Si substrate. Therefore, the AlSb islands played an important role in preventing excessive surface diffusion of Ga atoms on the Si surface and promoting two-dimensional growth of GaSb. A narrow X-ray diffraction rocking curve (around 200 arcsec) was obtained by optimizing the growth temperature and the thickness of the AlSb initiation layer. A high-quality GaSb/AlGaSb and InGaSb/AlGaSb MQW samples also can be grown on a Si substrate using this method. A strong emission of 1.55 μm at room temperature was obtained from these samples which is suitable for fiber optic communications systems. Furthermore, we can control the emission wavelength by simply changing well width. The emission energy shows a good agreement with the theoretical curve. The temperature dependence of the PL intensity showed large activation energy (~77.6 meV) from GaSb QW. The results indicated that the fabricated QW structure had a high crystalline quality, and the GaSb QW on Si for optical devices operating at temperatures higher than room temperature will be expected.

6389-25, Session 6

Electrically tunable interband cascade laser

S. Suchalkin, M. V. Kisin, S. Luryi, G. Belenky, State Univ. of New York/ Stony Brook; F. J. Towner, J. D. Bruno, Maxion Technologies, Inc.; C. J. Monroy, R. L. Tober, Army Research Lab.

Tunable semiconductor mid-IR lasers are in high demand for various military and civilian applications, such as free space communication, remote sensing, and environmental monitoring. Electrical tuning due to Stark effect is the most direct and robust method of changing the emission wavelength and provides the fastest time response and the finest wavelength adjustment. Type II quantum wells used in Interband Cascade Lasers (ICL) are especially attractive for Stark tuning because they are characterized by an inherently strong first-order Stark effect. In the presented work we proposed and demonstrated a mid-IR ICL with the generation wavelength electrically tunable in a wide range. The Stark tuning of a conventional semiconductor laser is hindered because, after the threshold is reached, both the carrier concentration and the voltage drop across the active region become pinned and do not change as the bias current increases. To resolve this problem, we propose the design based on tunnel-limited injection and accumulation of the injected carriers outside the optically active quantum wells. The accumulated charge provides for an additional electric field and, being decoupled from the threshold condition, can change with the bias current thus maintaining the laser wavelength tuning even above the laser threshold [N. Le Thomas, N. T. Pelekanos, and Z. Hatzopoulos, Appl. Phys. Lett. 83, 1304-1306, 2003.]. The tuning range of our device is 120nm (starting from the initial lasing wavelength $\lambda \sim 3.33$ μm), or 120 cm-1 was demonstrated.

6389-26, Session 6

Analysis of message extraction in optical chaos communications based on injection-locking synchronization of semiconductor lasers

K. A. Shore, A. Murakami, Prifysgol Cymru Bangor (United Kingdom)

In this paper, we employ a simple theory based on driven damped oscillators to clarify the physical basis for message extraction in optical chaos communications using injection-locked semiconductor lasers . The receiver laser is optically driven by injection from the transmitter

laser. We have numerically investigated the response characteristics of the receiver when it is driven by periodic (message) and chaotic (carrier) signals. It is thereby revealed that the response of the receiver laser in the two cases is quite different. For the periodic drive, the receiver exhibits a response depending on the signal frequency, while the chaotic drive provides a frequency-independent synchronous response to the receiver laser. Chaos Pass Filtering (CPF)can be clearly understood in the difference between the periodic and chaotic drives. Message extraction using CPF is also examined, and the validity of our theoretical explanation for the physical mechanism underlying CPF is thus verified.

6389-27, Session 6

Design and development of high quantum efficiency large area UV focal plane arrays for photon counting applications

A. K. Sood, Y. R. Puri, Magnolia Optical Technologies, Inc.; R. A. Bell, E. J. Egerton, iRobot Corp.; J. Roginsky, Naval Surface Warfare Ctr.; T. Cook, Boston Univ.

In this paper we will present innovative design approach for UV Photon Counting Focal Plane Array that is buttable to make 4096x 4096 UVFPA. This Focal Plane includes the building a large area silicon micro-channel plate (MCP) using GaN photocathode.

In this paper, we will show the design and simulation of silicon micro-channel plate with GaN photocathode with large area array with 2 micron pores and 3 micron pitch.

We will also present results for the ICP-RIE process to fabricate 2 micron pores, and Growth of high conductivity GaN photo-cathodes using MOCVD to produce 40% QE.

We will also present the approach for development of readout architecture and circuit for Silicon based MCP 4096x4096 UV FPA.The readout architecture scheme uses a series of charge sensitive amplifiers (CSA) to boost the charge received on each anode. The signal from each CSA is then passed into a shaping amplifier (SA) that produces a smooth waveform. The peak of the smoothed waveform is captured by a sample and hold (S/H) circuit that holds the signal until an analog to digital (A/D) converter can sample it. In addition to the shaping amplifiers for each channel the signals from the CSAs are summed in a fast amplifier (FA). Details of the ROIC circuit will be presented.

6389-29, Session 6

Recent advances in high power mid- and far-wavelength infrared lasers for free space communication

S. Slivken, M. Razeghi, Northwestern Univ.

The mid-infrared (3< lambda< 5 microns) and far-infrared (8< lambda< 14 microns) spectral regions are re-emphasized as a viable, yet underutilized spectral region that would be suitable for free space communications. Compared to existing near-infrared systems, the attenuation in some inclement weather conditions, such as dense fog, is significantly less, allowing the possibly for greater reliability and/or longer range. Also, as the atmospheric band pass regions are fairly wide, multiple laser sources can easily be combined in a wavelength division multiplexing type of system. One of the main hurdles for development of this technology is the laser source. The quantum cascade laser, thanks to recent advances in performance, is proposed as a realistic source for addressing these spectral regions. This diode laser source operates at room temperature, is compact, and can be directly modulated with a bandwidth similar to near-infrared diodes. Further, as the emission wavelength is easily adjustable across a wide range, all of the atmospheric transmission windows can potentially be utilized. The current status of quantum cascade laser performance in both atmospheric windows is reviewed, as well as the future outlook for this technology.

6389-30, Session 6

Wide field-of-view retroreflector for short range free space optical communications

J. F. Muth, K. Alhammadi, E. Grant, North Carolina State Univ.

There is increasing interest in using modulating retroreflectors for short range, free space optical communications. These devices are especially useful in applications where one platform is power limited or size constrained such that it is not practical to have a laser or the associated pointing and tracking system required for direct optical links. Traditional corner cube retroreflectors and cat's eye retroreflectors typically have a limited field of view. In this work we design and demonstrate an optical retroreflector where the field of view is maximized and is compatible with optical modulator. An optimized design demonstrate near 180 degree field of view is possible. A device assembled with commercial off the shelf components is demonstrated with a field of view of 120 degrees which was limited by package used for housing the optic.

6389-48, Session 6

Development of novel super continuum fiber lasers and wavelength tunable soliton pulses

N. Nishizawa, Nagoya Univ. (Japan)

Recently, the technologies of optical fibers have been advanced and the special fibers, such as highly nonlinear fibers and photonic crystal fibers have been demonstrated. As the light sources, passively mode-locked ultrashort pulse fiber lasers have been commercialized and attracted a lot of attentions in several fields.

The group of author has been working on the development and applications of high performance ultrashort pulse fiber lasers. In this paper, the recent progress of widely wavelength tunable ultrashort pulse and ultra wideband super continuum generation by use of ultrashort pulse fiber laser are reported.

In 1999, the widely wavelength tunable ultrashort soliton pulse generation has been demonstrated in the wavelength region of 1.55 - 2.0 um. In this light source, it was difficult to generate the ideal ultrashort pulses in the wavelength region around 1.55 um. Recently, we have demonstrated 1.0 - 1.7 um widely wavelength tunable ultrashort pulse generation system by use of Yb doped fiber laser and photonic crystal fibers. Using this source, we can cover the whole wavelength band used in optical communications.

In 2001, 1.0 - 2.0 um ultrawideband super continuum generation has been reported using ultrashort pulse fiber laser and highly nonlinear fibers. In terms of their applications, the large noise and the fine structures become serious problems. We have also analyzed the characteristics of super continuum generation and clarified the origin of noise and fine structures. Recently, we have successfully generated the ultra wideband, low noise, ultraflat, and highly coherent super continuum without any fine structures for the first time. Another novel super continuum generations are also disucussed.

Monday-Tuesday 2-3 October 2006

Part of Proceedings of SPIE Vol. 6390 Broadband Access Communication Technologies

6390-01, Session 1

Self-managing networks

V. Bahl, Microsoft Corp.

No abstract available

6390-03, Session 2

BREAD: a European coordination action for broadband for all

P. Van Daele, Univ. Gent (Belgium)

BREAD: A European Coordination Action for BroadBand for All. The BREAD - co-ordination action aims at developing a multi-disciplinary approach for the realisation of the 'broadband for all' concept within Europe. A multi-technological analysis of the evolving broadband technologies is developed, together with techno-economic, societal and regulatory aspects of the "broadband for all" concept and regional "success stories" of actual deployment. The BREAD project builds on an IST co-ordination and information exchange platform to enhance the interaction between the key players in the field and to invoke discussions on this multi-disciplinary approach. The presentation will illustrate the need for a multi-disciplinary approach towards BB4All and will give an overview of the status of the research work in Europe.

6390-04, Session 2

FAST copper for broadband access

M. Chiang, Princeton Univ.

FAST Copper Project is a joint research project by Princeton University, Stanford University, and Fraser Research Lab, funded by US NSF and in collaboration with AT&T. FAST (Frequency, Amplitude, Space, Time) Copper jointly optimizes the resources in these four dimensions to tackle the two main issues limiting rate and reach in today's twisted pair networks: signal attenuation and interference. Through innovations across signal processing, spectrum management, link layer scheduling, admission control, and survivable topology design, FAST Copper aims at boosting the application layer throughput of fiber/DSL broadband access by over one order of magnitude, enabling triple play of video, voice, and data over telephone lines in a ubiquitous and reliable way. This talk presents the key approaches and outlines research steps in FAST Copper Project.

6390-05, Session 3

Mobile wimax (802.16e)

J. Puthenkulam, Intel Corp.

Mobile WiMAX technology based on IEEE Standard 802.16e-2005 provides support for MIMO based Scalable OFDMA, Smart Antenna Techniques, QoS oriented MAC architecture with flexible scheduling features, Adaptive Modulation and Coding, ARQ, Hybrid ARQ schemes for increased reliability, Advanced Wireless Security, Mobility up to speeds of 120km/hr, Multicast/broadcast services, Power saving modes. Mobile WiMAX is meant to provide high data rates of IP based wireless connectivity enabling rich applications and services to be deployed in several RF frequency bands suitable for broadband wireless services.

6390-06, Session 3

Toward high-speed access technologies: results from MUSE

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The European MUSE project, which aims to enable "MUlti Service and access Everywhere", studies architectures, technologies and business scenarios facilitating the deployment of new Broadband Access Networks and Services. This paper gives an overview and particularly discusses results of some of the high-speed access technologies that are developed.

DSL techniques are being studied extensively as a means of increasing bandwidth for the end user, but investigations show that advanced coding algorithms are able to improve the transmission capabilities over a limited range. A system for transmitting VDSL signals over optical fiber has also been developed; this allows for distribution of line signals across an optical network whilst retaining the DSLAMs at the Central Office (CO). Deployment of Fixed Wireless Access technologies such as WiMax faces similar challenges. A Radio over Fiber technique has thus been developed that deploys efficient electro-optic conversion in the Radio Access Points, again keeping the signal processing at the CO. In order to minimize operational costs, passive outside plants may provide an attractive solution. A CWDM Double Ring architecture has been developed that reduces the amount of fiber in the network, while at the same time providing protection switching. In addition to FTTH applications, this system demonstrated distribution network functionality for the other described first-mile technologies. With the ensuring migration from DSLAMs to Optical Access Multiplexers, the increased power consumption requirements are proving problematic for operators. An Access Multiplexer for Optical Ethernet was developed with a high port density, demonstrating power-per-subscriber requirements closer to DSLAM values.

6390-07, Session 3

Measurement and modeling of short copper cables for ultrawideband communication

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High-speed communication using the copper network, originally installed for telephony, is one of the dominant Internet access techniques. Several variants of a technology referred to as digital subscriber line (xDSL) have been developed, standardized and installed during the last two decades. Essentially, xDSL achieves high rates by exploiting wide bands of the copper cable channel. The shorter the cable, the wider is the band that can be used efficiently for communication. Current xDSL standards use bands up to 18MHz. Cable properties have been studied by means of measurements, characterization and modeling up to frequencies of 30MHz.

Recent investigations have shown that is feasible both from technical and from economical point of view to exploit very short cable (up to 300m) even further and use bands above 30MHz. A prerequisite for further evaluation and the design of such ultra-wideband copper (UWBC) systems is the extension of existing cable models to higher frequencies. This paper presents wide-band measurement results of insertion loss and crosstalk coupling in a 10-pair cable of various length values for frequencies up to 400MHz. We compare the results to extrapolations of cable models that are established in the 30MHz-range.

6390-08, Session 4

Broadband wireless-over-fiber technologies for integrated services of communications and broadcasting

K. Yasukawa, Osaka Institute of Technology (Japan)

Digital broadcasting service and variety of communication services, 4-th generation mobile, broadband wireless-LAN etc are developed recently. Broadband wireless-over-fiber technologies may play an essential role for emerging integrated services of broadcasting and communications in the area of entrance network. Low-distortion transmission of broadband wireless signal is developed as a collaborative work of Osaka University, ATR and Osaka Institute of Technology supported by Strategic Information and Communication R&D Promotion Program (SCOPE) of Government.

6390-09, Session 4

Recent advances in optical access technologies

J. Kani, Nippon Telegraph and Telephone Corp. (Japan)

Fiber to the home (FTTH) is now the most popular fixed Internet access service in Japan; the increment of customers has exceeded that of ADSL since early in 2005. For further deployment toward the full-scale FTTH era, NTT has set a target of moving 30 million customers to FTTH by 2010. This presentation first looks over optical access technologies that support the further deployment of FTTH in the next few years. It next describes recent researches as well as tries to identify main issues toward the next generation optical access.

6390-10, Session 5

TUTORIAL: Hot issues in wireless broadband networking

R. Jain, Washington Univ. in St. Louis

In this brief tutorial we will discuss the top 10 issues in wireless broadband. This includes new development in wireless technologies as well as those in upper layers. The tutorial will cover issues related to both industry as well as research.

6390-11, Session 5

Design and performance of hybrid FSO/RF next-generation broadband wireless access networks

A. Sana, City College/CUNY

This paper proposes a novel Ethernet-based wired/wireless broadband access networking architecture that utilizes the existing wired trunk feeder fiber of typical EPON infrastructure along with a hybrid FSO/RF reliable wireless connectivity to the end-users (ONUs). By combining the benefits of both FSO and RF technologies, the proposed integrated networking solution can provide a downstream bandwidth of up to 2.5 Gbps per wavelength and 99.999% availability at a range of 1 km in all weather conditions

6390-13, Session 5

Performance improvement of radio on fiber ubiquitous antenna system using sub-carrier resource management

L. H. Hai, T. Higashino, K. Tsukamoto, S. Komaki, Osaka Univ. (Japan)

RoF ubiquitous antenna system is the universal infrastructure for the next wireless broadband networks, because of its advantages of multi-band operation and air interface independence. In this paper, we apply RoF ubiquitous antenna base stations for multi-base-station MIMO with OFDMA access wireless broadband system. We propose and evaluate new resource management schemes for multiple data streams (such as text, image, movie...) in the above wireless environment. The proposed schemes classified the service classes into some classes in which the number of sub-carriers are dynamically changeable according to the required data transmission rate. The computer simulation results show that the proposed scheme improves the number of users satisfying the required BER level as well as the average throughput.

6390-15, Session 6

Performance analysis of the ultralinear optical intensity modulator

N. Madamopoulos, National Hellenic Research Foundation (Greece); B. Dingel, Nasfine Photonics, Inc.

In the recent years, activities in the field of subcarrier multiplexing (SCM) systems, ultra-dense CATV, Radio-over-Fiber (RoF) communications, and other platform access systems have been seeing a lot of research and development interest. The linear optical intensity modulator is an important component in analog fiber-optic links finding applications in such systems. Often times the optical modulator is the component that limits the RF performance of such fiber-optics link system. Many efforts have been concentrated to improving the linearity of optical intensity modulators based on a variety of approaches. Recently, we have proposed a super-Linear optical modulator based on a unique combination of phase-modulator (PM) and a weak ring resonator (RR) modulator within a Mach-Zehnder interferometer (MZI). In this paper we describe this ultra-linear optical intensity modulator and we analyze its RF performance in terms of Compression Dynamic Range (CDR) and Spurious Free Dynamic Range (SFDR). Other features of this modulator design such as high manufacturing tolerance and simplicity of the optimization parameters are discussed.

6390-16, Session 6

Modeling software for optical broadband access network design and optimization

D. Herrmann, E. Ghillino, RSoft Design Group

Design and deployment activities for FTTH (fiber-to-the-home) access networks are on the rise and rapidly growing. Cable operators, RBOC/LECs, utilities, and municipalities are all increasingly focused on strengthening the access network to support the demands and delivery of current and future video, voice, data, and multimedia services to the customer premises. Advanced modeling tools OptSim, ModeSYS, and MetroWAND are RSoft's computer-aided design software that simulates a broad range of optical communication systems (such as CATV, CWDM/DWDM systems, Gigabit Ethernet, Wireless Optical, Radio-over-Fiber, etc.) and can be of significant help in optimization, validation, and performance analysis of the FTTH network design thereby shortening the time-to-market and reducing the deployment cost. In this paper, we describe the example of design, modeling and optimization studies for access architectures based on different standards of Passive Optical Networks (PON) for triple-play services, such as BPON, GEPON, and (still in development) WDM-PON using modeling and simulation tools. The modeling tools we used for this presentation have validated accuracy, flexibility in design and modeling of numerous optical networking applications, and are widely accepted for physical layer design of FTTH networks in particular, and for broadband networks in general (including Gigabit Ethernet as a first-mile solution, or Wireless Optical links as last-mile solution). Using / OptSim/ library of standard and predefined components many different what-if scenarios can be simulated to find the optimal performance to cost ratio. Statistical analysis capabilities allow studying the FTTH system nominal and end-of-life performance variations.

6390-17, Session 6

Fractal transmission in a hybrid RF and wireless optical link: a reliable way to beam bandwidth in a 3D grid

M. Kavehrad, The Pennsylvania State Univ.

Radio Frequency (RF) communications are generally reliable and well understood but cannot support emerging data rate needs unless they use a large portion of the precious radio spectrum. Free Space Optical (FSO) communications offer enormous data rates but operate much more at the mercy of the environment. The perennial limitations of FSO communications are manifested in the channel attributes of scintillation (optical turbulence) and path obscurations. Both phenomena reduce the availability of the optical channel to support reliable communications. Since RF paths are relatively immune to the same phenomenology, combining the attributes of a high data rate but bursty link (FSO) with the attributes of a low data rate (by comparison) but reliable link (RF) could yield attributes better than either one alone: high availability with high data rates.

Fractal modulation has been traditionally investigated for use in wireless radio frequency applications, and shown to be beneficial in fading channels and multi-rate environments. Additionally, recent research with ultra-short pulses has shown that such signals are more resilient to water clouds and that they are transmitted through water clouds using a modest laser light energy. In this presentation, we discuss a novel design for an FSO system that harnesses the merits of both fractal modulation and ultra-short laser pulse transmissions, leading to improved availability of the hybrid link.

6390-18, Session 6

Nonlinear optical tracking for high-speed free-space communications

A. E. Dudelzak, A. Koujelev, Canadian Space Agency (Canada)

High-speed free-space communications have been increasingly studied for applications ranging from short-distance ground-to-ground transmissions to inter-spacecraft links. Optical communications involving moving parties, especially at extra-long distances, require precise beam pointing and mutual tracking of communicating transceivers. The design concept and preliminary test results of a free-space communicator incorporating novel nonlinear optical tracking subsystem are presented. The development goal is to demonstrate a cost-effective, jitter-free terminal for Gbps-rate optical links. The tracking system consists of three subsystems: a coarse tracker (a 10.5 cm-diameter motorized Cassegrainian telescope); an intermediate electro-optical tracker (a voice-coil and a Si-based position detector); and a nonlinear optical fine tracker (a nonlinear liquid-crystal cell sensitive in the 1500 nm range). Three-stage tracking allows for efficient compensation of jitter of up to kHz while maintaining a sub-microradian pointing precision. A combination of the tracking system with a fiber-optic signal feed unit has been designed to demonstrate a 2.5-10 Gbps-level performance at the distances of about 5 km.

