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Technical Summaries

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SPIE Europe
2 Alexandra Gate
Ffordd Pengam, Cardiff, CF24 2SA
Tel: +44 29 2089 4747
Fax: +44 29 2089 4750
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8763-501, Plenary Session Wednesday

An autonomous structural health monitoring solution

Carol A. Featherston, Karen Holford, Rhys Pullin, Jonathan Lees, Mark J. Eaton, Matthew Pearson, Cardiff Univ. (United Kingdom)

Combining advanced sensor technologies, with optimised data acquisition and diagnostic and prognostic capability, structural health monitoring (SHM) systems provide real-time assessment of the integrity of bridges, buildings, aircraft, wind turbines, oil pipelines and ships, providing improved safety and reliability and reduced inspection and maintenance costs. The implementation of power harvesting, using energy scavenged from ambient sources such as thermal gradients and sources of vibration, alongside wireless transmission enables truly autonomous systems, reducing the need for batteries and associated maintenance in often inaccessible locations, alongside bulky and expensive wiring looms.

The design and implementation of such a system however presents numerous challenges. A suitable energy source or multiple sources capable of meeting the power requirements of the system, over the entire monitoring period, in a location close to the sensor must be identified. Efficient power management techniques must be used to condition the power and deliver it, as required, to enable appropriate measurements to be taken. Energy storage may be necessary, to match a continuously changing supply and demand for a range of different monitoring states including sleep, record and transmit. An appropriate monitoring technique, capable of detecting, locating and characterising damage and delivering reliable information, whilst minimising power consumption, must be selected. Finally a wireless protocol capable of transmitting the levels of information generated at the rate needed in the required operating environment must be chosen.

This paper considers solutions to some of these challenges, and in particular examines SHM in the context of the aircraft environment.

8763-1, Session 1

A MEMS vibration energy harvester for automotive applications *(Invited Paper)*

Rob van Schaijk, Interuniversity MicroElectronics Ctr. (Netherlands)

The objective of this work is to develop MEMS vibration energy harvesters for tire pressure monitoring systems (TPMS), they can be located on the rim or on the inner-liner of the car tire. Nowadays TPMS modules are powered by batteries with a limited lifetime. A large effort is ongoing to replace batteries with small and long lasting power sources like energy harvesters [1]. The operation principle of vibration harvesters is mechanical resonance of a seismic mass, where mechanical energy is converted into electrical energy. In general, vibration energy harvesters are of specific interest for machine environments where random noise or repetitive shock vibrations are present. In this work we present the results for MEMS based vibration energy harvesting for appliying on the rim or inner-liner.

The vibrations on the rim correspond to random noise. A vibration energy harvester can be described as an under damped mass-spring system acting like a mechanical band-pass filter, and will resonate at its natural frequency [2]. At 0.01 g2/Hz noise amplitude the average power can reach the level that is required to power a simple wireless sensor node, approximately 10 µW [3].

The dominant vibrations on the inner-liner consist mainly of repetitive high amplitude shocks. With a shock, the seismic mass is displaced, after which the mass will “ring-down” at its natural resonance frequency. During the ring-down period, part of the mechanical energy is harvested. On the inner-liner of the tire repetitive (one per rotation) high amplitude (few hundred g) shocks occur. The harvester enables an average power of a few tens of µW [4], sufficient to power a more sophisticated wireless sensor node that can measure additional tire-parameters besides pressure.

In this work we characterized MEMS vibration energy harvesters for noise and shock excitation. We validated their potential for TPMS modules by measurements and simulation.

(1) R Vullers, et al, IEEE solid circuit magazine, spring 2010, p. 29-38

(2) S. Roundy et al, ISBN 1-4020-7663-0, 2004

(3) R. Elfrink, et al, J. Micromech. Microeng. 20 104001, 2010

(4) R. Elfrink, et al, IEEE IEDM2011, p. 677-680

8763-2, Session 1

Wearable and flexible thermoelectric generator with enhanced package

Luca Francioso, Chiara De Pascali, Pietro Siciliano, Consiglio Nazionale Delle Ricerche (Italy)

In the framework of European ambient assisted living (AAL) program for increasing the quality of life of older people using pervasive information and communication technology (ICT) infrastructure, the interest of scientific community and caregivers for low cost solutions for wearable biometric monitoring sensors, energy autonomous and maintenance free has grown very fast during the last years. State-of-the art monitoring nodes are typically powered by rechargeable batteries, with known drawbacks for continuous operation from elderly . In order to extending the life-time of traditional batteries, intensive research is currently focused on the development of portable power generators able to harvest energy from environmental sources or body.

Present work shows recent progresses in thin film-based flexible and wearable thermoelectric generator (µTEG), finalized to support energy scavenging and storage of low consumption electronics in Ambient Assisted Living (AAL) applications. The prototype has an area of 5x5 cm2, realized by 2770 thermocouples of sputtered Sb-Te and Bi-Te thin films on 25 microns thick Kapton substrate. The discussed results mainly refer to a hybrid solution of packaging adopted to enhance the thermal gradient useful for the thermoelectric energy scavenging. A low cost process was designed to couple the thermoelectric module realized onto a Kapton foil to PDMS layer opportunely molded to enhance thermal insulation of cold junctions from heat source (the body skin, for the specific application). A transient thermal analysis of the PDMS/Kapton package was obtained by multiphysics simulation code and confirmed by thermal IR camera. The investigation allows the identification of the flexible package heat transfer properties vs PDMS thickness and thermal conductivity. Thermal camera data shows a thermal gradient between 7.5 and 10.5 °C between the body human skin and environment (hot and cold junctions). Fabrication process with optical lithography steps allows high resolution definition of thermoelectric semiconductors alloys.

8763-3, Session 1

Hybrid energy storage system for wireless sensor node powered by aircraft specific thermoelectric energy harvesting

Karthik Thangaraj, Cardiff Univ. (United Kingdom); Alexandros Elefsiniotis, Sarmad Aslam, Thomas Becker, EADS Deutschland GmbH (Germany); Ulrich Schmid, Technische Univ. Wien (Austria); Carol A. Featherston, Jonathan Lees, Rhys Pullin, Cardiff Univ. (United Kingdom)

Thermoelectric energy harvesting has been demonstrated to be the best solution for powering autonomous sensor nodes in aeronautical applications [1]. An artificial temperature difference is generated across a Thermo-Electric Generator (TEG) by applying a thermal mass and a cavity containing a phase change material, on one side and attaching a heat source on the other (fuselage) has been developed.

The overall energy harvested is sufficient to power up a wireless sensor node. As a part of this a power management system and an energy storage system are required in order to efficiently utilise and store the energy produced to operate the wireless sensor nodes for a prolonged time period within a flight cycle. This power management module is the most critical component since it is placed between the harvesting device and the WSN. The energy storage module is an important element of the power management powering the WSNs when there is no possibility to harvest energy. Super-capacitors are the preferred choice for a storage system as WSNs applications require high energy density. Lithium polymer batteries are also an option based on their higher number of possible recharge cycles and an operating temperature range which is suitable for aeronautical applications. The difference between capacitors and batteries is that a capacitor can dump its entire charge in a tiny fraction of a second, whereas a battery takes minutes to discharge completely. Batteries have more energy density as compare to the super-capacitor and super-capacitors have more power density as compare to batteries. The wireless sensor node application requires high power as well as high energy density for uninterrupted operation. Adding a capacitor in parallel to a battery in the storage system, will make an efficient hybrid storage system, which will be able to deliver higher power and higher energy density [2]. This paper designs such a system to improve the efficiency of thermoelectric energy harvester and a flexible storage to assist the power management system for powering the WSNs.