6390-19, Session 6

Experimental study on next-generation FSO communication system

K. R. Kazaura, K. Omae, T. Suzuki, M. Matsumoto, Waseda Univ. (Japan); E. Mutafungwa, Helsinki Univ. of Technology (Finland); K. Asatani, Kogakuin Univ. (Japan); T. Murakami, Koito Industries, Ltd. (Japan); K. Takahashi, Olympus Corp. (Japan); H. Matsumoto, Showa Electric Wire & Cable Co., Ltd. (Japan); K. Wakamori, Hamamatsu Photonics K.K. (Japan); Y. Arimoto, National Institute of Information and Communications Technology (Japan)

Free-space optical communication has emerged as a competitive and viable technology for offering high data rates, improved capacity, cost-effective and easy to deploy technology for providing connectivity between two points which are up to a few kilometers apart.

In this paper we present experimental work which demonstrates the practicality of next generation free-space optical (FSO) communication systems suitable for short-haul, high-speed, robust data links. This experimental system is placed between two buildings in the Waseda University campus area for a communication link spanning a distance of 1 km.

We outline the design of the optical antenna which uses 1550nm wavelength and directly coupling a free-space optical beam to a single-mode fiber without any OE/EO conversion to offer a 2.5Gbps communication link. The antenna is capable of overcoming most common factors inherent of FSO communication systems including tracking as well as atmospheric induced beam wander and scintillation effects. A high-speed tracking mechanism which utilizes a fine positioning mirror (FPM) capable of tracking and controlling the received beam and focusing most of beam power into the fiber is presented. This FPM is capable of mitigating the frequent power fluctuations caused by beam angle-of-arrival (AOA) variations.

This paper presents experimental results of the FSO communication system capable offering stable performance in terms of measured bit-error-rate (BER). Performance results showing increasing the systems data rate from 2.5Gbps to 10Gpbs are also presented.

6390-20, Session 6

Frequency domain equalization of optical channel distortion in free-space optical wireless communications

M. Kavehrad, S. Lee, The Pennsylvania State Univ.

This paper is about frequency domain equalization of optical channel distortions using liquid crystal modulation (LCM) technology. In communication channels such as in fiber optic transmission or free-space optical (FSO) communications, there can be channel dispersion, causing intersymbol interference (ISI). For example, in FSO, there is multi-scattering phenomenon, which at high bit rates causes ISI, severely degrading the error performance.

In digital RF communications, there are many well-established ways to reduce ISI and get close to the Nyquist condition, such as time domain equalizations (TEQ) and frequency domain equalizations (FEQ). In optical communications, analogous to RF signal processing, both of optical TEQ and electronic TEQ after photo-detection have been under extensive studies. Alternatively, the idea suggested in this paper is to extend the RF FEQ idea to light domain signal processing. For this purpose, we can employ a widely used 4F pulse shaping apparatus based on the Fourier transform relationship, and have the arbitrary pulse shaping idea extended to FEQ. If, under ideal conditions, the fine structure of comb-like spectrum of mode-locked laser can be resolved, we can design a pixellated amplitude/phase mask doing this task. As for the implementation algorithms, similar to RF equalization, it can be based either on channel inversion, or on adaptive algorithm such as least-mean-square (LMS). Adaptive algorithms simply adjust the parameters of each pixel of the mask iteratively until the error between the waveform generated by the pulse shaping system and the desired waveform, e.g., a minimum-ISI waveform, is minimized. A mask pattern can be realized for a real system by iterating through each pixel and dynamically adjusting parameters of each pixel in the pulse shaping system until the error between the output waveform and the desired waveform is minimized.

6390-21, Session 6

A feasibility study of PowerLine communication technology for digital inclusion in Brazilian Amazon

J. C. W. A. Costa, Univ. Federal do Para (Brazil)

In the current national scene, many actions point at projects of digital inclusion and citizenship. In this context, providing access technologies as a requisite for the implementation of these actions is primordial. In this way, many innovative experiences have been presented in the past few years. This paper presents a study on the PowerLine Communication - PLC technology; as a proposal for a feasible access network for Brazilian Amazon. First, the characteristics of the PLC technology are studied from an implanted indoor prototype at Federal University of Pará. The measures used in this prototype serve as input for a created model, from which it is intended to study the system more widely, considering factors such as: scalability, reliability and the physical characteristics.

6390-12, Poster Session

Performance analysis of high-capacity integrated fiber radio communication systems

A. Goel, Maulana Azad National Institute of Technology (India)

In present days one of the most spectacular trends in telecommunication is the development of high-speed wireless network. The next generation wireless communications systems need to be of a higher standard so as to support various wideband applications such as video conferencing, world wide web etc. Millimeter wave (mm) wireless communication systems are significantly important in today's communication especially to support various wideband applications. For exploiting the wideband capabilities of the mobile network, researcher have observed that mm waves when transmitted at 60 GHz, can provide bandwidth of around 4 GHz. Although, due to high attenuation losses (16 dB/km), the overall transmission distance is confined to relatively to shorter distance.

We therefore suggest modified wireless communication system with multimode optical fiber as feeder network for up gradation of existing wireless network. For this we have conducted the performance analysis of an integrated network comprising of wireless and optical fiber, which is capable of supporting data rates of the order of hundreds Mbps. A simulation model was developed and implemented using MATLAB, so as to investigate the performance of integrated fiber radio system. From the above investigation it has been observed that the performance of the optical fiber network even for distance of 80 KM is better, than with AWGN channel for SNR of 50 dB. Hence, an integration of optical wireless network suggests an excellent cost effective means for transmitting various wideband applications.

6390-22, Poster Session

A packet scheduling algorithm for ad hoc optical networks

K. V. S. Sairam, Bharat Institute of Engineering and Technology (India)

Most of recently algorithms are developed to address the problem of fair packet scheduling in optical ad-hoc networks. Fair packet scheduling in optical ad-hoc network is challenging for several reasons. First, the optical channel capacity is a scarce resource. Spatial channel reuse should be encouraged whenever possible. Second, the optical channel is shared among multiple contending nodes in a spatial locality. Location-dependent channel contention complicates the fairness notion. Third, the sender of a flow does not have explicit information regarding the contending flows originated from other nodes. Fair queueing over ad-hoc networks is a distributed scheduling problem by nature. Forth, conflicts between ensuring fairness and maximizing channel utilization. Finally, the scalability in the presence of node mobility is considered. This paper introduces a hybrid fair packet scheduling algorithm of two of the most recent algorithms: the Two-Tier algorithm and the BFMLM-FQ algorithm to achieve the optical ad-hoc network design challenges. For solving the limitations in the previous efforts due to local and global features, a proposed algorithm is investigated. In such algorithm local schedulers coordinate their local interactions and collectively achieve the desired global fairness. The performance of the hybrid algorithm is implemented with the help of ns2 network simulation.

6390-23, Poster Session

The research and scheme of RBAC using J2EE security mechanisms

F. Zhang, Daqing Petroleum Institute (China)

Access control based on RBAC makes the system suitable to the security strategy for special application, relieves burden of system administrators and can adapt itself to the adjustment of the system structure flexibly. But all the existing security mechanisms of the middleware technology can't support the RBAC model very well. The method using J2EE security mechanisms to support RBAC is showed in this paper. First, the configuration of J2EE security systems is given in the paper and the algorithm of J2EE authorization decision is designed. Then, the language of J2EE security description is used to define RBAC, and realization of the requirement of J2EE security service is given. It has achieved the anticipative effect in virtue of deployment and application on the platform of the national science technology infrastructure.

6390-24, Poster Session

A methodology for measurements of basic parameters in a xDSL system

J. C. W. A. Costa, A. Castro, L. V. Souza, E. Patrício, E. Brito, Univ. Federal do Para (Brazil)

xDSL (Digital Subscriber Line) is an enabling technology for high data rate communication and fast internet access over ordinary telephone lines (Plain Old Telephone Service- POTS). Since the copper infrastructure was not designed for high frequency use, measuring the physical layer of the loop is required to ensure successful deployment of xDSL services. In order to qualify a subscriber loop for xDSL transmission, basic parameters like transfer function, scattering parameter S11 and characteristic impedance should be known. The aim of this paper is to present a test methodology for measurements of these basic parameters. The characteristic impedance is measured by method open/short and it is compared with terminated measurement method defined in IEC (International Electrotechnical Commission) 611156-1. The transfer function and scattering parameter S11 of the DSL cooper loop are also measured of a real cable. This methodology is based in measurements of real twisted cable balanced of 1.400m length, 10 pairs, and 0.4 mm gauge. In order to improve the results analysis, we compared the measurements from the real cable with results from wireline simulators. The measurement of parameters of the xDSL cooper loop is done in an infrastructure set up in the LABIT (Laboratory of Technological Innovation) of the UFPA (Federal University of the Pará), that consist of a wireline simulators, a precision impedance analyzer, and a network analyzer. The results show a good agreement between the measurements performed with real cables and the measurements performed with the wireline simulators. The characteristic impedance found by both methods presented quite similar results.

6390-25, Poster Session

Characterization of subscriber local loop by measures and analysis of frequency response and TDR

J. C. W. A. Costa, A. Castro, I. Negrão, J. Reis, Univ. Federal do Para (Brazil)

The performance of a broadband access service such as Digital Subscriber Loop - DSL technology is directly related to the status of subscriber local loop. DSL technology could provide a higher data rate than a dial-up connection access, which uses a different frequency band. However, this higher data rate depends on local loop topology. This dependency is due to the fact that the local loop was first designed to plain old telephone system - POTS.

A subscriber local loop topology may contain some impairment such as gauge changes, open circuits, bridged taps along the line, and may have a long length which increases the signal attenuation. Such impairments bring about reflections on the main signal; these reflections could be weak or strong ones depend on the nature of the impairments. Furthermore, bridged taps cause strong reflections while gauge changes and open circuit causes weak ones. Additionally, it is easier to identify strong reflection than weak ones.

Telephone Companies which provide DSL services should have procedures or tools that characterize and evaluate the capability of a subscriber local loop in carrying DSL signals.

The main focus of this paper is to present methodologies and procedures which could be used by a DSL provider in order to characterize a subscriber local loop, that is estimate its length, presence of open circuits, bridged taps and gauge changes.

The subscriber local loop characterization will be based on Frequency Response and Time Domain Reflectometry - TDR simulations and measurements. The Frequency Response measurements consist in carrying out local loop attenuation per tone in DSL frequency band, that is, measurements that start at 4.3125 kHz and finish at 1.104 MHz for Asymmetric Digital Subscriber Line - ADSL (256 tons) and at 2.208 MHz for ADSL2+ (512 tons). The TDR measurements consist in: to send a half sine wave pulse with specific width along the local loop and, to analyze the reflected signal.

The analysis of such results will be used to characterize a subscriber local loop. The nature of the reflection will be perceptible at time and frequency domain, that is, every reflection caused by change of impedance along the local loop contains its signature. This signature will indicate or not presence of such impairments. The line length will be calculated by using the time of reflection knowing velocity of propagation of the pulse.

6390-26, Poster Session

Firewall using LINUX 8.0

P. Ganguly, CESC Ltd. (India)

Due to the excessive amount of security threats, the need of a firewall is felt. Again, this firewall also acts as a proxy server to talk to the internet. Any internal network can be masqueraded against the external world through this firewall. In case of different TCP/IP services like smtp, snmp, udp, tcp ,http , https, it can be restricted userwise.

This firewall uses the Sqid.conf configuration file as well as PAM (password authentication module) and the default index.html and other Configuration files of linux O/S.

The Web Browser used is Mozilla. Some CGI/PERL Scripts are used and other shell scripts are also used. Different Intranet services are also provided userwise and mentioned in the squid.conf file.

Squid Proxy

a. The Squid Proxy is acting as the Internal Firewall and separating the Intranet from the DMZ. There are two such servers configured identically and the user database is getting replicated among them automatically. But at a time only one server is connected to both the Internal Network and DMZ. In the event of the active one failing, the

physical connectivity has to be shifted to the other server and the system will be running without disturbance.

b. Anybody accessing the Internet or the DMZ servers will have to pass through the squid server (firewall).

c. By default every access to the outside is denied. Specific permission has to be given to gain outside access.

d. There will be multiple groups defined on the squid server. These groups will define the access restrictions. A particular group will have particular access permissions defined. A person belonging to a particular group will inherit the group permissions. A person who is a member of multiple groups will have access permission that is equivalent to the combined group permissions.

e. Only one simultaneous connection is allowed for one user. That means the same username/password can't be used simultaneously from two machines.

f. A specific route has to be added in the internal firewall so that the VLAN have access to the Internet world or the DMZ servers. This will enable to eliminate the unwanted VLANs those do not require to connect to the DMZ or the Internet world.

g. User authentication will be required for viewing any mail having active cookies inside it.

h. To bypass user authentication for prime users, a separate instance of Squid may be installed without any access list. The users will be connecting to proxy on a port other than port 80 (default one) where the second instance of Squid is running.

6390-27, Poster Session

Improvement to fairness algorithm of resilient packet ring network

W. Tang, S. Fu, L. Zhang, P. Shum, Nanyang Technological Univ. (Singapore)

Resilient Packet Ring (RPR) is the most promising solution to the bottleneck of metropolitan-area networks (MANs). In IEEE standard, there are two default algorithms to ensure the fair allocation of bandwidth for RPR network: conservative mode (CM) and aggressive mode (AM). The RPR-AM is a simple method but exhibits large oscillations especially under the scenario with unbalanced traffic. To overcome this shortfall, an improvement has been proposed in this paper. Instead of reducing its traffic add rate directly to a much smaller value advertised by the congested downstream node, the upstream nodes ramp down their add rates gradually as in RPR-CM. By inspection, the amount ramped up in the nearest interval can be approximated as the increment causing congestion in this interval. Between this increment in last interval and corresponding ramp down amount in this interval, the large one is chosen to guarantee that the congestion can be resolved fast. However, the accuracy of above approximation gets worse as longer time delay incurred with the network. For low complexity, only one parameter is introduced to compensate undesired effects induced by time delay. The proposed improvement has been implemented within our RPR simulator model with the aid of OPNET Modeler. The results show that the system performance has been much improved over original RPR-AM, regardless of time delay experienced. Moreover, both moderate response speed and high link utilization (full link utilization possible) can be realized simultaneously by adjusting the coefficient respect to the delay.

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6391-01, Session 1

An evaluation of flexible macroblock ordering in error-prone environments

Y. Dhondt, S. Mys, P. Lambert, R. Van de Walle, Univ. Gent (Belgium)

In our modern multimedia society consumers expect to be able to access multimedia content anywhere and anytime. This has resulted in the development and deployment of several different types of communication networks, both wired and wireless. Most of those networks are based on a best-effort model, implying that there is no guarantee that sent data will actually reach their destination. The current generation of video codecs exploits the temporal redundancy between successive frames to achieve high compression ratios. The downside of this technique is that loss of even the smallest packet can introduce an error which propagates through a number of successive frames, hereby severely damaging a large part of the decoded video. Due to real-time constraints, retransmission of lost data is, more often than not, not an option. Therefore, the study of error resilience and error concealment techniques is of the utmost importance since it can seriously limit the impact of a transmission error. In this paper an evaluation of flexible macroblock ordering, one of the new error resilience techniques in H.264/AVC, is made by analyzing its costs and gains in an error-prone environment.

Currently, all widespread video codecs, such as MPEG-2 Video and H.263, are block-based video codecs. This means that an encoder for such a codec splits every frame it receives into smaller blocks which are then coded one after another. Those blocks, often having a size of 16 by 16 pixels, are called macroblocks. In traditional codecs macroblocks are coded in raster scan order, meaning that, starting from the top left corner, macroblocks are processed row after row until the bottom right corner is reached. An advantage of this system is that previously coded blocks above and to the left of the current block can be used to obtain a better compression efficiency. However, there is also a serious disadvantage. When a packet gets lost during transmission, several successive blocks or even rows of blocks will be lost. This makes the reconstruction of the lost blocks rather hard since in most cases all surrounding information will be lost as well. H.264/AVC presents a solution to this problem by allowing a flexible coding order of the macroblocks.

In H.264/AVC, flexible macroblock ordering is realised by means of slice groups. Slice groups are sets containing one or more macroblocks from the same input frame. Each macroblock of a frame belongs to exactly one slice group. There can be up to 8 different slice groups for every frame. Each slice group is coded independently from the others and all macroblocks inside a group are coded in a raster scan order depending on their original location in the frame. By assigning the macroblocks to the different slice groups in a smart way, the impact of packet loss can be lowered dramatically. For example, if all neighbouring macroblocks of a macroblock belong to one or more other slice groups, a reconstruction algorithm can take advantage of the availability of the surrounding macroblocks to provide a better concealment. However, because of the independence between slice groups, the compression efficiency is lowered since often no neighbouring blocks can be used to compress the current block. Furthermore, the new ordering of the blocks, represented by a macroblock allocation map, needs to be passed from the encoder to the decoder resulting in an extra cost. Luckily this cost can often be limited by using predefined patterns which require only a few bits.

In this paper we discuss two aspects of flexible macroblock ordering. Firstly, we examine the costs of flexible macroblock ordering in terms of objective video quality. Secondly, we study the influence of flexible macroblock ordering in an error-prone environment where the decoder has the possibility to reconstruct lost parts. For our experiments we make use of the latest version of the H.264/AVC reference software, i.e. JM 10.2, to which we added extensive support for flexible macroblock ordering.

Previous experiments regarding the cost of flexible macroblock ordering always used a fixed quantisation parameter. However, most real-world applications, such as video conferencing and surveillance applications, use a fixed bit rate instead. Therefore we decided to do our experiments based on a fixed bit rate as well. Choices regarding specific rates are made depending on the target applications and networks. By using a fixed bit rate instead of a fixed quantisation parameter, it is possible to express the cost of flexible macroblock ordering by means of its influence on the objective quality of the compressed video. These measurements are conducted using the peak signal-to-noise ratio (PSNR) metric. Although one can argue that the chosen rate control mechanism might influence the results of the experiments, the same argument can be used concerning the choices made for the fixed quantisation parameters.

In the second part of the experiments, compressed video streams, both with and without flexible macroblock ordering, are transported over an error-prone network. Using the error concealment functionality of the reference software, we reconstruct all lost parts. The resulting decompressed video sequences are compared to the video sequence for which no loss occurred during the transmission. Again the PSNR metric is used to determine the objective quality. These experiments allow the study of the impact of flexible macroblock ordering as an error resilience tool.

Our first test results show that the cost of flexible macroblock ordering depends on several factors. The most important ones are the number of slice groups, the bit rate, and the type of frames. The cost of flexible macroblock ordering in terms of video quality varies between 0 and 4 dB. Furthermore, the experiments show that flexible macroblock ordering is better suited than the regular raster scan ordering when it comes to concealing errors. Flexible macroblock ordering is especially good at concealing errors in intra frames and frames containing a lot of motion. It also keeps the overall video quality higher for a longer period of time in case of serious packet loss.

6391-02, Session 1

A performance evaluation of the data partitioning tool in H.264/AVC

S. Mys, Y. Dhondt, D. Van de Walle, D. De Schrijver, R. Van de Walle, Univ. Gent (Belgium)

An increasing amount of coded video is sent over a variety of networks every day. Most of these networks are based on a best-effort model and cannot guarantee that all packets arrive in time at their destination. Consider for example several security cameras sending their captured and encoded video to a central server over a wireless network. In this particular case, packet loss ratios are certainly not negligible. Even when sending video over the internet, e.g. in a video-on-demand scenario, packet loss is not unusual.

In order to be able to better cope with packet loss, a number of error resilience tools are specified in the H.264/AVC specification. The goal of error resilience is to make it possible that a bitstream containing encoded video can still be decoded when parts of it are missing due to packet loss. On top of that, the visual quality of the decoded video sequence should remain as high as possible.

One of these error resilience tools, in particular the data partitioning tool, will be discussed and evaluated in this paper. Other important tools are flexible macroblock ordering and redundant slices.

H.264/AVC makes a clear distinction between the Video Coding Layer (VCL) and the Network Abstraction Layer (NAL). The encoded video is put into several NAL Units (NALUs), which can then be either stored or transmitted.

Normally each encoded slice is put into exactly one NALU. However, when using data partitioning, the coded data for a single slice is split up into three partitions, and each partition is put in a separate NALU. The following partitioning is defined in the specification:

- partition A contains the slice header, macroblock types, quantization parameters, prediction modes, and motion vectors.
- partition B contains residual information of intra-coded macroblocks.
- partition C contains residual information of inter-coded macroblocks.

The idea behind data partitioning is still to be able to use information from correctly received partitions when one of the partitions is lost. To be able to do this, it is important to know what the dependencies between the different partitions are. In this paper we will explain why partition A is independent of partitions B and C and partition B is

independent of partition C. The latter only holds true if a special option, constrained intra prediction, is enabled.