[1] Th. Becker, et al. Autonomous Sensor Nodes for Aircraft Structural Health Monitoring', IEEE Sensors Journal, Nov. 2009, Page: 1589 – 1595

[2] M. T. Penella-López, Manel Gasulla, Runtime extension of low-power wireless sensor nodes using hybrid-storage units. In: IEEE Transactions on Instrumentation and Measurement, March 2010, vol. 59, n. 4, p. 857-865

8763-4, Session 1

Nanostructured zinc oxide piezoelectric energy generators based on semiconductor P-N junctions

Steve Dunn, Joe Briscoe, Queen Mary, Univ. of London (United Kingdom); Mark Stewart, Paul M. Weaver, Markys G. Cain, National Physical Lab. (United Kingdom)

Evidence that a piezoelectrically induced voltage and current can be generated in a p-n junction-based ZnO nanorod device is presented. Low temperature solution-based techniques produce both all-inorganic and inorganic-organic hybrid diodes on flexible substrates. Bending of devices leads to voltages of 60 mV and current densities of 10 μA/cm2 in devices.

It has been demonstrated that piezoelectric polarisation of ZnO nanorods can generate a voltage in single nanorods and arrays. To date devices have focused on using a Schottky diode at one of the metal contacts. In this work we demonstrate that rectification can be achieved using a p-n diode, and that this leads to power being produced.

Scanning-electron microscope images show ZnO nanorods grow in a dense array, and can be grown 1-3 μm long and 50-100 nm wide by controlling the synthesis. The inorganic p-type layer penetrates the nanorods filling them intimately and producing a compact layer on top preventing shorts. The organic p-type layer does not fill between the rods leaving a cavity forming a compact layer on top of the rods. Current-voltage measurements show rectification in both diodes. Voltage and current peaks are generated when the devices are bent and released. Hydrostatic pressure measurements of the devices provide strong evidence that the effect results from a piezoelectric response in the material.

ZnO nanorods are grown directly onto 2 cm2 substrates in solution, and both inorganic and organic p-type layers are deposited from solution. Combined with the use of inexpensive plastic substrates this technology has the potential to produce low cost devices for harvesting of energy from vibrations and movement in the environment. The technology could easily be scaled up to produce large area devices to harvest large amounts of energy from the environment, or scaled down to power microdevices from small movements or vibrations.

8763-5, Session 2

Ceramic joints for pressure sensors development

Radovan Novotný, Jaroslav Kadlec, Radek Kuchta, Radek Vlach, Brno Univ. of Technology (Czech Republic)

Engineering ceramics have an important role to play in today's electronics industry. The manufacturing of ceramics parts with complex shapes, which are either quite expensive from the economic point of view or impossible to fabricate because there are physical limitations. Joining and bonding techniques have been accepted as an enabling technologies for the production of ceramics components, methods of joining ceramics to ceramics and ceramics to metals are necessary for production of large ceramic structures with complex shapes. The development of viable joining techniques and technologies could facilitate the assimilation of advanced ceramics into complex multimaterial structures and create complex components from segments with multi-functional characteristics. The pressure sensor as the subject of the research is assembled of a membrane and a base plate, both of them made of synthetically produced aluminum oxide. There is glass film for putting the membrane and the base plate together. The prepared structure is put into a linear oven and the temperature is increased up to the melting point of glass. Then the temperature is reducing slowly. The analysis of temperature influence on the pressure sensor manufacturing is a good way to verify the possibilities. The article describes the research work related to the ceramic joint quality evaluation, the thermal-structural analysis of ceramic joining and ceramic bond design and implementation. The role of ceramic material in electronics industry and motivation for joining ceramics is described, and important directions for future research are summarised, with emphasis on the statistical determination of poor joint, and how the interface of modification of a joint technology and process setting affects results. The requirements and ways for quality of joints are summarized, and the results of simulations of pressure sensor cooling after the removal from the oven during the joining are discussed. The experimental results are evaluated by using the t-test before and after process cooling modification.

8763-6, Session 2

Cu-Sn transient liquid phase wafer bonding for MEMS applications

Christoph Floetgen, Marta Pawlak, EV Group (Austria); Eric Pabo, EV Group Inc. (United States); Bart van de Wiel, Greg Hayes, TNO (Netherlands); Viorel Dragoi, EV Group (Austria)

Transient Liquid Phase (TLP) wafer-level bonding is a solution to provide hermetic sealing for fragile micro-devices as well as electrical interconnections of different components in production of Micro Electro-Mechanical Systems (MEMS) devices. The main benefit of TLP wafer-level bonding is the relatively low process temperature applicable during the bonding process, whereas the finished bonding interface can withstand significantly higher temperatures in post-bonding processes.