Knowing the mutual dependencies between the different partitions, it is clear that the quality of the decoded video will be best if the possibility of losing partition A is smaller than the possibility of losing partition B, which in turn is smaller than the possibility of losing partition C. This can be achieved in different ways. The most obvious one is the use of a differentiated network technology such as DiffServ or IntServ. Another possibility is using Unequal Error Protection (UEP) mechanisms on the network level.

For our experiments we encoded three CIF video sequences with different motion characteristics. A fixed number of 150 macroblocks per slice were used, resulting in 3 slices per picture. Constrained intra prediction was enabled, the intra period was 18 pictures and no B slices were used. A high quality (Quantization Parameter(QP) 26) and low quality (QP 40) version of each sequence was encoded. Each of those versions was once encoded with and without using data partitioning.

Packet loss was simulated by dropping NALUs using a random generator. The first scenario we simulated was a non-differentiated packet loss: 2, 5, 10 or 20 percent of the NALUs, uniformly distributed, were dropped.

In a second scenario we also simulated packet loss in a differentiated network. Two cases for this scenario were tested. In the first case, 5% of the lost NALUs were NALUs containing partition A, 25% were NALUs containing partition B and 70% were NALUs containing partition C. In the second case only one percent of the lost packages contained partition A, 5% partition B and 94% partition C. From hereon we will refer to the first case as “differentiated network case 1”and to the second case as “differentiated network case 2”.

A simple error concealment scheme (based on temporal error concealment) was used during the decoding of the incomplete bitstreams. A detailed description of this scheme is omitted in this abstract due to space constraints, but will be provided in the full paper.

Our test results show that the data partitioning tool performs good when applied in a differentiated network. We see that the PSNR decreases less when increasing packet loss ratio in a differentiated network using data partitioning compared to not using data partitioning. This decreased drop is more significant for high quality than for low quality video. It is also more significant for video containing a lot of movement than for video containing less movement. Finally we see that the PSNR decreases less in a differentiated network case 2 than case 1.

The test results show an increase in PSNR of up to 25% when using data partitioning in a differentiated network case 2 compared to not using data partitioning. For most sequences the PSNR is still better when using data partitioning in a differentiated network case 2 with 20% packet loss than when not using data partitioning and only 5% packet loss.

The overhead caused by data partitioning is acceptable. When using data partitioning we need three NALUs per slice in stead of one. Each partition must also specify a slice id, which consumes less than one byte if not too many slices (i.e. 14 or less) are used. Every NALU also has a 1-byte NAL header and is preceded in the bitstream by a 4-byte startcode. This means that data partitioning causes an overhead of approximately 13 bytes per slice. For our test sequences (3 slices per picture, 300 pictures per sequence), this results in an overhead of approximately 11 700 bytes. Relatively spoken this is about 5% overhead for low quality video and less than 3% for high quality video.

6391-03, Session 1

Macroblock-level adaptive dynamic resolution conversion technique

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In this paper, we propose a macroblock-level adaptive dynamic resolution conversion (MBA-DRC) scheme based on H.264 standard to increase an overall coding efficiency. In video compression, low detailed area such as background is very likely to be skipped or at least, coded only by small amount of transform coefficients because the residual signal energy is small after temporal or spatial prediction. It implies that, in low detailed area, the syntax element related to this coding mode consumes a relatively larger portion of bitstream than transform coefficients. Therefore we can improve the coding efficiency by reducing the resolution of this area because the number of syntax element such as macroblock type or motion vector can be decreased by doing so with minimal quality loss.

The proposed scheme, MBA-DRC makes a decision whether the image is spatially reduced or not in macroblock level rather than picture level to exploit the local characteristics of image. In more detail, based on R-D optimization, it decides whether consecutive four macroblocks can be reduced to one macroblock by downsampling. To apply a spatial or temporal predictive coding on the resolution-reduced macroblock, the reference block should be also reduced. The motion vectors and intra prediction modes in the resolution-reduced macroblock are updated to the corresponding four macroblocks in reconstruction process so that to be used for later spatial prediction between the neighboring blocks. The proposed scheme is implemented on H.264 standard codec and the simulation result shows coding gain of MBA-DRC against the conventional H.264 standard.

6391-04, Session 1

Flickering effect reduction for H.264/AVC intra frames

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The intra-only coding which compresses each frame of a video sequence without resorting to inter coding techniques such as motion estimation and compensation is very useful for some applications. Applications which require low complexity such as surveillance video system can benefit most from the intra-only coding because of its simple structure.

However, in intra-only coding for video sequences, so called flickering effect is a serious problem in subjective visual quality. Especially, the flickering effect is extremely visible in static regions such as background of the video sequence where no moving objects appear. Although these static regions are pretty much the same from frame to frame, they are compressed differently. This is due to the independent quantization in each frame. Moreover, a few changes of pixel values in the spatial domain might cause a significant effect to all frequency coefficients in the transform domain. Sometimes, the flickering effect is recognized as an inherent property of the transform based intra-only coding.

In this paper, we analyse why flickering effect happens and illustrate our results of observation using intra-only coding of H.264/AVC standard. Based on our analysis, we propose a flickering effect reduction scheme which utilizes statistical information of original picture in encoding procedure. The proposed scheme reduces flickering effect using control of luminance values in each 4x4 block and increase subjective visual quality.

6391-05, Session 1

Performance comparison of audio codecs for high-quality color ring-back-tone services over CDMA

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A color ring-back-tone service has been one of successful and profitable services for a cell phone service provider. It, however, does not deliver high quality when color ring-back-tone is chosen as music instead of voice. This is because the service is deployed in a framework of low-bit-rate speech coding while music is hard to be reconstructed with high quality by using the speech codec. In this paper, we investigate the use of an existing audio codec for the purpose of a high quality color ring-back-tone service. First of all, we exploit the limitations of the speech codec, especially enhanced variable rate coder (EVRC) that has been employed in CDMA systems, in a view of music quality. Next, we compare the performance of several existing audio codecs, where their bit rates are close to that of EVRC in order to directly replace EVRC with one of them. The audio codecs to be compared are different versions of MPEG AAC and the Enhance AAC+ coder that has been standardized as a core codec for the W-CDMA system. We perform a comparison category rating (CCR) test for a subjective quality test and the perceptual evaluation of audio quality (PEAQ) measurement for an objective quality test. It is shown from the experiments that the audio codecs usually provide better music quality than EVRC and also Enhance AAC+ operated at a bit-rate of 10 kbit/s with a sampling rate of 32 kHz is considered as a new candidate for the high quality color ring-back-tone service.

6391-06, Session 2

Quality assessment of media synchronization of preventive control schemes in video and voice communications

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This paper assesses the media synchronization quality of preventive control schemes at sources for stored video and voice over the Internet. To alleviate the deterioration owing to network delay jitter, we need to synchronize video and voice. Media synchronization control techniques are classified into four categories: Basic control, preventive control, reactive control and common control.

This paper focuses on the preventive control at media sources. The preventive control techniques are required to try to avoid asynchrony (i.e., out of synchronization).

Thus, The techniques are used before asynchrony occurs. We here deal with two preventive control techniques employed at sources: Advancement of transmission timing of media units (MUs), each of which is the information unit for media synchronization (e.g., a video picture), with network delay estimation and temporal resolution control of video. By experiment, we make a performance comparison among preventive control schemes which employ one or two preventive control techniques.

Experimental result shows that a scheme which exerts the advancement of transmission timing together with the temporal resolution control is the most effective in terms of the quality of media synchronization.

6391-07, Session 2

Influence of network latency in a remote control system using haptic media

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This paper deals with a remote control system by which an instructor trains a learner how to draw pictures or figures while conveying the sense of force through the Internet. Haptic feeling can be transmitted by the system. Applications of the system are a remote calligraphy system, a remote medical operation system, and so on. In this paper, we examine the influence of network latency on the output quality of haptic media by subjective assessment of drawing figures. As a result, we show that the MOS value can be estimated accurately from the summation of the network latency from an instructor's terminal to a learner's terminal and that in the opposite direction.

6391-08, Session 2

Perception of synchronization errors in haptic and visual communications

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This paper deals with an application in which conveys the haptic sensation experimented by a user to a remote user. In such an application, the user controls a haptic interface device with another remote haptic interface device while watching video. Haptic media and video of an object which a user is touching is transmitted to another user. When we transmit haptic media and video over the Internet, the network delay jitter disturbs the temporal relationships among the media streams. Thus, the quality of service (QoS) of the streams may seriously be degraded. To solve the problem, we need to carry out media synchronization control. The control uses the allowable range and imperceptible range of synchronization error between the two media streams. Therefore, we need to clarify the two types of range to carry out the control efficiently. By subjective assessment, we investigate the allowable range and imperceptible range of synchronization error between haptic media and video. We employ three objects and ask each subject whether the synchronization error is perceived or not for each object in the assessment. Assessment results show that we can more easily perceive the synchronization error in the case of haptic media ahead of video than in the case of the haptic media behind the video. The allowable range and imperceptible range of synchronization error between haptic media and video depend on the features of the object.

6391-09, Session 2

Performance evaluation of transport protocols for networked haptic collaboration

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Development of virtual reality (VR) technology and the rapid diffusion of network make the interest on remote collaboration increasing. Already, high definition (HD) video, multi-channel audio, and 3D computer graphic (CG) are used for various remote interaction applications and contribute to overcome the limitation of real world. However, it is still difficult to interact with remote participants as sharing the sense of touch because of current network constraints. A haptic interface requires an update rate of about 1 kHz for the user to accurately experience force feedback. Therefore, in order to provide haptic interactions in remote collaboration, we require a stringent level of QoS service from the network. Especially, network delay jitter and packet loss over the Internet may seriously degrade the output quality of haptic interactions [1]. Some of the initial work for these challenges focused on achieving compensation scheme (queue monitoring, virtual-time rendering, and so forth) for the network constraints [2-4]. Their work contributed to extend the maximum bound of acceptable delay, jitter, and loss to carry data from the haptic devices between several computers, even though it could not cover large and irregular network impairment in Internet.

Another challenge related with networked haptics is transport protocol for networked haptic collaboration. However, although studies have been made on collaborative virtual environments (CVE) without haptic interactions, there are few researches on networked haptic collaboration. Most CVE applications without haptic interactions use TCP or UDP as the transport protocol for the event data. For some CVE applications such as networked games, reliable UDP is a better option to benefit from both of their features [5]. In [6], authors proposed new transport layer protocol for tightly coupled collaborative tasks, called as SCTP (synchronous collaboration transport protocol). They also improved SCTP for telehaptics update messages and showed that the transport protocol, despite producing a noticeable delay effect, allows to improve haptic collaboration quality in the presence of jitter compared with light TCP and original SCTP [7]. However, until now, the trade-off relationship between reliability and interactivity for networked haptic collaboration is not yet defined definitely. It is important to derive the requirements of transport protocol for efficient networked haptic interaction under time-varying network environments.

In this paper, we evaluate the performance of transport protocols for haptic interactions which have deferent levels of reliability and interactivity. First, we consider TCP with the highest reliability and UDP with the highest interactivity. However, we expect that TCP is an unsuitable choice for networked interactions due to its high latency and UDP also lacks many necessary features from TCP such as reliability, sequencing, and connection management. Therefore, we attempt to evaluate three other protocols. One is reliable UDP which guarantees that packets always arrive in the order which they were sent but reduces the latency owing to TCP congestion control. Another is UDP with sequencing which will simply discard the lower sequence number packet if a packet with a higher sequence number has already been delivered. This allows the packets to be dispatched immediately as they arrive, and reduce latency due to buffering of reliable UDP. The other is the network-adaptive transport protocol which adaptively combines interleaved FEC (forward error correction) and delay-constrained ARQ (automatic request) based on the monitored network status [8]. We expect that the connection management module in the network-adaptive transport protocol can improve the haptic interaction quality because the networked haptic collaboration is very sensitive to network state. Moreover, if we consider the characteristic of haptic data that is small data size per packet but generated every millisecond, which can result in large overhead and heavy network load [9], new transport protocol for efficient networked haptic interactions can be designed.

We implement the network haptic collaboration testbed consisting of master, slave, and network emulator to carry out an experiment on the requirements of transport protocol for efficient networked haptic interactions. The master and slave nodes have haptic interface, PHANToM Omni, and participate at the haptic collaboration through network emulator. The master manages all objects in virtual environments and sends the update information to the slave node with

its own haptic cursor data. The slave also sends its haptic cursor data to the master but does not include calculation module of object movement because it just update the object information according to the data from master for consistency. For the network emulator, we use FreeBSD compiled with its internal 'tick' counter set to 1000 Hz rather than its default of 100Hz in order to synchronize with high update rate of haptic interface. FreeBSD's kernel-resident dummynet module enables the addition of configurable latency, bandwidth limits and packet loss to traffic flowing through the kernel's network stack. From the command line of a FreeBSD-based Ethernet bridge between the master and slave nodes, dummynet allows us to emulate a wide range of latency and packet loss scenarios. Therefore, the change of haptic interaction quality according to network impairment for running user-experience trials can be measured more exactly. We implement simple networked haptic collaboration application running on the testbed. The application is made based on CHAI3D library that is an open source, freely available set of C++ libraries for computer haptics, visualization and interactive real-time simulation. When the haptic cursor makes contact with the surface of a block, a force is generated based on the depth of penetration of the cursor into the block. The users can pick up a block by using the haptic cursors and move towards the other block. The task is considered accomplished if it is placed on top of (and not dropped onto) the other block.

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6391-10, Session 2

A synchronized multiplexing scheme for view-switchable stereoscopic HD video over IP system

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Despite of hyped interests in the multi-view 3D video, HD (high definition) version of multi-view video systems have been neither technically nor commercially viable yet. Only recently, several academic institutes and companies are showcasing prototype products that can provide multi-view 3D video services over the IP networks [1-2]. For ATTEST (advanced three-dimensional television system technologies) project [1], researchers developed a 2D-compatible multi-view 3DTV system for broadcast environments. To deliver natural viewing experience, ATTEST project proposed an efficient approach to generate 3D contents based on a depth camera. Also, MERL (Mitsubishi Electric Research Laboratories) proposed a multi-view 3DTV prototype system with real-time acquisition, transmission, and auto-stereoscopic display [2]. This system can provide 16 viewpoints and 1024Å~768 pixels per viewpoint so that immersive 3D experience can be enjoyed without special glasses. However, these luxurious prototypes have not yet considered the emerging services based on the media delivery over upcoming broadband IP networks.

In this paper, we propose a prototype realization of view-switchable stereoscopic HD video transport that can extend the software-based stereoscopic HD video transport system over IP networks [3]. To avoid the expensive hardware cost and limited extensibility of existing hardware-based multi-view prototypes, we realize a synchronized multiplexing scheme for MPEG2-compressed multi-viewpoint HD videos (from multiple HDV camcorders). The proposed synchronized multiplexing enables us to multiplex a selected number of acquired HD views (including the stereoscopic multiplexing) by re-mapping the time base of all multiplexed HD views. When doing this, it also provides a flexible adjustment of slightly mismatched (i.e., time-skewed due to network-based capture input via IEEE 1394 and others) HD streams. It is expected that, several multiplexed (in diverse grouping of HD views) streams are transported over separate multicast IP-channels so that all end-users can enjoy their own view by joining the multicast channel of their choice. Thus, with the proposed synchronized multiplexing, we can display synchronized view when the end-users switch the view.

As explained above, when we perform the synchronized multiplexing, we synchronize selected collection of HD views to a reference (virtual) stream so that all multiplexed HD views have a common time base and thus can be used for synchronized presentation. For example, with the proposed synchronized multiplexing, left and right streams of each are multiplexing into one stream by re-mapping the PID (Program Identification) of associated streams based on reference stream. It can be combined with dropping of duplicated component such as audio TS (transport stream) packet, PSI (program specific information), and others. Also, this synchronized multiplexing scheme assumes that all camcorders are clock-synchronized (via GENLOCK or similar alternative) and the frames are acquired with synchronization. However, it is still possible each MPEG2-compressed HD video stream has different time base and, as a result, different PCR (program clock reference), and PTS (presentation time stamp) are associated with TS packets of each stream. Thus, to achieve synchronized playout, the proposed system checks the arrival time of associated frames from each camcorder and compares them based on the IEEE 1394 cycle clock to estimate the difference in time base. This time difference is reflected in the PCR and PTS value of TS packets to achieve synchronized time base. Finally, with a testbed consisting of a server with four HD cameras, four clients, and three multicast routers, we can verify that all end-users can enjoy the switching of viewpoint on the same time base.

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6391-11, Session 3

Optimum intra-cluster cooperative caching in content delivery networks

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With the advancement of multimedia technologies and high speed networks, multimedia entertainment applications are now becoming popular over the Internet. Cooperative caching is one of the ways to improve the performance of multimedia content delivery networks (CDN) for disseminating multimedia contents on demand. Traditionally, large content delivery networks exploit infrastructure support through the use of geographically distributed high performance servers. Moreover, hierarchical overlay network topology is required for CDN servers to perform content routing and content delivery efficiently. This hierarchy consists of a set of cluster while some close CDN servers form a cluster. In this paper, we propose an optimum intra-cluster caching scheme for content delivery networks.

Each CDN server applies an admission control algorithm to either

accept or decline a request based on available resource. Moreover local CDN server may require performing content routing and then delivering to the user. Local hit and cluster hit judge the performance of caching policy. If local CDN server has the content and serves it to the user, it is then marked as a local hit. But if the request is satisfied by a CDN server inside the same cluster, then it is a cluster hit. Global hit means request is handled by any CDN server in the content delivery network. Obviously, high local hit and high cluster hit save networks bandwidth. Our novel optimum intra-cluster caching scheme outperforms digest based scheme, directory based scheme, pure hashing scheme and semi hashing scheme.

The largest Content Distribution Networks (CDN) provide an infrastructure of thousands of geographically distributed servers, which are placed at the edge of Internet that is, at the main ISP points of presence. A CDN includes a content-aware routing mechanism to dispatch the client requests to the “most convenient” edge server. There are several possible routing mechanisms, but the most used solution is based on a combination of dynamic URL rewriting at the origin server and DNS interposition. With respect to the traditional proxy caching, a CDN solution can achieve very high cache hit rate. However, proxy caching is typically free, while CDN services are highly expensive.

6391-12, Session 3

A hierarchical P2P overlay network for interest-based media content lookup

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More and more homes are getting connected with high-speed access networks. Homes are also beginning to build in-house home networks. Based on protocols such as UPnP (universal plug and play), HAVi (home audio video interoperability), and Jini, the proliferation of next-generation convergence devices will promote the explosive generation of ordinary content by home consumers and the sharing of content among themselves. With the advent of A/V (audio/video) home network that owns a variety and abundant of content, in near future, people will want to make a community based on their interest for the content sharing among home networks, we call it as DHC (digital home community), as people do on current P2P (peer-to-peer) file sharing system[1,2]. We may view the DHC as more formalized home-network-extended construction of current P2P file sharing community. So, users may want the effective content lookup technique that reflects their interest in detail in the DHC.

Many techniques are proposed to lookup the content that user wants in P2P network environment, but those are not appropriate for DHC[3]. The structured P2P techniques, such as Chord and CAN, that ensure the bounded lookup time have some limitations to support accurate content lookup, since those utilize DHT (distributed hash table)-based scheme requires accurate key value. The unstructured P2P techniques, such as Guntella and Freenet, that can provide detailed content lookup have limitations in supporting content lookup within bounded time, since most of them use flooding scheme for content lookup. In addition to these limitations of existing P2P techniques, there are not many researches for content lookup reflect the user’s interest.

In this paper, we propose a content lookup technique, called IGN (interest-based grouping network), that supports the detailed interest-based content lookup within bounded time in DHC. The IGN utilizes Chord[4] and de Bruijn graph[5] for hierarchical P2P overlay network construction. In the IGN, the many interest groups that are consisting of peers sharing same interest are formed and each interest group includes representative node, or super node(in the IGN, each node is home gateway of home network). The super node of each interest group forms the Chord ring and the Chord supports bounded lookup time, or path lengths are O(log n) hops, among many interest groups. In each interest group, the peers form the de Bruijn graph. In the G(m,n) Bruijn graph, the maximum routing path between any peers is n and the query can be transmitted to another peer unless m paths between two nodes are not failed. To lookup content in the IGN, we use two lookup keywords, (interest-group, keywords in group). The interest-group indicates a certain interest group and the keywords in group indicates metadata[6] style lookup keyword containing detailed user’s interest. For example, the lookup keyword can be (Movie, Action&1980s&..). By using de Bruijn graph, in the interest group, the IGN can support the bounded lookup time and assist the detailed content lookup (it is possible to add metadata-based lookup, since de Bruijn graph does not require accurate key value for query routing). Like this, by utilizing the Chord and de Bruijn graph, the IGN forms hierarchical P2P overlay and tries to support the interest-based content lookup in detail within bounded time. Usually, there exist multiple users or preferences and multiple devices that can store content in the home network and home networks have star topology that is centered on the home gateway. Although many effective content lookup techniques are proposed, most of them do not reflect the characteristic of home network like above. Thus, there can be some problems when those are applied to IGN, like unnecessary traffic in the home network and low scalability. The IGN uses home gateway of each home network and propose the effective way to lookup content for home users in special P2P network that is consisting of home networks.