A popular choice for materials in TLP wafer-level bonding is Cu and Sn, because of the relatively low materials cost and high availability. Additionally, the Cu-Sn-system also incorporates the mentioned advantage of a low melting point solder, and high re-melting point of formed alloys with copper (inter-metallic phases, IMCs) during bonding process. The goal in Cu-Sn-TLP bonding is to achieve a complete transformation of Cu and Sn into the inter-metallic Cu3Sn-phase.

The bonded interface quality (defects level, bond strength, compositional homogeneity of the built IMCs) strongly depends on process parameters like e.g., applied contact pressure on bonding area, bonding time and the used temperature profile. These parameters have to be adapted to the initial layer stack design.

The present work aims to establish a correlation between the different bonding parameters mentioned above and the initial metal layers quality on the bonding layer's final structure, composition and quality. The use of non-patterned, i.e. full area metalized, wafers rules out any possible influence of patterns geometry on bonding mechanism.

The metal base area can then be assumed being semi-infinite, thus making the layer thicknesses measured by high resolution optical microscopy nearly true indicators on material volumes. In addition, the influence of possible wafer-to-wafer misalignment is ruled out, a priori. This would lead to the development of a more generalized method to design bonding metallization and corresponding bonding conditions to allow for high quality bonds.

8763-7, Session 2

Analysis of thermal vias in molded interconnect devices

Joerg Reitterer, Franz Fidler, Ferdinand Saint Julien-Wallsee, TriLite Technologies GmbH (Austria); Ulrich Schmid, Technische Univ. Wien (Austria)

The ongoing miniaturization of micro-opto-electro-mechanical-systems requires new compact multifunctional packaging solutions. Three-dimensional molded interconnect devices (MID) are a suitable packaging technology for a wide range of applications by combining integrated electronic circuitry and mechanical support structures into one compact housing. Due to the inherently large thermal resistance of thermoplastic MID substrate materials, temperature-sensitive applications require clusters of thermal vias in order to reduce the thermal resistance of the packaging. Specific examples of such temperature sensitive applications are, e.g., laser displays or laser lighting applications where individual MID pixels may contain multiple laser diodes generating a large amount of waste heat. This paper presents the analysis and optimization of various thermal via design parameters of MIDs including hole diameter, pitch, plating thickness of the Cu/Ni/Au metallization layers as well as the void level of the filling material inside the vias. Finite element method simulation results show that the heat flow through the MID substrate enveloping the via cluster is much more significant than the heat spreading in the lateral direction and hence, the predominantly one-dimensional heat conduction allows analytical simplification by modeling the thermal vias as a network of thermal resistors. The simulation results show that the thermal resistance of the MID packaging can be reduced by a factor of 30 by adding a cluster of laser-drilled thermal vias with a hole diameter of 150 µm and a pitch of 325 µm in a hexagonal via arrangement. For small ratios of pitch to hole diameter the heat conduction predominantly takes place in the Cu-plating of the vias with a negligible influence of the void level of the material inside the vias. In the full paper the simulation results will be compared to measurements on suitable MID test structures. Furthermore, the plating thickness of the Cu/Ni/Au metallization will be measured and incorporated into the simulation model.

8763-8, Session 2

Characterization of a quartz-based chip capping package for RF MEMS

Guido Sordo, Alessandro Faes, Giuseppe Resta, Jacopo Iannacci, Fondazione Bruno Kessler (Italy)

In the last decade Micro Electro Mechanical-Systems (MEMS) technology experienced a significant development in various field of Information and Communication Technology (ICT). In particular MEMS for Radio Frequency (RF) application have emerged as a remarkable solution in order to fabricate components with outstanding performances.

The encapsulation of such devices is a relevant aspect to be addressed in order to enable wide exploitation of RF MEMS technology in commercial applications. A MEMS package must not only protect fragile mechanical parts but also provide the interface to the next level of the packaging hierarchy in a cost effective technology. Additionally, in RF applications the electromagnetic impact of the package has to be carefully considered.

Given such a scenario, the focus of this work is the characterization of a chip capping solution for RF MEMS devices. Such solution uses a quartz cap having an epoxy-based dry film sealing ring. Some of the most relevant issues affecting RF MEMS devices once packaged, e.g. the mechanical stress induced by the cap and the hermeticity of the package, are studied as a function of different bonding parameters. Dimensional parameters of the sealing ring (thickness and width), and process parameters like temperature and pressure have been considered.

The package characterization is performed by using basic test vehicles such as strain gauges and humidity sensors, designed to be integrated inside the internal cavity of the package itself. The strain gauges and the humidity sensors are respectively realized as polysilicon piezoresistors, and capacitors with a polymide layer as dielectric. Experimental data are reported including calibration of the sensors as well as environmental measurements with and without capping, in order to assess the quality of the proposed packaging technology.

8763-9, Session 3

Novel applications of piezoresistive thin film systems based on hydrogenated carbon

Saskia N. Biehl, Christian Rumposch, Christian Recknagel, Fraunhofer-Institut für Schicht- und Oberflächentechnik (Germany)

Thin film sensor systems based on hydrogenated carbon have the advantage to combine two very important characteristics. They show a piezoresistive behaviour and also a tribological stability caused by a high hardness and wear resistance. Therefore they can be applied on the surface of machine parts or used for building up universal insertable sensor modules like sensory washers.

A real challenge is the deposition of a whole sensory layer system on technical components like a spindle, which have a length of 480 mm and an outer diameter of about 90 mm. The functions of the layer system directly applied in the contact zone between spindle's shaft and tool holder are the measurement of the clamping force of the tool holder, the imbalance of the used tool and the process forces during machining. For this application a self-contained thin film sensor system is investigated. Directly in the spindle's shaft an insulating alumina layer is deposited in a thickness of about 4 µm followed by electrode structures out of 200 nm thin chromium coating. On top of this the piezoresistive hydrogenated carbon layer in a thickness of about 1 µm is deposited, covered by a wear resistant and insulating top coating. Therefore a silicon and oxygen modified carbon layer in a thickness of about 2 µm is used.

Another very important application is the sensory washer. The thin film sensor system, consisting out of the piezoresistive sensor layer deposited directly on the washer surface, the electrode structures out of chromium for the local detection of the load distribution in the washer system and the insulating layer as top layer out of the silicon and oxygen modified carbon layer, has a thickness in the range of 9 µm. In the latest investigations this layer system is connected with a RFID-chip for contactless data transmission.

8763-10, Session 3

Optical properties of copper oxide thin films as selective sensing principle for hydrogen sulfide detection

Janosch Kneer, Univ. Freiburg (Germany); Jürgen Wöllenstein, Univ. Freiburg (Germany) and Fraunhofer-Institut für Physikalische Messtechnik (Germany)

For over three decades the optical properties of copper oxide thin films (Cu2O, CuO) have been under investigation in semiconducting applications, most prominently in photovoltaic's. Exposure of the p-type semiconductor copper oxide to reducing hydrogen sulfide favors a selective reaction to copper sulfide, already at RT conditions. Concerning sensing devices, this was first reported in 1992 by Miura et al.. The reported device is based on copper oxide / tin dioxide heterostructures, which change their resistivity due to H2S exposure. The effect clearly distinguishes from the typically utilized sensing effects of chemisorption. Because of the (partial) transition of the oxide surface to a sulfidic layer, the changes not only in the electrical

but also the associated optical properties are of high interest as sensing principle. Observation of changes in the transmission and absorption behavior gained from spectroscopic analysis shall enable a more fundamental understanding of the surface interactions and the subjacent electronic processes.