We conform our proposed IGN framework through simulation by using Overlay weaver[7]. We modify the Overlay weaver to mimic the P2P overlay that is consisting of home networks. As a core of our verification work, by comparing with other approaches, we verify our works and point out the advantages of IGN, those are the detailed interest-based content lookup within bounded time and more suitability to the DHC.

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6391-13, Session 3

Joint source and space time decoding over fading channel

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Introduction

Data compression suffers decompression performance degradation over wireless fading channel. Variable Length Code (VLC) and Reversible Variable Length Code (RVLC), largely used in lossless data compression, are especially sensitive to channel errors. V. B. Balakirsky introduces bit based trellis structure for VLC decoding, which exploits redundancy of VLC and RVLC and increases error resilience. Meanwhile, Space time trellis coding (STTC) is a high bandwidth efficient method and provides reliable communication over fading channel. By coding over both space dimension and time dimension, space time codes achieve maximum space diversity and provide coding gain.

Joint source space time decoding

In this paper a joint decoding of the concatenated scheme of VLC (RVLC) and space time trellis code is proposed to address the issue of data compression and transmission over fading channel. Fig.1 shows the encoder diagram. In this scheme a bit based interleaver is used to improve time diversity while preserving maximum spatial diversity. At the receiver, as is shown in Fig. 2, source and space time code is jointly decoded to improve decompress performance. Soft-in-soft-out MAP algorithm is adopted for both source decoder and space time decoder. The likelihood of each bit can be first extracted from STTC decoder and sent to source decoder as a priori information; in turn the soft output of source decoder is feedback to STTC decoder. By iterative information exchange, the final coding gain increases without bandwidth expansion.

6391-14, Session 3

Server-assisted prefetching for Internet streaming media delivery

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Delivering streaming media content over the Internet is a challenging problem. A client-proxy-server structure is often used in studies in this area. Based on this structure, many mechanisms have been proposed to address the delivery problem such as proxy caching and prefetching. While the existing techniques can improve the performance of accesses to reused media objects, they are not effective in reducing the startup delay for first-time accesses as they only perform prefetching for the currently accessed objects. In this paper, we propose a more aggressive server-assisted prefetching scheme to reduce the startup delay of first-time accesses. In this scheme, proxy servers prefetch media objects before they are requested. In such aggressive "beforehand prefetching", correct prediction of objects that are to be prefetched is a big concern. In our scheme, we make use of server's knowledge about access patterns to ensure the accuracy of prediction. Because user access pattern for streaming media objects usually follows Zipf-like distribution, we have the servers to locate the most popular media objects and provide such information to proxy servers as hints for prefetching. A proxy server makes decision based on the server's hints and its users' profile and prefetches suitable objects before they are accessed. Using this method, even initial requests for those objects will be able to be served without delay. Results of trace-driven simulations show that our proposed scheme can effectively reduce the ratio of delayed requests by up to 38% with very marginal increase in traffic.

6391-15, Session 3

A hybrid admission control algorithm for multimedia server

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The main goal of admission control algorithm (ACA) is to accept enough traffic to efficiently utilize server resources, while not accepting requests whose admission may lead to the violation of the service requirements. In literature, two types of guaranteed services are proposed: deterministic service and statistical service. In deterministic service, performance bounds are guaranteed for all packets on a connection even in the worst case. In statistical service, probabilistic performance bounds are guaranteed. Since human perception is tolerant to brief distortions in audio and video, providing deterministic guarantees to each client is superfluous. Furthermore, the worst-case assumptions that characterize most of these techniques may needlessly constrain the number of clients that are served simultaneously, and hence, may lead to severe under-utilization of server resources. This is because, the average time spent in accessing a media block from disk, in practice, and is significantly smaller than the corresponding worst-case times. Hence, in order to improve the utilization of server resources, a multimedia server must employ an admission control algorithm to satisfy all the goals. In this paper, we are proposing a hybrid admission control algorithm (HACA) that can handle a larger number of clients satisfactorily. One interesting feature of this method is different admission policies for different clients based on their service requirements. The performance of admission control algorithm is dependent on the disk-scheduling algorithm. In this paper we also demonstrate a new disk scheduling technique named near optimal disk scheduling algorithm (NODSA) that derives a sequence of accessing media blocks from disks so as to minimize both seek time and rotational latency. The NODSA as well as the techniques for minimizing overflow of rounds presented in this paper significantly improves the performance of this admission control algorithm. In this paper we mention two terms, safe guard and epsilon, by adjusting their values we can control the overflow of rounds. We have demonstrated the effectiveness of HACA and NODSA through extensive simulation.

6391-16, Session 3

Implementation of a robust transmission system for astronomical images over error-prone link

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The James Webb Space Telescope (JWST) is expected to produce a vast amount of images that are valuable for astronomical research and education. To support research activities related to JWST mission, NASA has provided funds to establish the Structures Pointing and Control Engineering (SPACE) Laboratory at the California State University, Los Angeles (CSULA). One of the research activities in SPACE lab is to design and implement an effective and efficient transmission system to disseminate JWST images across the network.

In on our previous research, a prioritized transmission method was proposed to provide the best quality of the transferred image based on the joint-optimization of content-based retransmission and error concealment. In this paper, the design and implementation of a robust transmission system is presented to utilize our previously proposed methods over error-prone link. The implemented system includes three parts. First, a zero-tree based error-resilient wavelet codec is used to compress the incoming astronomical image at the sender. Tree-based interleave is adopted in packetization to increase the system's capability to combat burst losses in error-prone channel. Second, various error concealment approaches is investigated and implemented at the receiver to improve the quality of reconstructed image. The transmission system uses UDP as transport protocol, but with an error control module to incorporate the optimal retransmission with the delay constraint. User friendly graphic interface is designed to allow easy usage for users with diverse background.

6391-17, Session 3

Design and implementation of dual-stream high-performance transport system for uncompressed HD video streaming over gigabit IP network

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The ongoing trend of next-generation services benefiting from greater available bandwidth including high-definition video (HD) streaming services is the result of recent emergence of high-speed broadband Internet. The uncompressed (commonly referred as HDTV) SMPTE-292M [5] is widely used interconnect for HDTV equipment [7]. Media stream of 1080i interlaced, 30 fps, 1920x1080 and 20 bits/sample is 1.485 Gbps and thus there are a number of challenges to supporting full-rate in real-time uncompressed HD Video, primarily due to limitations of the end system and Gigabit Ethernet incompatibilities to provide sufficient bandwidth of about 1.5Gbps to transport video data at full frame rate.

The most relevant related works include high-speed transport protocol, Ultragrid [1] and NTT Japan i-Visto[6]. Regarding high-speed transport issue, recently, several high-speed TCP protocols have been developed [5]. In fact, for the reliable high-speed UDP transport, there are SABUL, UDT[8], Tsunami, and RBUDP. However, the main focus of these high-speed UDP transports is on the reliability, which cannot be met when we require real-time support at the same time. Thus, it is required to add the support of the real-time high-speed transport that is suitable for video over IP networks [3]. In comparison to these existing systems, the proposed dual-stream transport system is attempting to build cost-effective and to achieve full-rate uncompressed HD video system. Our dual-stream transport is designed with off-the-shelf network components where video stream is muxed across two gigabit NIC ports in order to aggregate their bandwidth. In addition, we propose real-time operating system (RTOS) abstraction layer to be added to minimize the size of receive buffer needed to absorb jitter and to improve performance in achieving full-rate delivery by minimizing the loss and balancing competition by fair allocation of system resources for video data stream over two dedicated NIC ports.

The dual-stream transport idea is to manipulate the framewise partitioning so as to send packets across two different interfaces in order to aggregate their bandwidth. This approach has advantages like to application and higher layers, the video stream looks like a single flow [9]. Therefore all existing streaming applications can benefit transparently, without being rewritten to explicitly do stream-splitting

themselves. It can be highly dynamic as if the route through an interface becomes congested packets can simply be copied through an alternate interface which adds enhanced reliability. Likewise, RTOS support is provided to optimize parameters along with reliability, such as power consumption, latency, jitter and fair sharing of resources.

This paper presents the design and implementation of uncompressed HD video dual-stream transport system over Gigabit IP network targeting the ultimate goal of establishing a new HD video delivery framework which can handle acquisition, processing, delivery and rendering of uncompressed HD video at full-rate. Furthermore, these processes must be completed within the set times, since the receiver terminal must obtain the video data in real-time. Finally, it is also very important to leverage the flexibility and cost-effectiveness of software-based real-time realization. To this end we have designed and implemented dual-stream transport with off-the-shelf network components where video stream is muxed across two gigabit NIC ports in order to aggregate their bandwidth. Although the idea of dual stream on two NIC ports is straightforward but there are a number of challenges primarily in supporting full-rate delivery. Our system is designed in a way that after receiving frames, framewise partitioning is performed by splitting alternative frames, (even and odd) and muxing them across two dedicated NIC ports at the sender and merging them in a similar fashion at the receiver to display in real-time at full-frame rate. For the design of required transport, we focus on achieving over full-rate real-time delivery with off-the-shelf network components. We used RTP to provide the end-to-end delivery service with real-time characteristics [2]. RTP and its companion control protocol (i.e., RTCP: RTP control protocol) include payload type identification, sequence numbering, time-stamping, and delivery monitoring. In addition for real-time processing it is important to send video data at a specified rate. Implementing the sending and receiving process to split and merge video data at the specified rate is important, we proposed and developing RTOS abstraction layer support. Furthermore this layer is expected to minimize the size of receive buffer needed to absorb jitter and fair system resource allocations.

In this paper discuss design and implementation of dual-stream transport system for real-time uncompressed HD video delivery over Gigabit IP Network. Our dual-stream transport's preliminary results show the video data delivery in case of stored media 1920x1080 and 20 bits/sample streaming at 25~27fps at 980Mbps which is uniformly balanced across two NIC ports. An enhanced version is under development, which we expect to support the full 30 frames per second. In this paper we propose abstraction layer development and plugging of dual-stream transport into live stream are underway. We shall perform local area as well as wide area test to verify the tractability of our implemented design.

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6391-18, Session 4

Multiframe mesh editing using differential coordinate features

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With the wide use of 3-D mesh sequences, there have been many attempts to edit, deform, and interpolate 3-D mesh frames. In the sequence editing, the correspondence matching between consecutive frames is often the preliminary step for later processing phases. However, the correspondence matching is an ill-posed problem, and the result of mesh editing often causes unexpected artifacts.

In this paper, we propose a reliable mesh editing algorithm using differential coordinate features. The proposed algorithm minimizes the intra and inter frame deformation energies in the editing procedure. First, the deformation energy of intra frame is determined based on the differential coordinate features from one frame. Note that, for each vertex, the differential coordinate is defined as the average coordinate deviation of the vertex from the neighboring vertices. Second, the deformation energy of inter frame represents the temporal deformation and is defined as the Euclidian distance between the corresponding vertices in consecutive frames. We also set the region of interest (ROI) using the variation of differential coordinate features between consecutive frames. By processing only ROI, we can reduce the computational complexity dramatically. Extensive simulation results demonstrate that the proposed algorithm yields visually pleasing editing results.

6391-19, Session 4

Approaches to consumer image organization based on semantic categories

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The proliferation of digital cameras and scanners has resulted in personal image databases that are large enough to require automated tools for efficient browsing and image retrieval. Current systems attempt to simulate intelligent image organization by automatically generating clusters of images using low-level image features [1]. However, these low-level image clusters do not match well with an image organization structure based on the user's semantic model of their image collection. Our research effort is in the spirit of closing the "semantic gap" through using subjectively derived categories to cluster images, allowing the user to correct and label these clusters through a graphical user interface. The goal of the current research was threefold: (1) to develop image clustering algorithms that are more consistent with users' search goals for their personal image collections; (2) to provide users with the option of correcting and labeling these image clusters; and (3) to understand user behaviors and needs while they are using an automated image organization system. A user-needs study confirmed that two of the most important semantic classes in the consumer domain are events and people. This result provided an initial schema to develop an organization system for images. Automatic event clustering [2] is based on temporal two-means clustering and block-based histogram correlation, which use date-time information from the camera metadata and color similarity between images. The event-clustering algorithm automatically sorts and clusters images from an unorganized set into separate events and subevents. Images in an event are associated with the same setting or activity, while images in a subevent have similar image content within an event. Faces are detected by using a combination of fast, cascaded classifiers, and a verification step. Face recognition is based on anthropometric measurements derived from facial feature points, which are computed using an active-shape model with face detection results as a starting point. Faces are clustered by similarity [3] between facial measurements using a hierarchical clustering strategy developed for use in the consumer image domain. Metadata generated by these automatic algorithms are stored, along with the image capture metadata, in a relational database as part of a flexible architecture that allows for the addition of more automatic algorithms in the future. The database allows for flexible search options that the users can tailor to their search goals.

To establish both usability and systems performance requirements for the event- and face-clustering algorithms, a pilot usability study was

conducted using a prototype user interface designed to test satisfaction with the results of the respective clustering algorithms as applied to the consumers' own images. For the systems usability study, digital camera users provided images from their personal collections. A semi-random sample of a limited number of images per user was clustered with face- and event-clustering algorithms. The number of images used in the study was restricted because of the length of time that we could reasonably require from a study participant. The face detector found 70% of the frontal and near-frontal faces in the test set, out of which the facial-clustering algorithm cluster 72% of the faces correctly. The guided discovery method and rating scales were used to gather subjective feedback, with respect to algorithm performance and usability, and to establish ground truth and compute performance metrics. The users' subjective evaluations and ground truth data were compared to objective algorithm performance to identify areas for improvement. When specifically asked about the utility of semi-automatic algorithms for image organization, users expressed a great deal of enthusiasm about the timesaving nature of such a software tool. The study results indicate that some improvements in the event- and face-clustering algorithm performance would more effectively assist the users in finding their images. The face detection algorithm could also be improved to avoid detecting "non-faces" as faces. Users were pleased with the event-clustering algorithm's performance at the event level. For events, some semantic knowledge of the type of event could improve the perceived correctness of automatically generated categories. Since the utility of image organization and retrieval algorithms will be more fully realized when users' image collections reach larger sizes, we conducted a follow-up study to further refine the event-clustering algorithm parameters with additional study participants and using larger image sets. In the follow-up study, ground truth for events and subevents was collected for a sample of 1000 images that were provided by each of 15 digital camera users. Users completed a number of tasks, including rating the acceptability of default-algorithm event clusters; making corrections to event boundaries and rating the acceptability of corrected event clusters; and splitting events into subevents and rating the acceptability of corrected event clusters with subevents. Subject evaluations indicated that algorithmically generated event clusters were acceptable because mean acceptability ratings were in the mid to upper end of the scale. In addition, the algorithm recall was 0.90 and precision was 0.70 relative to user ground truth. Experimental observations indicate that at the current operating point, the majority of users removed event boundaries to merge clusters. Overall, they split very few events. Given this result, the ground truth data were used to tune the final algorithm with the ultimate goal of producing the same event boundaries as ground truth. After tuning, the overall performance of the algorithm was improved. An analysis of the post-tuned algorithm indicates that it performs much better for precision (pre-tuned = 0.70, post-tuned = 0.84) by only slightly degrading recall (pre-tuned = 0.90, post-tuned = 0.83). Therefore, the post-tuned algorithm has better performance for matching events to the ground truth, but slightly poorer performance for the need to split events. In addition, the performance of the algorithm can be improved through introducing a variable adjustment controlled by the user to suit their image collection idiosyncrasies. As precision and recall must be balanced in algorithm tuning, we must also balance algorithm performance with the user interface workflow. In this case, the task of merging events appears to be more straightforward than splitting events. Thoughtful integration of algorithms within a user interface is paramount to user acceptance and a successful user experience. Future testing will be concerned with a larger number of users and visualizations of other types of semantically relevant algorithms through more advanced user interface designs.

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6391-20, Session 4

Turbo codes based image transmission for channels with both random errors and packet loss

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Research in image communications over noisy channel has shifted to the consideration of state-of-the-art source codes such as the set partition in hierarchical trees (SPIHT) and JPEG2000 to preserve the source coding efficiency. Consequently, one major concern is how to design a channel coding scheme so that unequal error protection and then the optimization bandwidth allocation can be obtained with the best possible end-to-end performance. When channels with both random error and packet loss are considered, the product codes, often consisting of convolutional codes in one direction and the Reed-Solomon (RS) codes in the other, are popularly adopted. Recently, product codes composed of Turbo codes and RS codes are studied as well, where the optimization is along the RS direction while the random errors are assumed to be completely corrected by the turbo codes.

In this paper, we study the image transmission with turbo codes only, but an interleaver is applied before the transmission. Therefore, the packet loss is equivalent to random bit erasures throughout the frame. This process can be further regarded as a randomly punctured turbo code with reduced rate (the punctured positions are exactly determined by the interleaver and lost packet numbers, but still different from the conventionally regular puncturing). More packet loss results in higher code rate. As a result, when both packet loss and random errors occur, the channel coding design is considered as the design of optimal punctured turbo codes for given bit error rate. The advantages of this include the convenient optimization design for parameters of both packet loss and random error, and the reduced redundancy compared to the products codes.

6391-21, Session 5

Empowering file-based radio production through media asset management systems

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In recent years, IT-based production and archiving of media has matured to a level which enables broadcasters to switch over from tape-based to file-based workflows for the production of their radio- and television programs. This technology is essential for the future of broadcasters as it provides the flexibility and speed of execution the customer demands by enabling, among others, concurrent access and production, faster than real-time ingest, centrally managed annotation and quality preservation of media. In terms of automation of program production, the radio department (encompassing 6 radio stations) is the most advanced within the VRT, the Flemish broadcaster. Since a couple of years, the radio department is working with digital equipment and producing its programs mainly on standard IT equipment. Historically, the shift from analogue to digital based production has been a step by step process initiated and coordinated by each radio station separately, resulting in a multitude of tools, some of them developed in house, lacking integration. To make matters worse, each of those stations adopted a slightly different production methodology. The planned introduction of a company wide Media Asset Management System allows a coordinated overhaul to a unified production architecture. Benefits include the centralised ingest and annotation of audio material and the uniform, integrated (in terms of IT infrastructure) workflow model.

Needless to say, the ingest strategy, metadata management and integration with radio production systems play a major role in the level of success of any improvement effort. This paper presents a data model for audio-specific concepts relevant to radio-production. It includes an investigation of ingest techniques and strategies. Cooperation with external, professional production tools is demonstrated through a use-case scenario: the integration of an existing, multi-track editing tool into a commercially available Media Asset Management System. This will enable an uncomplicated production chain, with a recognisable look and feel for all system-users, regardless of their affiliated radio station, allowing retrieval and storage of information and metadata centrally.

6391-23, Session 5

Transition logo detection in sports videos for highlight extraction

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There have been active research activities on extracting highlights from sports videos. In this research, we investigate the issues of the transition logo detection for automatic highlight extraction. Transition logos are usually inserted into the sports videos broadcasting to inform the viewers of the slow-motion replays. Their accurate detection will be helpful to determining the appearance of slow-motion video segments, which may further contribute to a more precise highlight extraction. Video features are extracted from the MPEG-2 bit-streams for subsequent processing. The motion and color characteristics of transition logos are utilized to indicate their existence. Experimental results show the feasibility of the proposed scheme.

6391-24, Session 5

Robust anchorperson detection for TV news segmentation via visual features

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People now live in busy days;therefore, to spend time watching TV news every day is not that easy. Moreover, huge amount of TV news are happening at days, such as social, entertainment, politics, sports news, and etc. It is important to develop automatic techniques for efficiently index, browsing and searching TV news that happens in one day. As we know TV news is composed of several stories which are introduced by anchorperson and each story is organized of anchorperson and report's shot shown in Fig. 1. TV news segmentation is essential to detect the story boundary accordingly as a preprocessing step for further proposes.

In order to divide TV news into story units, the boundary between story units should be detected accurately. In this work, we designed a scheme for TV news segmentation via video content analysis techniques and explored the efficient visual features.

6391-25, Session 6

Collaborative virtual experience based on reconfigurable simulation

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In educational science, there is a concept called constructivism, which means that a human being responds to many things existing in his/her environment, and using them to construct and to organize his own knowledge. Therefore, resulting knowledge creation is unique to the individual. This principle indicates that a student can gain more knowledge through the experience of building the knowledge itself, compared to receiving instructions from teacher. By this principle, a student who participates in planning and design phase can experience simulation based on what he/she has designed or configured, not just experiencing simulations with a pre-designed set of parameters. This is why a reconfigurable simulation is needed for educational purpose.

Even though VR technology does not provide significant difference in promoting student's understanding of a science lesson, it definitely promotes motivations for students in learning such science. VR has brought dynamic and interesting visualization so that users feel easy to understand what is going on in the simulation. Meanwhile, there are still more aspects to be investigated in creating a useful VE, such as the use of color, texture, and sound in the scene designs, the use of suitable haptic devices, and the target age group of the users.

According to a previous research, the best age group to use VR-based simulation for science learning is middle school students (around 13 years old). Therefore, science on that level needs to get more attention to be realized into VR systems. The Domino Simulation is a good example of simple science for young teenagers. This simulation focuses on physics learning especially Newton's law of dynamics (force-related). In this paper, we will explain what can be experienced by users of Domino Simulation. Moreover, the simulation is reconfigurable by users, so that they can experience different simulation environment due to different configurations they make.

We have implemented an application for simulation-based virtual experience, based on VR systems and simulation of physics law. The system allows reconfiguration of the simulation elements so that users can see the effects of the different configurations. The network support enables users to work together when interacting with the simulation, and see each other's simulation results.

6391-26, Session 6

Integrating multiple HD video services over tiled display for advanced multi-party collaboration

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Recently multi-party collaborative environments are widely used to large-scale distributed meetings, remote cooperative works, and distance lectures. Especially high-quality video service has been highlighted to improve quality of experience (QoE) in multi-party collaborative environments. For example, Microsoft ConferenceXP supports 640x480-sized video transmission from multi-points, and McGill University's Ultra-Videoconferencing system supports uncompressed HD (high-definition) video. These systems demand high-end facilities for computing and networking. But it is difficult to use these systems for other cases, e.g. low-end collaboration system. In addition, they cannot display multiple high-resolution video streams simultaneously due to restricted size of display. Therefore providing multiple HD video services is a challenge since all participants want to select video services considering network/system performance and to watch high-quality videos on high-resolution display.

To address the challenge, the first issue is to find out a compromise when users' QoS requirements for video services do not correspond to network/system performance of collaborative environments. For this, it is necessary to define 1) service capability such as format, quality, and QoS control methods, 2) node capability such as available bandwidth, multicast, and CPU performance, and 3) user preferences such as preferred quality and size. To find out a compromise over diveristy of the capabilities, capability negotiation method should be suggested to find out service capability to maximize users' satisfaction under the restriction of node capability. The second issue is to show multiple video simultaneously on high-resolution display. The high-resolution display should handle session announcement methods to receive multiple video streams selectively from all participants. High-resolution display should also have high-performance computational resources since decoding and displaying multiple high-quality videos is resource-consuming job. By this reason, scalable display structure is necessary to build relatively low-cost display with preferred high-resolution.

In this paper, we present a practical system for integrating capability negotiation methods and high-resolution tiled display system over multi-party collaborative environments. First, we present capability negotiation methods to find out and tune the service capability to provide acceptable video services for all participants. For this, user selects media service with preferred capability considering user preferences. After checking whether the service provider has enough resources to provide the service, the service provider announces the service capability to other participants. If there are existing nodes matching their node capability for the service capability, they can receive the service; otherwise, they can ask service capability modification, for the service provider. Consequently the service provider determines acceptable service capability for all participants. Secondly, we describe a high-resolution tiled display, consisting of arrays of LCD monitors to form a 4 by 2 display with 6400 * 2400 resolution, that is designed to support multiple simultaneously high-quality video streams from local and remote sites. The tiled display has decomposable decoding and display structure based on high-performance network to handle multiple high-resolution videos effectively. To receive and display the video streams, we propose a series of methods to listen session information, choose video streams, assign decoding jobs, and display decoded videos over the tiled display.

The proposed system is realized by combining the tiled display system and the multi-party collaborative environments. For its evaluation, the implementation results are placed on multiple sites over 1Gbps research development network, and each site transports SD/HD digital videos and shows them on the tiled display. The demonstration results show that the proposed system can improve QoE over multi-party collaborative environments.

6391-27, Session 7

A model for the distribution of watermarked digital contents on mobile networks

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The rapid development of multimedia and networking technologies has transformed the Internet into the main distribution channel of digital contents for electronic commerce. Furthermore, the development of mobile devices has promoted the diffusion of multimedia applications on mobile communication networks. However, the major obstacle to the business tied to the web distribution of digital media is the possibility of unlimited unauthorized copying in the digital domain, which threatens intellectual property rights. As a consequence, in absence of proper Digital Rights Management Systems (DRMSs), there exists an actual risk that content owners and producers lose the revenues they can receive from the web distribution of their digital contents. Digital watermarking can be considered a key technology for the copyright protection of digital contents. However, many DRMSs exploiting watermarking technologies adopt content distribution models purposely designed for fixed networks, which cannot be adapted to mobile networks. Therefore, mobile DRMSs (MDRMSs) based on watermarking technologies represent a challenge to provide a secure environment to distribute protected digital contents on mobile network systems without violating the legal rights of the content owners. This paper presents a model for the distribution of watermarked digital contents for MDRMSs able to achieve a trade-off between the needs of efficiency and security.

6391-28, Session 7

Robust watermarking for authentication of 3D QSplat models

S. Park, Y. Lee, Seoul National Univ. (South Korea); C. Kim, Korea Univ. (South Korea); S. Lee, Seoul National Univ. (South Korea)

In this paper, we propose a new scheme for digital watermarking of three-dimensional (3-D) point data in QSplat data structure. The proposed watermarking algorithm can support the authentication, the proof of ownership, and the copy control of 3-D data. QSplat is widely used to represent 3D models for fast rendering of huge models. In QSplat, a cloud of points are hierarchically organized into a tree using bounding spheres. Each tree node contains the center and radius of the sphere, the color, the normal, and the width of a normal cone. In the embedder, we use the quantization index modulation on position data. Specifically, one of the two quantization indices is assigned to each position according to the watermark. To make the watermark imperceptible and robust, the watermark is embedded into proper leaf nodes only. Since the proposed algorithm changes the point geometry with the negligible amount of degradation, it can be applied to unstructured point clouds as well as QSplat data. We analyze the perceptual disturbance induced by the watermark. For the purpose of safety, our algorithm adopts a pseudo-random number sequence (PRNS) generated from a known stego-key. In the detector, we can detect the watermark without using the original model. Experimental results show that our watermarking scheme is robust against numerous attacks, including additive random noise, shifting, rotation, cropping, and their combinations.

6391-29, Poster Session

A comparison of HMM and global rule induction techniques on story boundary extraction in news video

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Machine learning approach has been successfully utilized in several research works. In this paper, we propose two effective machine-learning techniques: Hidden Markov Models (HMM); and global rule induction, on segmenting stories in news video. In our framework, we employ audio-visual and text features to represent each input shot. We adopt a hybrid approach to categorize each of the input shots into one of the meaningful classes. And we employ HMM or rule induction technique to perform story segmentation based on the shot category information and other temporal features. We tested our framework on ~120-hours of news video provided by TRECVID. The results show that we could achieve accuracies in F1-value for the HMM of over 77% and global rule induction of over 75%. It is, thus, demonstrated that our machine-learning framework is effective and is adequate to cope with large scale practical problems.

6391-30, Poster Session

360-degree viewing display for collaborative tasks on the round table

K. Sakamoto, T. Nishida, Shimane Univ. (Japan)

This paper describes 360 degree viewing display system that can be viewed from any direction (ie, the display has a 360-degree viewing angle). The authors have ever researched 3D display systems using the polarized glasses and liquid crystal shutter glasses, image splitter such as the parallax barrier or lenticular screen and holographic optical elements. These image splitting technologies for displaying stereoscopic 3D image are available for developing the tabletop display that can provide different images to different users surrounding the system. Hence we developed tabletop display system for collaborative tasks cooperated by two users.

Conventional monitor display is viewed from one direction, that is, the display has narrow viewing angle and observers can not view the screen from the opposite side. We developed the dual views display system utilizing the image splitting technologies for displaying stereoscopic 3D image. This tabletop display can provide different images to two users surrounding the system. However screens on the monitor can not be viewed by all users that cooperate in doing collaborative tasks on the round table.

In this paper, we describe the 360 degree viewing display for collaborative tasks on the round table. This newly developed 360 degree viewing system have a liquid crystal display screen and 360 degree rotating table by motor. The principle is very simple. The screen of monitor rotates at a uniform speed. Then the observer can view the monitor screen at any position surrounding the round table. But the solid of revolution is formed when the image screen is rotated. Hence the angle of view is controlled by the slit or the optical element in order that the screen faces an observer and he can view only 2D image on screen without 3D solid image.

Prototype display has commercial 5.4 inch LCD display. The 360 degree turn table is made using an electric drill. The drill is operated at 700 rpm. The result of test running is very good. The rotating LCD panel enables to be viewed from any direction. It is possible to use this display system for doing collaborative tasks on the round table.

6391-31, Poster Session

Robust compression of 3D point clouds using multiple description coding

S. Park, Seoul National Univ. (South Korea); C. Kim, Korea Univ. (South Korea); S. Lee, Seoul National Univ. (South Korea)

Compressed 3-D point cloud data are very sensitive to channel errors, and the visual quality of the reconstructed point data can be severely degraded due to the error propagation problem. However, little effort has been made for robust transmission of compressed point data.

In this work, we propose a robust transmission system for point cloud data based on the multiple description coding (MDC). First, 3-D points are ordered by their geometry innovation values for progressive reconstruction, where the innovation values are computed based on Fleishman et al.'s progressive point set surface algorithm. Then, the reordered points are partitioned into two sub sets using the even/odd index sampling. Each subset is respectively encoded by the progressive point set surface algorithm. Finally, the two compressed bitstreams are transmitted over distinct channels to the decoder. At the decoder side, the two bitstreams are independently decoded and merged together to make the final 3-D reconstruction model. If both channels are available, the decoder reconstructs a high resolution data. On the other hand, if only one of the channels is available, a lower quality point data is obtained with acceptable visual performance. Thus, the proposed algorithm can provide an acceptable quality reconstruction even though one channel is totally lost. Simulation results on various point data demonstrate that the proposed algorithm is a promising scheme for 3-D data transmission over noisy channels.

6391-32, Poster Session

Using edge histogram descriptor of MPEG-7 for the measurement of image quality and modifications

C. S. Won, Dongguk Univ. (South Korea)

A novel image quality assessment using the edge histogram descriptor (EHD) of the MPEG-7 is presented. No additional data and no fragile watermark are needed for the quality assessment and the image content authentication. The PSNR (Peak to Signal-to-Noise Ratio) or the mean-square error (MSE) obtained by the extracted EHD from the received image and the original meta-data of the EHD is used to detect the level of the image degradation and any illicit modification of the image.

6391-33, Poster Session

Information searching protocol: a smart protocol for specific content search over Internet

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Information is very important to Internet users in many aspects. However, searching for a specific information from Internet is not easy as wishes. Although there are many search engines available to support the content search, the search mechanisms cannot be performed using a path name of URL as a search key. Thus, users who have a partial path name of URL cannot use their knowledge to narrow down the search results from the search engine. Therefore, it is the time consuming to find the required web site from a long list of search result while users' knowledge cannot fully be applied. This paper proposes a search protocol named Information Searching Protocol (ISP) that supports the multiple search contents for users who know a partial path name of URL and some part of required contents. The ability of this protocol allows users to enter a partial URL path name including with keywords in order to gain access to the required web site. The result of implementing this protocol shows that the search results are narrow down to specific web sites that are closed to, or matched to the need of users.

6391-34, Poster Session

Extended multicast connectivity solution for collaborative environments

N. Kim, H. Lee, J. Kim, Gwangju Institute of Science and Technology (South Korea)

The Access Grid (AG) [1] provides collaboration environments over the IP multicast networks. IP multicast enables efficient exchange of multimedia contents among a number of users. However, since lots of current networks are still multicast-disabled, it is not easy to deploy multicast-based AG. In response to the slow deployment of IP multicast, a number of application-layer multicast architectures have been developed. These architectures can be sorted into two categories: peer-to-peer architectures and proxy based architectures [5]. In peer-to-peer architectures, group members are organized to replicate and forward packets to each other, without any reliance on router. In proxy based architectures, dedicated servers need to be placed over the Internet by a service provider. These servers receive packets from the data source and forward them to individual receivers via unicast delivery. AG community provides a proxy based solution, QuickBridge. However, QuickBridge has several limitations. First, since it requires many open ports, QuickBridge is not applicable to users under Network Address Translator (NAT)/Firewall-based private networks. Second, like other proxy based architectures, the QuickBridge server can be the performance bottleneck.

In our previous work [6], we proposed an alternate multicast connectivity solution for AG based on the UMTP (UDP Multicast Tunneling Protocol) [4], AG Connector. AG Connector works by creating a UDP tunnel between UMTP Server and UMTP Agent. UMTP Server is one tunnel endpoint already in multicast network and UMTP Agent is the other trying to access multicast network. By taking advantage of flexibilities of UMTP, AG Connector improves the efficiency of network and system utilization and allows reuse of multicast-based AG applications without modification. However, since UMTP Server does not provide an admission control algorithm for connection request from UMTP Agent, a UMTP Server possibly have more UMTP Agents than it can support. This can cause UMTP Server failure. In addition to this, our previous work did not fully address the NAT/firewall traversal issues.

In this paper, we extend our previous work and propose an extended multicast connectivity solution for the AG which can support more users including users under NAT/Firewall-based private networks. NATs and firewalls impose restrictions on pair-wise connectivity of hosts in the Internet. NATs only allow inbound traffics coming as a response for the request from internal host and firewalls filters packets based on filtering rules. Therefore, easy traffic control is the key for traversing NAT/firewalls. Our solution accomplishes this by exchanging packet through the tunnel with encapsulation. Our solution works as one of proxy based architecture. A number of UMTP Agents for a UMTP Server can cause server failure and this single point of failure makes all UMTP Agents connected to the UMTP Server multicast unreachable. The UMTP, however, does not address the way to balance server load. To solve this scalability problem, we add features of peer-to-peer architecture to the AG Connector. We construct an overlay path among UMTP Agents and distribute the load of server on data delivery by putting data replication role to several designated UMTP Agents. We present some statistics collected during the live conferences using AG and compare the result with other multicast connectivity solutions.

6391-35, Poster Session

Virtual revolving lantern: kaleidoscopic floating images by interactive tabletop hologram

Y. Iwaze, K. Sakamoto, Shimane Univ. (Japan)

We developed prototype tabletop holographic display system. This system consists of the object recognition system and the spatial imaging system. In this paper, we describe the recognition system using a RFID tag and 3D display system using a holographic technology.

A 3D display system is useful technology for virtual reality, mixed reality and augmented reality. We have researched spatial imaging and interaction system. We have ever proposed 3D displays using the slit as a parallax barrier, the lenticular screen and the holographic optical elements(HOEs) for displaying active image. The purpose of this paper is to propose the interactive system using these 3D imaging technologies. In this paper, the authors describe the interactive tabletop floating image display system. The observer can view virtual images when the user puts the special object on the display table. The key technologies of this system are the object recognition system and the spatial imaging display.

The goal of our research is to build the display system as follows; when kids put objects on the table, the display system gives users virtual 3D images, which is floating in the air, and the observers can touch these floating images and interact them such that kids can make play clay. The hologram reconstructs some virtual images when the hologram is reconstructed using some colors of illumination light. This system interacts; these virtual images are selectively displayed according to circumstances and the users and floating images take mutual action when the user touches the virtual image. Thus this system displays some virtual image as the user puts an object on the table. The object recognition system using RFID technologies recognizes the kind of objects and attributions by its unique IDs. The spatial imaging system provides floating virtual images to the users. According to the ID tags, illuminated hologram is selected or changed, then the "virtual revolving lantern" holographic display interactively reconstructs another image.

6391-36, Poster Session

Integrating multiview transmission system into MPEG-21 stereoscopic and multiview DIA (digital item adaptation)

S. Lee, I. Park, Yonsei Univ. (South Korea); M. Kim, Kangwon National Univ. (South Korea); H. Byun, Yonsei Univ. (South Korea)

As digital broadcasting technologies have been rapidly progressed, users' expectations for realistic and interactive broadcasting services have also been increased. As one of such services, 3D multi-view broadcasting has received much attention recently. In general, all the view sequences acquired at the server are transmitted to the client.

Then, the user can select a part of views or all the views according to display capabilities. However, this kind of system requires high processing power of the server as well as the client, thus posing a difficulty in practical applications. To overcome this problem, a relatively simple method is to transmit only two view-sequences requested by the client in order to deliver a stereoscopic video. In this system, effective communication between the server and the client is one of important aspects.

In this paper, we propose an efficient multi-view system that transmits two view-sequences according to user's request. The view selection process is integrated into MPEG-21 DIA (Digital Item Adaptation) so that our system is compatible to MPEG-21 multimedia framework. DIA is generally composed of resource adaptation and descriptor adaptation. It is one of merits that SVA (stereoscopic video adaptation) descriptors defined in DIA standard are used to deliver users' preferences and device capabilities. Furthermore, multi-view descriptors related to multi-view camera and systems are newly introduced. The syntax of the descriptions and their elements is represented in XML (eXtensible Markup Language) schema. If the client requests an adapted descriptor (e.g., view numbers) to the server, then the server sends its associated view sequences. Finally, we present a method which can reduce user's visual discomfort that might occur while viewing stereoscopic video. This phenomenon happens when view changes as well as when a stereoscopic image produces excessive disparity caused by a large baseline between two cameras. To solve for the former, IVR (intermediate view reconstruction) is employed for smooth transition between two stereoscopic view sequences. As well, a disparity adjustment scheme is used for the latter.

6391-37, Poster Session

On the design and implementation of an automated astronomical image analyzer

J. Dong, H. Boussalis, C. Liu, L. Zhao, S. Orellana, G. Sharaf, California State Univ./Los Angeles

Astronomical image analysis plays an important role in many research activities including the search of origins and planet formation. Currently the software tools used in this type of research, such as IRAF and Skyview, are extremely powerful but require the users to receive intensive training before usage. In addition, a large amount of human supervision is needed to extract useful data from the images due to the lack of automated analysis ability. Sponsored by the National Aeronautical Space Association (NASA), the Synergetic Education and Research in Enabling NASA-centered Academic Development of Engineers and Space Scientists (SERENADES) Laboratory was established at CSULA. An important on-going research activity in this lab is to develop an easy-to-use image analysis software with the capability of automated object detection to facilitate astronomical research and education.

This paper presents the design and the implementation of an automated astronomical image analyzer. The design objective is to provide a convenient tool for astronomers and general users to extract useful data regarding objects of interest in images. This software adopted our previously proposed object detection algorithm to perform foreground segmentation, object extraction and labeling. The object detection results are further refined using the intensity model of astronomical entities. To better serve the needs of astronomical research, advanced features such as batch processing and automated object matching are enabled in our developed software. With batch processing capability, objects in multiple images of different wavelengths (visible, infrared, near-infrared) can be detected simultaneously. Automated object matching allows users to link the same object detected in different images with different wavelength, and compare their parameters.

One major concern in the design of scientific application is user friendliness. In our design, high degree of human-computer interaction is achieved by incorporating animation technologies. Thus, the user can conveniently navigate the images with zooming and panning functionalities. In addition, the user can select object of interest in the image to obtain its parameters such as universal coordinates. Feedback from users with diverse backgrounds demonstrated that the software satisfies the needs of different users very well.

6391-40, Poster Session

Tree-based server-middleman-client architecture: improving scalability and reliability for voting-based network games in ad hoc wireless networks

H. Fujinoki, Southern Illinois Univ.

In this project, a new efficient architecture, Tree-Based Server-Middleman-Client (TB-SMC) architecture, is proposed to improve network traffic scalability from the perspective of minimizing energy consumption at each wireless transceiver at the same time to improve reliability in multi-player games in ad-hoc wireless networks. The TB-SMC architecture solves the two major problems in ad-hoc wireless networks, frequent link failures and significance in energy consumption at wireless transceivers by using two new techniques, tree-based routing architecture and subscription-based propagation of game state.