Thin films of metallic copper are deposited via PVD and subsequently oxidized with varying temperatures, carefully controlled, as the thin film composition and stoichiometry are highly temperature dependent and distinguish severely from the materials bulk properties. In addition, pure sulfidic thin layers are taken under comparative investigations. Shifts and variations in the materials band gap can be derived from the spectroscopic measurements making changes in the material composition separable from chemisorption effects, which are only affecting the carrier density in the surface. Thus the optical studies will contribute to a basic understanding in the overall semiconducting behavior. Furthermore the principal ability of an all optic read-out as sensing mechanism for the detection of hydrogen sulfide is investigated using thin film samples in a total internal reflection set-up, similarly to set-ups in biosensing. Under exposure of H2S, changes in the light intensity due to absorption can be detected.

8763-11, Session 3

Stable conducting nanocomposite electrodes for sensors used in high temperature harsh environments

Robert J. Lad, Scott C. Moulzolf, David J. Frankel, Mauricio Pereira Da Cunha, Univ. of Maine (United States)

Miniature sensors that are instrumented onto machinery operating in harsh gaseous environments at high temperature (up to 1200oC) are needed to provide real-time measurements of parameters such as temperature, pressure, strain, or corrosion. Such data is critical for carrying out condition-based maintenance strategies for reducing maintenance costs, and improving process efficiency and materials lifetime. A major technological challenge for these high temperature sensors is stability over long time periods, since conducting thin film electrodes with thicknesses ~100 nm typically undergo rapid agglomeration and chemical degradation while operating at high temperatures. In this work, stable nanocomposite films comprised of either Pt-Rh/ZrO2 or Pt-Rh/HfO2 were co-deposited using multiple e-beam evaporation sources onto langasite (La3Ga5SiO14) substrates, both as blanket films and patterned interdigital transducer films for surface acoustic wave (SAW) sensor devices. The films and devices were tested after different thermal treatments in a tube furnace up to 1100°C. The Pt-Rh/HfO2 films were found to be slightly more stable than the Pt-Rh/ZrO2 films, maintaining conductivity > 1x106 S/m after 4 hours at 1000°C. X-ray diffraction (XRD) analysis of the nanocomposite films indicates that they are made up of mixed phases of c-Pt-Rh and m-HfO2 (or t-ZrO2). SEM analysis shows that nano-grained HfO2 (or ZrO2) precipitates form at the Pt-Rh grain boundaries, and act as pinning sites that retard Pt-Rh grain growth; EDAX analysis shows that dewetted areas are enriched with Ga and La. Scanning electron microscopy (SEM) analysis reveals that finger electrodes of SAW transducers with 2 ?m lateral dimension undergo morphological changes after annealing above 900°C. A 50 nm thick Al2O3 diffusion barrier grown using atomic layer deposition (ALD) was found to be effective in minimizing interdiffusion between the nanocomposite film and the langasite crystal. The impedance, Q factor, and temperature sensitivity measured from prototype wireless SAW devices made from these nanocomposite films will be reported.

8763-12, Session 3

Fabrication and properties of $SmFe_2$-PZT magnetoelectric thin films

Ioanna Giouroudi, Technische Univ. Wien (Austria); Mohammed Al Nassar, Jürgen Kosel, King Abdullah Univ. of Science and Technology (Saudi Arabia)