Performance of the TB-SMC architecture was compared with the client-server and the peer-to-peer architectures using discrete event-driven simulation experiments. We implemented networked multi-player tic-tac-toe using JAVA to compare the performance of the two architectures. In the scalability experiments, as the number of end players increased from 10 to 200 in a network with 400 nodes, the TB-SMC architecture was observed to reduce the network traffic load to approximately 1/14 of the client-server architecture. In the reliability experiments, the TB-SMC architecture improved the number of successfully delivered players' votes by 31.6, 19.0, and 12.4% from the client-server architecture at high (link failure of 90% for each link), moderate (50%) and the low (10%) link failure probability, respectively. These results demonstrated the advantage in the TB-SMC architecture in error-prone ad-hoc wireless networks. Not only for network games, the TB-SMC architecture will improve usability in critical applications, such as communications among solders deployed in an enemy nation.

Tuesday-Wednesday 3-4 October 2006

Part of Proceedings of SPIE Vol. 6392 Three-Dimensional TV, Video, and Display V

6392-01, Session 1

An optical viewer based on integral imaging for three-dimensional images

F. Okano, J. Arai, M. Okui, NHK Science & Technical Research Labs. (Japan)

Integral photography (IP) is well known technique to form 3D images. The method uses a single lens array during both pickup and display. To produce an IP image composed of many elemental images, a lens array is positioned immediately in front of photographic film. Numerous small elemental images are focused on the film, with their number corresponding to that of the micro-lenses. The film is then developed to obtain a transparent photograph. For reproduction, this transparent photograph is placed where the film had been and is irradiated from behind by diffused light. The light beams passing through the photograph retrace the original routes and then converge at the point where the object photographed had been, forming autostereoscopic 3D images. If the input lens array and output lens array are connected with a diffuser which is put instead of the film and transparent photograph, this device acts as an optical viewer to observe 3D object. The two lens arrays are both composed of many gradient index lenses (GRIN lenses). The length of elemental GRIN lenses that compose the input array is 3/4 of the one cycle of the meandering optical path, and the length of elemental GRIN lenses composing the output array is 1/4 of the one cycle. In this paper, we obtain resolution characteristics of the viewer, and we show the characteristics are dependent on the diameter of the elemental lens.

6392-02, Session 1

3D imaging, visualization, and recognition of biological microorganisms

B. Javidi, Univ. of Connecticut

We present optical imaging techniques for real time automated three-dimensional (3D) visualization and identification of biological microorganisms. 3D sensing and reconstruction is performed by single-exposure on-line (SEOL) digital holography. A coherent 3D microscope-based Mach-Zehnder interferometer records Fresnel digital holograms of microorganisms. Complex amplitude holographic images are computationally reconstructed at different depths by an inverse Fresnel transformation. For pattern recognition/identification, two approaches are addressed. One is 3D morphology-based recognition and the other is shape-tolerant 3D recognition. In the first approach, a series of image recognition techniques are used to analyze 3D geometrical shapes of microorganism which is composed of magnitude and phase distributions. Segmentation, feature extraction, graph matching, feature selection, training and decision rules are presented. For the second approach, a number of sampling segments are arbitrarily extracted from the reconstructed 3D biological microorganism. These samples are processed using a number of cost functions and statistical inference theory for the equality of means and equality of variances between the sampling segments. Experimental results with sphacelaria alga, tribonema aequale alga, and polysiphonia alga are presented.

6392-04, Session 1

Orthoscopic long focal depth integral imaging amplitude modulation and pixel processing

B. Javidi, Univ. of Connecticut; R. Martínez-Cuenca, G. Saavedra, Univ. de Valencia (Spain); M. Martínez-Corral, Univ. de València (Spain)

Integral imaging (InI) is a 3D imaging technique that works with incoherent light and provides with auto-stereoscopic images without the help of special glasses. InI is based on integral photography which was proposed by Lipmann in 1908. In the past few years the technology has approached the level required to apply the IP concept to 3D TV and display. In the capture stage of an InI system an array of microlenses generates a collection of plane micro-images onto a CCD. In the reconstruction stage the set of elemental images are displayed in front of another microlens array, providing the observer with a reconstructed 3D image that is seen with horizontal and vertical parallax. Since its inception, InI has satisfactorily tackled many of its challenges. In this sense the useful methods have been proposed to improve the spatial resolution, to enhance the limited depth of field or to expand the viewing area. Other drawbacks still need for smart strategies to face them. In this contribution we show that two of most important challenges of InI can be overcome by a very simple digital signal processing consisting in a global pixel mapping within the elemental images set. Our proposals are supported by both numerical simulations and experimental results.

6392-05, Session 1

Integral imaging with variable image planes using polymer-dispersed liquid crystal layers

Y. Kim, H. Choi, J. Kim, S. Cho, B. Lee, Seoul National Univ. (South Korea)

Integral imaging (integral photography) is a three-dimensional display technique, first proposed by Lippman in 1908. Recently the integral imaging attracts much attention as an autostereoscopic three-dimensional display technique for its many advantages. It has continuous viewpoints within the viewing angle and does not need any special glasses. It also provides full parallax and can display real-time three-dimensional (3D) animated images owing to the advancement of the display devices. However, the limitation of image depth is the primary weak point. Integral imaging uses a lens array and a display device. Thus a focused image plane is formed by lens law using the focal length of lenses and the gap between lens array and the display device. We call the focused image plane the central depth plane. Integral imaging reconstructs the original 3D object exactly only at the central depth plane, and the image quality degrades as it goes away from the central depth plane. Therefore the thickness of the 3D image to be displayed is limited due to image quality degradation. In this paper, we propose an integral imaging with variable image planes using PDLC (polymer-dispersed liquid crystal) layers. Parallel layered PDLC films and a projector are adopted as a display system and enable to vary the location of image plane. We can control the transparency of PDLC films electrically and make each film diffuse the projected light successively with different depth from lens array. The explanation of the proposed system is provided and the experimental results are also presented.

6392-06, Session 2

Stereo-photography with handphone

J. Son, Hanyang Univ. (South Korea); S. Kim, Korea Institute of Science and Technology (South Korea); K. Cha, SAMSUNG Electronics Co., Ltd. (South Korea); M. Park, Korea Institute of Science and Technology (South Korea); S. Jang, Korea Telecom (South Korea)

Hand phone (Mobile Phone) is now becoming a true multimedia center for internet, computer, telephone and television, and at the same time, there is also growing interests of displaying 3 dimensional(3-D) images on the phone for the purpose of gaming and new service developments.

Hand phone (HPh) is a hand held device, so its size cannot be bigger than that a user can hold onto his/her palm. In this sense, the size of its display panel can be hardly exceeding more than 3inchs. This size limitation also limits the available resolution of the panel to 240 x 320 (320 x 240). This resolution is not enough to display multiview images but to stereoscopic images. A stereo image pair for the stereoscopic image display can be obtained by the camera embedded on the HPh (HPh camera). Hence it will not be difficult to install a stereo-photographic function to HPh if a viewing zone forming optics and a software for processing the stereo image pair is implemented in the HPh.

Taking a stereo image pair with HPh camera is one of difficult task because of the instability of hand movement. The instability can result differences other than parallax between left and right view images in the pair. If the differences are exceeding the permitted values, the pair cannot be fused.

In this paper, the conditions of taking a stereo image pair which can be fused as a 3-D image, with hand phone photography and processing the pair to be displayed without moirés are described. And also installing detachable viewing zone forming optics in the hand phone is introduced.

6392-07, Session 2

Three-dimensional imaging system with a stereo vision capturing and wavefront reconstruction

K. Nitta, N. Nishikawa, O. Matoba, T. Yoshimura, Kobe Univ. (Japan)

A three-dimensional imaging system which consists of an equipment for stereo vision capturing and optical wavefront recontruction is developed.

In the system, after acquisition of stereo images, depth maps are calculated by means of an area-based stereo matching algorithm. Hologram pattern is generated from the obtained depth maps with digital signal processing and displayed on a spatial light modulator. A three-dimensional(3D) image is reconstructed by illuminating plane wave of coherent light to the modulator. The most feature of the imaging system is to contstruct a holographic display without an optical interferometer for hologram recording. We fabricate a prototype of a stereo vision equipment and capture a target object. To obtain the depth map, we apply various methods of area-based stereo maching. The experimental results showed that a sum of absolute difference method provides desired depth maps. We calcuate an in-line hologram pattern with electronic signal processing. In the numerical reconstruction, 3D objects are reconstructed successfully. These results have shown usefulness of the proposed system.

6392-08, Session 2

Novel autostereoscopic single-user displays with user interaction

K. Hopf, Fraunhofer-Institut für Nachrichtentechnik Heinrich-Hertz-Institut (Germany)

Most of the existing autostereoscopic displays impose fixed viewing positions. Others provide a limited performance providing a multitude of fixed positions. In between these viewing zones an acceptable 3D impression cannot be generated. Based on results of the European ATTEST project, the Fraunhofer Institute for Telecommunications (HHI) has developed the Free2C 3D display technology, which provides free positioning of a single viewer within an opening angle of 60 degrees. A second common artefact of today's available displays is the presence of crosstalk between left and right view. The optics of the Free2C displays is designed such that extremely low crosstalk, excellent colour reproduction and high brightness are achieved.

Simple and intuitive interaction is a requirement for multi-modal 3D displays. For this reason, a novel technology has been integrated into the control console that can recognize a person's hand and its gestures. Displayed 3D objects floating in front of the screen can be rotated by simple gestures and virtual buttons can be pressed by pointing at them (virtual 3D touch screen).

Several applications are currently used by customers and have been presented at trade shows, exhibitions and showrooms. Feasible applications can be based on computer generated content, live video created by stereoscopic cameras and films stored on hard disk.

One promising application for attractive stereoscopic representations are immersive media presentations. The Free2C Kiosk and the 3D Media Center combines a high-resolution autostereoscopic 3D display with a video-based hand-gesture recognition device for direct manipulation of virtual 3D objects floating in front of the screen.

Beside technical aspects of the developed autostereoscopic display technology, the presentation includes topics of our video-based interaction technique and introduces promising applications of autostereoscopic single user displays.

6392-09, Session 2

Autostereoscopic displays for visualization of urban environments

V. Markov, S. A. Kupiec, MetroLaser, Inc.; A. Zakhor, Univ. of California/Berkeley

Two approaches in designing autostereoscopic displays capable of providing collaborative viewing of real time 3D scenery will be presented and discussed. Both techniques provide multiscopic "look around" capabilities and are applicable for situation rooms or mobile units. In particular, we will discuss a prospective use of these displays for interactive visualization of detailed three-dimensional models of urban areas and the specific demands associated with managing and rendering large volumes of highly detailed information. Recent advances in scanning, survey and registration in urban areas has provided a wealth of detailed three-dimensional data and imagery. Recent events have shown an extreme need and demand for systems capable in a high-level 3D visualization upon homeland security posed by terrorist actions and natural disasters within urban areas, as well as for military operations in urban terrain (MOUT). The capacity to visualize sightlines, airflow, flooding, and traffic in real time 3D within dense urban environments is increasingly critical for military and civilian authorities, as well as urban planners and city managers. Development of a high-quality 3D imaging systems is critical also for such areas as medical data imaging, gaming industry, mechanical design and rapid prototyping.

6392-10, Session 2

Flatbed-type 3D display systems using integral imaging method

Y. Hirayama, H. Nagatani, T. Saishu, R. Fukushima, K. Taira, Toshiba Corp. (Japan)

We have developed prototypes of flatbed-type autostereoscopic display systems using one-dimensional integral imaging method. The integral imaging system reproduces light beams similar of those produced by a real object. Our display architecture is suitable for flatbed configurations because it has a large margin for viewing distance and angle and has continuous motion parallax.

We have applied our technology to 15.4-inch displays. We realized horizontal resolution of 480 with 12 parallaxes due to adoption of mosaic pixel arrangement of the display panel. It allows viewers to see high quality autostereoscopic images. Viewing the display from angle allows the viewer to experience 3-D images that stand out several centimeters from the surface of the display. Mixed reality of virtual 3-D objects and real objects are also realized on a flatbed display.

In seeking reproduction of natural 3-D images on the flatbed display, we developed proprietary software. The fast playback of the CG movie contents and real-time interaction are realized with the aid of a graphics card.

Realization of the safety 3-D images to the human beings is very important. Therefore, we have measured the effects on the visual function and evaluated the biological effects. For example, the accommodation and convergence were measured at the same time. The various biological effects are also measured before and after the task of watching 3-D images. We have found that our displays show better results than those to a conventional stereoscopic display.

The new technology opens up new areas of application for 3-D displays, including arcade games, e-learning, simulations of buildings and landscapes, and even 3-D menus in restaurants.

6392-11, Session 3

Combined optimal quantization and lossless coding of digital holograms of three-dimensional objects

A. E. Shortt, T. J. Naughton, National Univ. of Ireland/Maynooth (Ireland); B. Javidi, Univ. of Connecticut

Digital holography is an inherently three-dimensional (3D) technique for the capture of real-world objects. Many existing 3D imaging and processing techniques are based on the explicit combination of several 2D perspectives (or light stripes, etc.) through digital image processing. The advantage of recording a hologram is that multiple 2D perspectives can be optically combined in parallel, and in a constant number of steps independent of the hologram size.

Although holography and its capabilities have been known for many decades, it is only very recently that digital holography has been practically investigated due to the recent development of megapixel digital sensors with sufficient spatial resolution and dynamic range. The applications of digital holography could include 3D television, virtual reality, and medical imaging. If these applications are realized, compression standards will have to be defined. We outline the techniques that have been proposed to date for the compression of digital hologram data and show that they are comparable to the performance of what in communication theory is known as optimal signal quantization. We adapt the optimal signal quantization technique to complex-valued 2D signals. The technique relies on knowledge of

the histograms of real and imaginary values in the digital holograms. Our digital holograms of 3D objects are captured using phase-shift interferometry. We complete the compression procedure by applying lossless techniques to the quantized holographic pixels.

6392-12, Session 3

Development of a HMD-type multifocus

S. Kim, D. Kim, M. Park, Y. Kown, Korea Institute of Science and Technology (South Korea); J. Son, Hanyang Univ. (South Korea)

A HMD type multi-focus 3D display system is developed and proof about satisfaction of eye accommodation is tested. Four LEDs(Light Emitting Diode) and a DMD are used to generate four parallax images at single eye and any mechanical part is not included in this system. The multi-focus means the ability of monocular depth cue to various depth levels. By achieving multi-focus function, we developed a 3D display system for only one eye, which can satisfy the accommodation to displayed virtual objects within defined depth. Therefore this proposed 3D display system has a possibility to solve the problem that the 3-dimensional image display system using only binocular disparity can induce the eye fatigue because of the mismatch between the accommodation of each eye and the convergence of two eyes. The accommodation of one eye is tested and a proof of the satisfaction of the accommodation is given as a result by using the proposed 3D display system. We could achieve a result that focus adjustment is possible at 5 step depths in sequence within 2m depth for only one eye. Additionally, the change level of burring depending on the focusing depth is tested by captured photos and moving pictures of video camera and several subjects.

6392-13, Session 3

View-dependent scalable coding of light fields using ROI-based techniques

Y. Taguchi, K. Takahashi, T. Naemura, The Univ. of Tokyo (Japan)

In recent image-based rendering (IBR) systems, multi-view video streams of a 3D scene, also known as a dynamic light field, are captured with hundreds of cameras or thousands of lenslets, which require a huge amount of data. When we need a 2D view of the scene at a current viewpoint over a network, we often transmit only the portions of the streams that contribute to a desired view, instead of all the streams. This is effective for reducing the amount of data to transmit. However, we cannot change the viewpoint until after the round trip time of the network with such a transmission policy. This is the problem to be solved in this paper.

This paper proposes a scalable coding architecture for dynamic light fields, in which a region of interest (ROI) approach is applied for multi-view data sets. Our method considers the image segments to synthesize a desired view as ROIs, which are compressed and transmitted with high priority. Meanwhile the data for neighboring views, existing near the ROIs, is transmitted according to the increase of the bit rates. We can render high-quality novel views around the current viewpoint before the arrival of the next frame data. Since that area expands from the neighborhood of the current viewpoint with increasing the bit rate, we call it “view-dependent scalability.” By changing the weight ratio between the ROIs and the outside of ROIs, we can control the view-dependent characteristics of the synthetic quality, with which the movement speed of a remote user’s viewpoint could be considered. We present a preliminary implementation of this scheme using a JPEG2000 codec, and evaluate the view-dependent scalability by measuring the quality of synthesized views against the distance from the current viewpoint.

6392-14, Session 3

Stereoscopic imaging: filling disoccluded areas in image-based rendering

C. A. Vazquez, W. J. Tam, F. Speranza, Communications Research Ctr. Canada (Canada)

Depth image based rendering (DIBR) is a method for converting 2D material to stereoscopic 3D that has recently received much attention. With DIBR, information contained in a gray-level (luminance intensity) depth map is used to shift pixels in the 2D image to generate a new image as if it were captured from a new viewpoint. The larger the shift (binocular parallax) the larger the perceived depth of the generated stereoscopic pair. However, a major source of problem with DIBR is that the shifted pixels now occupy new positions and leave areas that they originally occupied “empty.” These disoccluded regions have to be filled properly, otherwise they can degrade both image and depth quality. In this study we investigated different methods for filling in these disoccluded regions: (a) Filling regions with a constant color, (b) Filling regions with horizontal linear interpolation of values on the hole border, (c) Solving the Laplace equation on the hole boundary and propagate the values inside the region, (d) Horizontal interpolation with depth information taken into account, (e) Variational inpainting with depth information taken into account, and (f) Preprocessing of the depth map to prevent disoccluded regions from appearing. The methods differed in the time required for computing and filling, and the appearance of the filled-in regions. We compared the outcome for several test images, examining both image quality and depth quality.

6392-15, Session 3

Transmissive optical imaging device with micromirror array

S. Maekawa, National Institute of Information and Communications Technology (Japan); K. Nitta, O. Matoba, Kobe Univ. (Japan)

We propose a new optical imaging device. This device consists of many micromirrors placed perpendicular to the surface of a flat and thin metal plate. The micromirror array is implemented by the inner walls of minute square holes, which are pitted densely on the device. The basic operation mode is based on the two-times reflection by a pair of adjacent mutually-perpendicular mirrors. Although the principal of operation is based on the reflection by mirrors, the device is transmissive and deflects light. Since this imaging system forms a real image at a plane symmetric point, the depth of 3D image is inverted. The optical defect is low optical transmittance and stray light caused by no-reflection and one-time reflection light. We produced the device experimentally with nano-precision cutting technology, and evaluated it.

6392-16, Session 3

Perspective view reconstruction of partially occluded objects by using computational integral imaging

Y. S. Hwang, B. Javidi, Univ. of Connecticut

In this paper, we present experiments to reconstruct perspective views of a partially occluded object by using computational integral imaging. Synthetic aperture integral imaging utilizing a digital camera has been adopted.

6392-17, Session 4

3D optics

G. Barbastathis, Massachusetts Institute of Technology

No abstract available

6392-18, Session 4

Integral floating 3D display system: principle and analysis

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Integral floating system is a floating display system which is based on integral imaging and it is developed to show three-dimensional movie with great feel of depth. In integral floating system, a three-dimensional image produced by integral imaging is imaged by a convex lens or a concave mirror to form a real image. Therefore, the real image produced by the integral floating system shares various properties with the image produced by the integral imaging system: both provide continuous viewpoints and full parallax, and both have the limited viewing angles and expressible depth range. The limitations on the viewing angle and the expressible depth range should be resolved to make the integral floating system feasible. Thus, the analysis on the viewing angle and the expressible depth range is especially important to improve the viewing characteristics of the integral floating system. Here, the limitations on the viewing angle and the expressible depth

range of integral floating system are analyzed based on the existing analysis on the limitation of the viewing angle and the expressible depth range of integral imaging systems. Besides the viewing angle and the expressible depth range, viewing window, which is a unique viewing parameter of the integral floating system, is explained to fully understand the integral floating system. Integral floating system with improved viewing characteristics and their principles will be explained on the base of the given analyses.

6392-19, Session 4

Developments of 128-directional 3D display system

J. Ouchi, H. Kamei, K. Kikuta, Y. Takaki, Tokyo Univ. of Agriculture and Technology (Japan)

We developed a new VR system which enables direct interaction between 3D images and fingers without wearing special 3D glasses and makers on fingers. Moreover, it is free from visual fatigue. The system consists of the 128-directional 3D display, the PC cluster, and the fingertip detection system.

The 128-directional display provides natural 3D images which do not have the convergence-accommodation conflict and have very smooth motion parallax. It differs from conventional multi-view displays in that it precisely reconstructs rays from 3D objects. It contains 128 LCD panels and 128 images displayed on them are projected in different horizontal directions with the angle pitch of 0.23°.

The PC cluster consists of 16 PCs. Each PC controls eight video signals. All of the 128 video signals synchronize with each other using the TCP/IP signals. We developed the software which enabled to display widely-used VRML data interactively on the 3D display.

The fingertip detection is implemented using a stereo IR-camera. The 3D position of a fingertip is estimated by the stereo method. We used the compact image processor (SH4 + SuperVCHIP) which can calculate the coordinates of a fingertip at the video rate. The calculation results are transmitted to the PC cluster via the TCP/IP.

We made two application programs. One enables to manipulate VRML data by a fingertip. The frame rate depends on the data size, but is ~30 fps for typical VRML data. The other is the 3D drawing program which allows users to draw line images in the air.

6392-20, Session 5

Research on gaze-based interaction to 3D display system

Y. Kwon, K. W. Jeon, S. Kim, Korea Institute of Science and Technology (South Korea)

There have been reported several researches on gaze tracking techniques using monocular camera or stereo camera. The most popular used gaze estimation techniques are based on PCCR (Pupil Center & Cornea Reflection). These techniques are for gaze tracking for 2D screen or images. In this paper, we address the gaze-based 3D interaction to stereo image for 3D virtual space. To the best of our knowledge, our paper first addresses the 3D gaze interaction techniques to 3D display system..

Our research goal is the estimation of both of gaze direction and gaze depth. Until now, the most researches are focused on only gaze direction for the application to 2D display system. It should be noted that both of gaze direction and gaze depth should be estimated for the gaze-based interaction in 3D virtual space.

In this paper, we address the gaze-based 3D interaction techniques with glassless stereo display. The estimation of gaze direction and gaze depth from both eyes is a new important research topic for gaze-based 3D interaction.

We have two research approaches. One approach is based on the well known eye vergence characteristics. However, it is not well reported about the relationship between the degree of eye vergence and the stereo image depth. Here, we present our experimental researches on this relationship while using parallax barrier stereo image display. The other approach is based on the gaze vector of each eye. The gaze vector is estimated from each eye and then the crossing point of these two gaze vectors is estimated as 3D gaze point. We present our algorithm for the gaze vector based 3D interaction and experimentation data.

6392-22, Session 5

A smart remote controller for free viewpoint generation of the future 3D TV

M. Park, S. Kim, Korea Institute of Science and Technology (South Korea); J. Son, Hanyang Univ. (South Korea)

There have been many researches on multi-view image processing for free viewpoint generation. However, most of the previous studies focused on the way how to generate free viewpoint images with a sense of naturalness considering simplicity of computation and computational burden. In this paper, we present a smart way for the future 3D TV users to enjoy free viewpoint scenes. One of the merits of the free viewpoint system is to generate images according to the user's viewpoint. In that case it is necessary to choose some objects or positions in a given 3D space from multi-view images because the system requires a basis position to generate a scene that corresponds to the user's viewpoint.

Our proposed remote controller displays some of the selected regions on the screen as candidates for the possible bases. The regions are computed on the theory of human visual attention. It uses several features of given images like colors, luminance, orientations, competitions among features and etc. One of six viewpoints, top, bottom, front, rear, left, right view is chosen according to the user's preference using a touch screen. The proposed remote controller system is smart in that it provides the users with some candidate regions automatically based on the theory of human visual attention and offers the users some choice of viewing angles with easy.

We implemented the proposed remote controller using PDA (personal digital assistant). 3D TV is built using a desktop computer assuming future 3D TV is able to communicate with other devices and has computational capability. 3D TV is networked with the PDA, a smart remote controller for free viewpoint generation using wireless Internet communication. The part that generates free viewpoint images is not built in our current system because the proposed one is independent of the methods that generate multi-view images. Though the proposed remote controller is still incomplete to compute exact positions that correspond to user's viewpoints it is expected to be used as a very useful device for the future 3D TV users with some further improvements.

6392-23, Session 5

Scan made diffraction screens for HoloTV: diverging sources case

J. J. Lunazzi, Univ. Estadual de Campinas (Brazil) and Institute of Physics (Brazil); D. S. Ferreira Magalhães, Univ. Estadual de Campinas (Brazil)

The projection of holo-like images (1) on diffractive screens is an achievement to be kept on the evolution of 3D TV systems because although not rendering color, the resulting images are perfect in most other properties: distorsionless, large size, continuous parallax viewing, sharpness only being limited to the conventional 2D system employed. Although acquisition of real images is not a simple task and multiplies the necessary bandwidth by the number of slices in which the total volume is divided, it is not impossible to obtain. Furthermore, a simplified system was previously presented (2) which is very easy to construct and can impress an audience in spite of the technical limitations mentioned above. A secondary but practical limitation is the need of special holographic techniques to make large sizes (one meter square) screens because highly stable systems or pulsed powerful lasers are required. Since the main property of the screen is that of a diffractive lens we designed a way to make such a screen by creating with a beamsplitter two small width laser beams which are directed at local zones of a convex mirror pair. The diverging beams acts as object and reference beams when reaching a small part of the holographic film and the common origin of the virtual source of both beams is kept when the incidence at the mirrors is changed. By sequentially illuminating the film short exposures can make an stable interference pattern to be registered and a large screen is made through the junction of exposed regions. We describe our first experimental system made of diverging beams (virtual object and reference sources).

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6392-24, Session 5

Perceptual depth range adaptation for eight-view autostereoscopic displays

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We propose a system that takes an arbitrary 8-view scene and optimizes it for a given 8-view autostereosopic screen. The aim of the system is to minimize the ghosting, caused by crosstalk between neighboring views, while keeping the maximally possible dynamic depth range. The system takes the following steps:

1. The depth range of the original scene is estimated by using sub-pixel image registration

2. The 'biggest perceptual offender(s)' in the scene is found. This is the area with the most pronounced and higher horizontal frequency. The HVS of an observer sees ghosting (double edges) only when above the contrast sensitivity function (outside the masking range of CSF).

3. By using a combination of resampling and blur we aim at mitigating the cross-talk effect while preserving the most of disparity depth cues. The goal of the optimization is that all "perceptual offenders" are fitted in the masking range of the human CSF. At the same time the apparent disparity is optimized for the screen size. The optimization is done by changing three parameters of the scene:

3.1. Fractional pixel shift of all planes, while keeping the same relative displacements among the neighboring planes. This is going to compress/expand the depth of the whole scene relative to the ground point (screen surface). The fractional shift is done simultaneously with the rescaling of the collection of views for the screen size. The goal is to minimize the disparity for the biggest "perceptual offenders".

3.2. Local blur on specific spots. This will also mitigate the effect of the crosstalk, and bring it in the masking range of the CSF.

3.3. Local contrast changes.

4. Various combinations of the previous three parameters will result in various artifacts. The last stage is a perceptual quality assessment, which acts as a feedback for the optimization. It controls the trade-off between binocular depth cues and overall stereoscopic quality, when targeting a specific multiview screen.

6392-25, Session 5

A thin size 3D-2D convertible integral imaging system with a pinhole array on a polarizer

H. Choi, S. Cho, J. Kim, B. Lee, Seoul National Univ. (South Korea)

A thin size 3D-2D convertible display using the principle of point light source array is proposed. The 3D-2D convertibility is essential for the penetration of the 3D display into the current 2D display market and various methods were proposed to realize it. We have already proposed a 3D-2D convertible system using a lens array and a parallel light source. However, that system needs a bulky structure more than tens of centimeters because of the parallel light source and is not suitable for the flat panel displays. In this paper, an improved system is proposed which adopts a pinhole array on a polarizer of the conventional liquid crystal display panel and requires no special type of backlight source. With that method, the depth of the proposed system can be below one centimeter. Additionally, the use of a pinhole array on a polarizer enhances the light efficiency of the proposed system in the 2D mode by more than ten times of the 3D modes. This is also essential since the 3D mode is an additional function for a 3D-2D convertible system. The main function is the 2D mode and it should provide a high luminance. As a result, the 2D image quality of the proposed system can be compatible with the existing 2D displays for most aspects. The method will be proven by experimental results.

6392-26, Session 5

Development of the 3D adapter using an optical grating film for stereoscopic viewing

K. Sakamoto, T. Morii, Shimane Univ. (Japan)

A liquid crystal display (LCD) recently comes into common use. When the screen is divided in half, it can display two stereoscopic images in the same size. The left and right regions provide the stereoscopic images for left and right eyes. LCD screen has the characteristic of polarization. For example, when the 1/2 wave plate is attached to the right region, the observer, who wears the polarized glasses, can view the separated left and right stereoscopic image. However both stereoscopic images are not in the same position because the center of left and right regions has an interval, then it is difficult for the observer to view the 3D image by the stereoviewing.

One of the solutions to this problem is to use the 4-mirror stereoscope. This 4-mirror stereoscope is an easiest way to see stereoscopic images. But this paper describes another solution.

We developed the 3D adapter using an optical grating film for stereoscopic viewing. The principle is very simple. The optical grating film shifts both left and right images to the same position. The observer watches overlapped stereoscopic images for left and right eyes. But it is possible to separate left and right images when the observer wears polarizer glasses. This optical grating film is thin and works as a prism. The optical film appropriately locates apart from the display panel so that stereoscopic left and right images are overlapped.

The prototype stereoscopic display consists of the commercial 5.4 inch LCD panel. The screen size of observed image is 55x70 mm because of dividing screen in half. We attached the 1/2 wave plate to the half region on the screen. Hence the left image has vertical polarization and the right image has horizontal polarization, for example, because the LCD panel has unidirectional polarization. When the observer wears the polarized glasses, left and right images are separated and stereoscopic 3D images are observed.

6392-27, Session 5

Display of magnified 3D images in integral imaging by use of intermediate-view reconstruction technique

J. Hyun, D. Hwang, Kwangwoon Univ. (South Korea); J. Park, Kwangwoon Univ (South Korea); D. Shin, E. Kim, Kwangwoon Univ. (South Korea)

In this paper, a new II system that can magnify 3-D reconstructed images by employing an intermediate-view reconstruction technique(IVRT) is proposed, in which the number of the elemental images obtained from one-step pickup process could be computationally increased by use of an IVRT without needs of mechanical movement and long multi-step pickup process. To show the feasibility of the proposed II system, some optical experiments on magnification of 3-D reconstructed images with real 3D object have been carried out and its results are presented.

6392-28, Session 5

Implementation of color matching between mobile camera and mobile LCD based on RGB-LUT

C. Son, K. Park, T. Park, Y. Ha, Kyungpook National Univ. (South Korea)

The trend of multimedia convergence appears in the mobile phone providing the various functions such as the web browsing, 3D-game, television broadcasting, image capturing, not restricted to only communication means. Thus, many manufactures try to invest the area related with a super highway communication network, encryption technology for a reliable e-commerce operation, next-generation memory chip. Especially, the importance of mobile color reproduction or the necessity of image quality is gradually embossed with the beginning of the built-in camera function, digital multimedia broadcasting, video communication of WCDA. Until now, the color reproduction for mobile phone mainly focuses on the improvement of the color fidelity, for example, contrast or brightness, gamut, LCD angle, and LCD backlight. However, with the multimedia convergence, color-matching technique between mobile camera and mobile LCD should be considered in mobile phone for a better image quality. Therefore, this paper developed the color matching between mobile

camera and mobile LCD based on the concept of the conventional ICC profile applied to imaging device. ICC profile is approximately composed by three steps, i.e., characterization of the mobile camera and mobile LCD, gamut mapping. First, mobile camera characterization models the relationship between digital RGB value and CIELAB value by the polynomial regression method. Polynomial order is suggested by inducing manipulated RGB digital value with CIELAB value based on the opponent color theory. Next, mobile camera characterization is modeled by sigmoidal function different from conventional method such as GOG and S-curved model. Then, gamut-mapping algorithm is executed to overcome the gamut difference of mobile camera and mobile LCD. However, these steps require complex computation and a lot of memory. Finally, RGB-look up table is designed based on the representative digital value for real time processing. As a result, the realistic and high-quality images are reproduced by applying the proposed lookup table to mobile phone.

6392-29, Poster Session

A new coding technique of digital hologram video based on view-point MCTF

Y. Seo, Hansung Univ. (South Korea); H. Choi, J. Yoo, D. Kim, Kwangwoon Univ. (South Korea)

In this paper, we propose an efficient coding method to compress the data of a digital hologram video using 3D scanning, MCTF (Motion Compensated Temporal Filtering), and 2D video compression technique.

A digital hologram video, whose amount of data is huge, is first converted into a well-controlled data form and is re-arranged in highly correlated order using 3D scanning scheme. Spatial and time redundancy is removed from the rearranged data by MCTF and the residual data is encoded by H.264/AVC and lossless coding techniques. The hierarchical property of MCTF provides scalable transmission of digital hologram video. The proposed algorithm consists of seven steps as follows.

- Separation of the captured 3D object into RGB color space components
- Localization by segmenting the fringe pattern
- Frequency-transform using M * N (segment size) 2D DCT (2 dimensional discrete cosine transform) to derive the instant shape information
- 3D segmentation and scanning to find correlation between the segmented fringe patterns and form a sequence of frame to convert the spatial redundancy to a temporal redundancy
- Classification of coefficients to enhance the coding efficiency
- MCTF to remove the redundancy using open-loop prediction method in a frame sequence
- Hybrid video coding with H.264/AVC, DPCM (Differential Pulse Code Modulation), and lossless coding techniques.

The experimental results showed very high NC values of 0.93 in even 120:1 compression ratio. Also, moving holograms showed better compression efficiency than still holograms. In comparison to the previous methods, ours are from 8 to 16 times better in compression efficiency. Thus, we expect it to contribute to reduction in the amount of data for communication and storage of a digital hologram.

6392-30, Poster Session

Parallax barrier 3D reflection display using polarizer slit

M. Nishida, K. Sakamoto, Shimane Univ. (Japan)

A 3D display system is useful technology for virtual reality, mixed reality and augmented reality. We have researched spatial imaging and interaction system. We have ever proposed 3D displays using the slit as a parallax barrier, the lenticular screen and the holographic optical elements(HOEs) for displaying active image.

A display system requiring no special glasses is useful for 3D images. The parallax barrier display system has superior characteristics, such as having a planar screen and a thin panel. However, a conventional parallax barrier display system is only transmission type display (rear projection type display). In this paper, we describe the reflection parallax barrier 3D display for building large screen system such as 3D movie theater or argumented reality system of car's passenger cabin or aquarium.

Principal components of the reflection-type(front projection) 3D display are the polarizer slit barrier, 1/4 wave plate, reflection screen (silver screen). The silver screen is an image plane on which the stereoscopic images are projected by projector. The slit is an image splitter such as the parallax barrier. The projected stereoscopic image must pass through the slit, then this slit consists of the polarizer. The screen must preserve polarization. The projection screen is coated with a special polarization preserving material. The silver screen has this characteristic. Silver surfaced screens are required to maintain polarization for 3-D projection and rotate polarization. The 1/4 wave plate (phase film) is attached to the screen, then the polarization plane of projected image (incident light) is rotated at the surface of screen. Therefore, the polarizer slit blocks observed image (reflection light) in order to separate the parallax images for each eye. Then the observer perceives separated stereoscopic image for left and right eyes through the slit aperture.

6392-31, Poster Session

The basic experiments of cine holography as physics education in universities

H. Katsuma, S. Hiyama, Tama Art Univ. (Japan); T. Shibuya, M. Wakaki, Tokai Univ. (Japan)

3D image recording and holographic interferometric experiments were typical in conventional ones for physics education. In this point,we have given many papers in SPIE conference. Fundamental experiments were carried out for student to understand basic concept of holographic memory for 3D cine holography as next generation large format recording technique. Holographic data for holographic cinematography recording experimental using two beam optical configuration was carried out for fundamental student experiment. 1. We could perform recording experiment successfully with simple instruments. 2. The storage capacity becomes increased by muliple hologram recording,but the images becom overlapped visually. 3.The reproduction of the datas of cine holography is possible in a short time,but we must consider the method of reproduction and transfer to the electrical signal for student experimet application. 4.The light intensity of object beam and reference beam must be equal at reduction recording.

6392-32, Poster Session

3D recognition of occluded and distorted objects using computational integral imaging

S. Hong, B. Javidi, Univ. of Connecticut

No abstract available

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6393-01, Session 1

Applications of nanophotonics to classical and quantum information technology

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Moore's Law has set great expectations that the performance/price ratio of commercially available semiconductor devices will continue to improve exponentially at least until the end of the next decade. Although the physics of nanoscale silicon transistors alone would allow these expectations to be met, the physics of the metal wires that connect these transistors will soon place stringent limits on the performance of integrated circuits. The global interconnect layer of these metal wires is responsible for conducting information over "long distances" on a chip, and to and from the chip edges. These long wires are becoming the primary bottleneck for chip design and operation. The relatively slow propagation of electrical signals down the global interconnect and the relatively long distances that need to be covered are the primary limitations to the clock speed of a processor chip, and this problem is getting worse as feature sizes (e.g. wire widths) are getting smaller.

The global interconnect can also consume a substantial fraction (as much as half) of the power used on a chip built using current architectures, and this problem will worsen as the wire widths sizes shrink. We will describe a Si-compatible global interconnect architecture — based on chip-scale optical wavelength division multiplexing — that could precipitate an "optical Moore's Law" and allow exponential performance gains until the transistors themselves become the bottleneck. Based on similar fabrication techniques and technologies, we will also present an approach to an optically-coupled quantum information processor for computation beyond Moore's Law, encouraging the development of practical applications of quantum information technology for commercial utilization. We will present recent results demonstrating coherent population trapping in single N-V diamond color centers as an important first step in this direction, and we will describe parallel research in other promising materials (such as endohedral fullerenes). Finally, we will ask the question, "Why should we study quantum computation — really?", and propose an answer.

6393-02, Session 1

Rapid micro-optical prototyping technology for fabricating optical interconnection modules at the MCM and PCB level

C. Debaes, M. Vervaeke, J. Van Erps, L. Desmet, H. Ottevaere, V. Gomez, P. Vynck, S. Van Overmeire, Y. Ishii, A. Hermanne, H. Thienpont, Vrije Univ. Brussel (Belgium)

One of the remaining challenges to solve the interconnection bottlenecks at the Printed Circuit Board (PCB) and Multi-Chip-Module (MCM) level, is to adequately replace the galvanic interconnects with high-performance, low-cost, compact and reliable micro-photonic alternatives. At our labs of the Vrije Universiteit Brussel we are therefore optimizing and deploying a rapid micro-optical prototyping technology for micro-optical interconnect modules, which we call Deep Proton Writing (DPW). The special feature of this prototyping technology is that it is compatible with commercial low-cost mass replication techniques such as micro injection molding and hot embossing. In this talk, we will address more specifically the following components, made with the DPW technology:1) out-of-plane couplers for optical wave-guides embedded in PCB, 2) peripheral fiber ribbons and two dimensional single- and multimode fiber connectors for high-speed parallel optical connections, and 3) intra-MCM level optical interconnections via free-space optical modules. We will give special attention to the optical tolerancing and the opto-mechanical integration of components in their packages. We use both a sensitivity analysis to misalignment errors and Monte-Carlo simulations. It is our aim to investigate the whole component integration chain from the optoelectronic device packaggin to the micro-opto-mechanical assembly of the interconnect module.

6393-03, Session 1

Nanopillar coupled periodic waveguides: from basic properties to applications

D. N. Chigrin, Univ. Bonn (Germany)

The novel type of dielectric waveguides, which consists of several rows of periodically arranged dielectric cylinders, will be addressed. In such a nanopillar coupled periodic waveguide, light confinement is due to the total internal reflection, while modes dispersion is strongly affected by the waveguide periodicity. A theoretical study of coupled periodic waveguide properties will be presented along with their possible applications.

6393-04, Session 1

Coupled-mode theory for stimulated Raman scattering in high-Q/Vm silicon photonic band gap nanocavity lasers

X. Yang, C. W. Wong, Columbia Univ.

High-Q/Vm photonic crystal nanocavities in 2D triangle lattice photonic crystal slabs [1] have critical importance in fundamental studies and integrated nanophotonics applications, such as channel add/drop filters, low-threshold lasers [2], and enhancement of optical nonlinearities [3]. Motivated by recent pioneering work in light generation and amplification through stimulated Raman scattering (SRS) in planar silicon waveguides [4,5] and silica-based high quality factor (Q) microcavities [6], we have proposed high-Q and ultrasmall modal volume (Vm) photonic band gap nanocavities in monolithic silicon for the observation of enhanced stimulated Raman amplification and ultralow threshold Raman lasing [7]. Coupled-mode theory can reflect the nonlinear response of silicon resonators including photonic band gap nanocavities [8-10]. For enhanced SRS in our designed high-Q/Vm silicon photonic band gap nanocavities, the coupled-mode equations for the pump mode and Stokes mode supported by the nanocavities are derived to describe the dynamics of coupling between these two cavity modes. The loss rates of cavity modes due to radiation, linear material absorption, two-photon absorption (TPA) and free-carrier absorption (FCA) are included in the model, with which the actual lasing threshold can be estimated. The refractive index shift from the Kerr effect, free-carrier dispersion (FCD), and thermal dispersion are also considered in the coupled-mode equations. These equations can be numerically integrated based on the parameters and 3D finite-difference time-domain results to describe the dynamical behavior of the system. The lasing threshold scales with Vm/QpQS of the nanocavity. The estimated SRS lasing threshold is around several hundreds of ôÌW. Experimentally, an ultra-broadband supercontinuum (spectrum from 1100 nm to 1900 nm) is developed to observe the pump and Stokes resonances of the nanocavities coupled with photonic crystal waveguides.

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6393-05, Session 2

Realization of 3D isotropic negative index materials using self-assembled microfabrication technology

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We report a method to realize a three dimensional (3D) homogeneous and isotropic negative index materials (3D-NIMs) using a low cost and massively parallel manufacturable microfabrication and microassembly technique. The construction of self-assembled 3D-NIM array was realized through two dimensional (2-D) planar microfabrication techniques exploiting the as-deposited residual stress imbalance between a bi-layer consisting of e-beam evaporated metal (650nm of chromium) and a structural layer of 500nm of low stress silicon nitride deposited by LPCVD on a silicon substrate. A periodic continuation of a single rectangular unit cell consisting of split-ring resonators (SRR)and wires were fabricated to generate a 3D assembly by orienting them along all three Cartesian axes. The thin chromium and silicon nitride bi-layer is formed as hinges. The strain mismatch between the two layers curls the structural layer (flap) containing the SRR upwards. The self-assembled out-of-plane angular position depends on the thickness and material composing the bi-layer. This built-in stress-actuated assembly method is suitable for applications requiring a thin dielectric layer for the SRR. The split-ring resonators and other structures are created on the membrane which is then assembled into the 3-D configuration. Efforts are currently underway to develop a parallel microfabrication and self-assembly process using a thicker released holding plate (~5 to 10 microns) with deformable hinges for the SRR and wires. Unlike the research-based approach of fabricating a single structure for characterizing the unique properties of NIM, our mass-manufacturable process may offer opportunities for reproducible fabrication of 3D-NIM materials with frequencies from microwave to optical domain.

6393-06, Session 2

Fabrication of optical negative index meta-structure at sub-10 micron using nanoimprint lithography

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Negative index meta-materials (NIM) that exhibit unique and unprecedented properties have recently attracted worldwide attention. It has opened doors to new avenues in nano-photonics and optical integration. However, how to fabricate these meta-structures with high-precision, high-throughput and low-cost remains a challenge especially for short working wavelengths (i.e. infrared). Here, We report the development of an approach to fabricating optical meta-structures operating at sub-10 micron infrared range using nanoimprint lithography (NIL). The metal meta-structure consists of a large array (100umX1mm) of L-shaped resonators (LSRs). The smallest dimension is 45 nm with better than 10 nm critical dimension control. Metallic LSRs are chosen because they adapt to a four-fold rotational symmetry and the excitation of the magnetic dipole moment is more isotropic and insensitive to the azimuth angle of the electric field.

More details in design, fabrication process flow, theoretical studies and experiment data will be presented.

6393-07, Session 2

Transmission and reflection of highly anisotropic layered semiconductor structures with plasmonic resonances

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Negative refractive index materials have contributed significantly to the recently renewed interest in metamaterials. One possible method to realize negative index behavior is to create artificial structures that result in a simultaneously negative permittivity and permeability for the system. Yet, scaling these structures to sizes appropriate for the mid-infrared is difficult because of the required nanoscopic size. A second method to achieve a negative index is to design a sample with a sufficiently anisotropic permittivity. [V. A. Podolskiy and E. E. Narimanov. Phys. Rev. B 71, 201101 (2005)] Here, we report our work on degenerately doped quantum wells and n+/i/n+ heterostructures with plasmonic resonances, two systems capable of achieving such anisotropy.

We designed, grew, and characterized samples with degenerately doped quantum wells and n+/i/n+ heterostructures as well as bulk and low-doped control samples. The AlInAs/GaInAs quantum well samples had 85 Å barriers and wells, with the wells doped \> 2x10^(19) cm^(-3). The n+/i/n+ samples consisted of alternating layers of AlInAs/GaInAs of 80 nm thickness with a doping density of approximately 1x10^(19) cm^(-3) in the GaInAs layers.

We performed transmission and reflection measurements as a function of wavelength, incidence angle, and polarization. Both systems exhibit anomalous wave propagation corresponding to a rapidly changing index in spectral regions consistent with theoretical predictions. We find low-reflection resonances of approximately 11 dB in the quantum well samples that are wavelength tunable by more than 15% and can be eliminated in the transverse electric polarization by application of a dielectric cap layer. A comparison of the transverse magnetic and transverse electric polarizations with the theoretical model of the n+/i/n+ structures shows that we have achieved the necessary anisotropy to observe left-handed behavior.

6393-08, Session 3

Prospect of quantum dot lasers and single photon sources for advanced optical communication systems

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Since the first proposal of quantum dots by Arakawa et al. in 1982, various efforts have been devoted to the development of quantum dot lasers and related photonic devices. Recent remarkable progress in quantum dot laser technology has demonstrated high-temperature stability, high speed modulation and low * -parameter, most of which were theoretically predicted by the author in 1980', though the problem of inhomogeneous broadening has not been completely solved. It is anticipated that quantum dot lasers will become a core technology to realize high-performance light sources for optical telecommunication, for which data traffic is continuing to increase rapidly.

In this presentation, we address historical overview, the current state of arts and future prospects of the quantum dot lasers for advanced communication systems. Recently a new venture company has been launched in Japan, which accelerates efforts to deliver the quantum do laser modules/chips into a commercial market together with other related companies in Europe and USA. Moreover, an application of the quantum dots to sources of single photons and entangled photons at the telecommunication wavelength is also discussed.

6393-09, Session 3

Nonlinear absorption of highly stacked InAs quantum dot layers on an InP(311) substrate

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Tailored saturable absorption (SA) characteristics is investigated experimentally for highly stacked InAs quantum dots (QDs) layers on InP substrates and it is found that sensitive SA performance of 4 - 8 % transmission changes are available in planar type devices. Saturable absorbers composed of semiconductor quantum dots have been expected to have advantages of a low-frequency chirp, low saturation intensity, and a broad bandwidth due to inhomogeneous broadening. High-density (5 x 1012 cm-2) InAs QDs layers stacked more than 150 layers on an InP (311) substrate were recently fabricated with a strain-controlled technique for 1.5-* m communication devices. We characterized nonlinear optical absorption of the highly-stacked QDs layers. The transmission increase for the vertical incidence was observed as much as 1 %, and transmittance decreased at higher intensity of incident pulse. The temporal behavior of the transmission increase showed two decay components of a few picoseconds and several hundred picoseconds decay. The nonlinear absorption was explained by the SA of the QDs layer and the two photon absorption of the InP substrate. The features of the SA are suitable for application to a mode-locker for generating short optical pulses. Typical saturation intensity was estimated as 35MW/cm2. Analysis showed that we could tune the SA characteristics by adjusting the numbers of QD layers, thickness of residual InP substrate and antireflection coating on the surfaces. We obtained planar type saturable absorbers at with 4% transmittance change for a traveling type and 8% change for reflective type, respectively.

6393-10, Session 3

Sb-based quantum dot for creating novel light-emitting devices for optical communications

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Developing light-emitting devices operating at the optical-communications wavebands of 1.3 and 1.55 microns with high performance and at low cost will enable us to achieve ubiquitous networking. One of the key technologies for creating these novel light emitters is fabricating active media for optical communications on GaAs and Si substrate. Therefore, we have focused on the antimonide-based quantum dot structures (Sb-based QDs) grown on GaAs and Si substrates; these structures have narrow band gap properties. Recently, we successfully demonstrated optical-communications waveband emissions from vertical-cavity laser (VCL) structures containing the Sb-based QDs embedded in a GaAs matrix. The VCL structures are monolithically fabricated by using the InGaSb QDs active media and GaAs/AlAs distributed Bragg reflectors (DBRs). We observed 1.3- and 1.55-micron emissions from the Sb-based QD VCL structures under optical-excitation and current injection conditions at room temperature [1]. We also tried to fabricate optical-communications light-emitters on Si substrate by applying the Sb-based QDs. We found that the InGaSb QDs structures can be grown on the Si surface with molecular beam epitaxy. The Sb-based QD on the Si surface is expected to become new material for fabricating integrated opto-electronics devices with using silicon-technologies. We believe that Sb-based QDs will lead to breakthroughs in fabricating novel light-emitting devices for optical-communication and ubiquitous networks. [1] N. Yamamoto et al. Jpn. J. Appl. Phys. 45 (2006) in press

6393-11, Session 4

Electrodeposition of semiconductor nanowires and detailed characterization of their growth quality

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Nanowires, as a one-dimensional nanostructure, are of both fundamental and technological interest. Because of their unique electronic and optical properties as well as their facility of handling, nanowires will play a key role in assembly of nanoscale devices. It is known that much of this interest depends on fabrication of the materials. One needs not only well-controlled wire dimension, composition and crystal quality, but also the smoothness of wire surface and sharpness of interfaces within any multilayered nanowire. Hence good fabrication should be associated with careful characterization of the as-deposited samples. In this paper, we will first compare different synthesis methods of semiconductor nanowires (PVD, CVD, VLS, lithography, electrodeposition, etc.) by analysing their advantages and inconveniences, then present our own work on the electrodeposited CdSe luminescent nanowires.

Using a low cost and low temperature approach by electrochemistry, CdSe nanowires have successfully grown within polycarbonate template. Depending on the host pore dimension of the substrate, wire diameter can be varied from 400 nm down to 30 nm and wire length from few microns to a dozen microns. Metastable zinc blende structure mainly exists in the as-deposited nanowires, whereas wurtzite structure is obtained after heat treatment. A combination of different characterisation techniques, such as X-ray diffraction, SEM, TEM-HRTEM and EDXS, was used to investigate the growth morphology, crystalline structure and defects in the nanowires. The luminescent properties of CdSe nanowires have also been studied by means of photoluminescence.

6393-12, Session 4

Superconducting nanowire single-photon detectors for applications

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We have demonstrated Superconducting Nanowire Single-Photon Detectors with a detection efficiency of 67% at 1.05-μm optical wavelength and 57% at 1.55-μm wavelength. The devices were tested at 1.8 K while biased to 97.5% of the critical current Ic of the nanowires. The detectors used ~ 3-nm-thick NbN films patterned to 100-nm-linewidth and wound into a meander (or, more precisely, boustrophedonic) pattern with a 50% fill-factor that covered a 3.5 μm Å~ 3.5 μm area. A large number (\> 100) detectors arrayed across two chips were tested and the devices returned to the fabrication laboratory for the addition of an integrated λ/4 resonant optical cavity. We then tested the devices again and observed an enhancement of the detection efficiency by a factor of ~ 2 due to the integrated resonator. After the addition of a second optical enhancement, an anti-reflection layer, a third set of tests were performed that showed an additional slight enhancement of detection efficiency. Finally, electrical and optical models were developed to partially explain the observed performance. The integration of the device with an optical cavity, the large number of devices fabricated and tested, the exceptional performance of the devices, and our theoretical understanding of the device operation have helped clarify a path to integration of these devices into future single-photon communication, imaging, and electronics-diagnostic applications.

6393-13, Session 4

Photonic devices and systems embedded with nanocrystals for new functionality

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In this talk, we will review our research efforts and results on the development of photonic devices and systems embedded with nanocrystals for new functionality such as optical modulation, communication, and imaging in different operating optical wavelength ranges extending from the ultraviolet to the near infrared. We will also summarize our research work and future prospects on nanocrystal doped devices within the European Union Phoremost Network of Excellence on nanophotonics.

6393-14, Session 4

Observations of optical nonlinearites in strongly quantum confined PbSe nanocrystals for all-optical tunable nanophotonics

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Lead chalcogenides possess large optical nonlinearities [Gopinath] and nanocrystals [Brus] such as PbS and PbSe offer access to the regime of strong quantum confinement for nonlinear studies. Significantly enhanced nonlinearites are expected in PbS and PbSe nanocrystals due to the surface-induced large separation of charge between delocalized electrons and localized holes, with nonlinear susceptibilities scaling as (R/ aR)3 where R is the crystallite radius and aR the exciton Bohr radius. Large nonlinear properties have been shown in PbS nanocrystals in solution [Yoshino] and embedded in nanocomposites. [Liu, Li]

Here we study the nonlinear properties of monodisperse PbSe nanocrystals, in colloidal solutions and drop-cast as thin films (2-3 μm) on silicon substrates. PbSe nanocrystals have a larger exciton Bohr radius aR (46 nm) compared to PbS (20 nm) [Murray], with possible similar crystallite radius (~ several nanometers), and a larger refractive index (~5.0) compared to PbS (~4.2) in the C-Band. The large refractive index offers strong optical confinement thereby enhancing the optical nonlinearity of PbSe nanocrystals.

In addition, lead salt nanocrystals provide electronic transitions at the near-infrared telecommunication wavelengths. These characteristics make PbSe nanocrystals an interesting material for a range of applications such as optical switching.

Monodisperse PbSe nanocrystals were synthesized and suspended in either chloroform or trichloroethylene. The absorption maximum of the first excitonic peak at 1590 nm was used to determine the nanocrystal size to be 4.5 nm in diameter [Murray].

We used the Z-scan technique [Sheik-Bahae] to determine the Kerr nonlinear coefficient (n2) and two photon absorption coefficient (β2), which embody the real (refractive) and imaginary (absorptive) parts of the third-order nonlinear coefficient * ;(3) of the PbSe nanocrystals, for the wavelength range of 1.2 - 1.6 μm. Such nonlinearities in PbSe nanocrystals suggest promising applications in ultrafast all-optical tunable nanophotonics.

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6393-15, Session 4

Heteroepitaxial growth of InP nanowires on silicon surfaces with large diameters

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Although misfit dislocations limit the growth of thin film of InP on Si surfaces, single crystal III-V nanowires have been synthesized on Si in the recent past. This opened opportunities for integrated high speed optoelectronics with Si technology. We report the MOCVD assisted synthesis of InP nanowires on Si (more than 8% lattice mismatch) with very thick diameters of almost 1um. This unusually thick diameter was also accompanied by almost two order of magnitude faster growth rate than that reported in literature. An explanation of this unusual observation will be proposed. Details of the growth mechanism and characterization will be discussed.

6393-16, Session 5

Photonically engineered nanostructures: device concepts and material characterization for all-optical switching

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Combining organic materials with high Kerr-nonlinearities and resonant photonic nanostructures could lead to new fast switching elements. To determine the nonlinear coefficients of promising materials, we fabricate hybrid Fabry-Perot cavities by incorporating the organic material between two dielectric mirrors.

Using an ultrafast pump and probe setup we spectrally resolve the nonlinear transmission of pulses that are spectrally broader than the cavity resonances. The experimental data is compared to finite-difference time-domain simulations in order to deduce the nonlinear coefficients. This novel method is robust and does not suffer from systematic uncertainties such as beam shape distortions or thermal effects. The analysis is performed for various organic materials. In the same setup switching behaviour can eventually be demonstrated with appropriate materials.

As a next step we are developing planar integrated hybrid photonic structures. Here, circular-grating resonators are very attractive as they can act as basic device structures for switching. We propose a design based on optimization with full 3D finite differential time domain numerical simulations. While the design of the generic resonators enables controlled in and out coupling, the all-optical switching performance is comparable to that of Fabry-Perot micro-cavities.

6393-17, Session 5

Coherent phonons in nanostructures

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Phonons are usually considered to be the origin of scattering and dissipation for electronic dynamics in nanostructures. The generation of coherent acoustic and optical phonons via femtosecond laser pulses opens the pathway to control phonon dynamics in amplitude and phase [1]. Hence the optical properties of semiconductor nanostructures can be modulated at phonon frequencies in a well defined way, e.g. via femtosecond pulse shaping methods. We employ a new experimental technique based on two synchronized femtosecond lasers with GHz repetition rate to study the dynamics of coherently generated acoustic phonons in semiconductor heterostructures [2]. Through zone-folding effects the phonon frequencies can be tailored from a few ten GHz to the THz frequency range. The prospects of using such high frequency phonons for the modulation of optical signals in photonic crystals or combined phonon-photon cavities are discussed.

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6393-18, Session 5

Active manipulation of surface plasmons in metal-molecule-metal devices

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Molecular electro-optical switches are one of the major milestones in the development of optoelectronic memory elements as well as a long-standing goal of highly integrated photonic circuits. We are investigating the use of photochromic compounds to realize such structures. We have fabricated gold and aluminum metal-molecule-metal junctions with photochromic molecules such as Spiropyrans and

Azobenzenes as the active switching element. The switching of these photochromic molecules results in a change in the real and imaginary part of the refractive index that is easily detected in a home-built surface plasmon resonance sensing system. The experimental results and modeling of these switching events will be presented. After characterizing the switching behavior, we fabricated a three-terminal, plasmonic switch. In this device, a surface plasmon-polariton (SPP) pump was used to locally switch photochromic molecules between transparent and absorbing states. In this way, the SPP pump could control the propagation of a SPP signal through the same molecular region. These structures serve as prototypes for future plasmonic switches.

6393-19, Session 5

Ultrafast all-optical bistability in AlGaAs photonic crystals

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In recent years, photonic crystal literature has seen the dual fold increase of cavity quality factor (Q) coupled with reduced cavity mode volumes (V) on the order of a wavelength (lambda/n)^3 [1]. The extreme localization and control of this light intensity in a photonic crystal presents the possibility for greatly enhanced intensity dependent third-order, Chi(3), nonlinear effects. The decreased interaction length of nonlinear effects thus enable an amazing array of experiments. One such experiment is all-optical bistability. A great body of research was developed on bistability in the 1980's [2]. More recently a number of solid-state ultralow power photonic band gap microcavities have resurrected the literature to produce a wealth of proposed structures such as all-optical transistors, switches, logic gates, and memory devices which employ all-optical bistability [3,4].

The proposed device is an edge-tuned linear cavity defect of three missing air holes (L3 cavity) in AlGaAs, a material known to have large Kerr coefficient n2 as compared to Si. We employ theoretical analysis consisting of both analytical models and finite-difference time domain (FDTD) methods similar to that in Ref. 3 to ensure robust design and to estimate the power threshold of the proposed device. The proposed nanocavity experiment suggests low powers (~10^2 uW) and ultrafast switching (~ps) on chip limited only by photon lifetime. This is an improvement over silicon based experiments, which are limited by thermal effects [5]. Empirical measurements of the Kerr n2 value of the AlGaAs sample are also presented.

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6393-20, Session 5

Design of a 1:N switch using nonlinear optical materials in one-dimensional photonic nanostructures

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Photonic crystal superprism structures exhibit a rapid change in the group propagation direction with wavelength. For a fixed wavelength, a small change of the refractive index in such a superprism structure also results in a rapid change in the group propagation direction. We present a theoretical investigation of switching in active one-dimensional photonic nanostructures with coupled defects (cavities). This switch can be realized as a multilayer thin-film stack or alternatively in a planar waveguide geometry. The device will allow the switching of an incident laser beam to one of N output positions using either electro-optical or all-optical effects. We consider organic optically nonlinear layers, since organic materials show large nonlinear effects and fast switching times. The proper design of the layer structure is a key component for optimizing the performance of the device. We investigate the most effective position for the integrated nonlinear layers. The active layers can be placed inside the cavities or they can serve as coupling layers between cavities. Both approaches are evaluated with respect to performance parameters such as switching energy and necessary number of layers.

6393-22, Poster Session

All-optical wavelength conversion configuration with increased extinction ratio

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All-optical wavelength conversion of information is a very interesting and applicable topic addressed by various researchers in the fields of optical information technology and communication. In this paper we present two concepts of performing all-optical wavelength conversion while the novelty of this manuscript is in presenting a configuration providing increased extinction ratio of conversion. Both concepts are based on the photorefractive effect in crystals. By generating diffractive photo refractive pattern we improve the conversion extinction ratio. In the first concept two beam pairs are used to create two index gratings in the medium and by that receive wavelength conversion. In the second concept, the fanning effect in the photorefractive medium is used to perform wavelength conversion using only one beam pair. The paper presents theoretical analysis followed by experimental proof of concept and discussion on possible applications for the field of information technology.