Magnetoelectric (ME) thin film composites are attracting a continually increasing interest due to their unique features and potential applications in multifunctional microdevices and integrated units such as sensors, actuators and energy harvesting modules. By combining piezoelectric and highly magnetostrictive thin films, the potentialities of these materials increase. In this paper we report the fabrication of double layer SmFe2-PZT thin films and the investigation of their properties. First of all, a 100 nm SiO2 layer was deposited on top of the Si substrate and followed by a 20 nm Ta layer. Afterwards, a 100 nm Pt bottom electrode was sputtered. Spin coating was employed for the deposition of the 100 nm thin PZT layer. A PZT solution with 10 %Pb excess was utilized for this fabrication step. Finally, a 100 nm thin SmFe2 film was deposited on top of the PZT layer by sputter deposition. The microstructure of the films was characterized by X-Ray diffractometer (XRD) and atomic force microscopy (AFM). A piezoelectric evaluation system, aixPES, with TF2000E analyzer component was used for the electric hysteresis measurements of the thin films and a vibrating sample magnetometer (VSM) was employed for the magnetic characterization. The double-layer thin films exhibit both good ferromagnetic and piezoelectric properties. The SEM observation confirmed that the double layer thin films are crack-free. The quantitative chemical composition of the samples was confirmed by energy dispersive spectroscopy (EDS). The variation of the ME coefficient is being determined at room temperature by the electric field generated in the film under an AC driving magnetic field of 15 Oe, which is generated by a solenoid, superimposed onto a DC magnetic bias field of up to 1.5 KOe, which is generated by an electromagnet. The ME effect is studied in detail and representative results will be shown and discussed.

8763-13, Session 4

High-speed ultra-broad tuning MEMS-VCSELs for imaging and spectroscopy *(Invited Paper)*

Vijaysekhar Jayaraman, Praevium Research, Inc. (United States); Benjamin Potsaid, James Y. Jiang, Thorlabs Inc. (United States); Garrett D. Cole, Advanced Optical Microsystems (United States); Martin Robertson, Christopher Burgner, Demis John, Praevium Research, Inc. (United States); Ireneusz Grulkowski, Massachusetts Institute of Technology (United States); Scott T. Sanders, Univ. of Wisconsin-Madison (United States); James G. Fujimoto, Massachusetts Institute of Technology (United States); Alex E. Cable, Thorlabs Inc. (United States)

In the last 2 years, the field of micro-electro-mechanical systems tunable vertical cavity surface-emitting lasers (MEMS-VCSELs) has seen dramatic improvements in laser tuning range, and has also expanded into new wavelength bands and new applications. In this paper, we describe the design and performance of high-speed ultra-broad tuning range 1060nm and 1310nm MEMS-VCSEL for medical imaging and spectroscopy. Key results include achievement of the first MEMS-VCSELs at 1060nm and 1310nm, with >100nm tuning demonstrated at 1060nm and >150nm tuning at shown at 1310nm. These tuning ranges represent the widest reported for MEMS-VCSELs at any wavelength, and are comparable to ranges achieved in more complex and slower external cavity lasers based on edge-emitting gain chips. Wide tuning range has also been achieved in conjunction with high-speed wavelength scanning at rates beyond 1 MHz.

The wide tuning range and high speed of these devices, coupled with very long dynamic coherence length, has enabled advancements in both swept source optical coherence tomography (SS-OCT) imaging and spectroscopy. SS-OCT of the human eye with 1060nm VCSELs, for example, has demonstrated imaging from the anterior eye through retinal and choroidal layers using a single instrument for the first time. At 1310nm, the high-speed VCSEL has enabled real-time 3-D SS-OCT imaging of large tissue volumes in endoscopic and pathology lab settings. The long coherence length of the VCSEL has also allowed industrial metrology over meter scale distances previously unattainable with SS-OCT imaging systems employing other swept sources. Lastly, these devices have demonstrated utility in high repetition rate absorption spectroscopy. The narrow dynamic linewidth of MEMS-VCSELs has enabled accurate high-speed measurement of multiple water vapor and HF absorption lines in the 1310nm wavelength range, useful in gas thermometry of dynamic combustion engines.

8763-14, Session 4

High-precision optoelectronic sensor device for monitoring fermentation kinetics and maceration of wine

Francisco Jiménez-Márquez, Javier Vázquez, Juan Ubeda, José Luis Sánchez de Rojas Aldavero, Univ. de Castilla-La Mancha (Spain)

The fermentation process that turns must into wine is traditionally monitored manually by enologists, with no or little aid from automation tools so far. This supervision requires the enologist to follow a daily routine consisting of must sampling and subsequent analysis at least twice a day during the whole fermentation span and for every single fermentation tank, which is awkward and time-consuming, especially in regions like La Mancha (Spain), where production takes place at a massive scale.

In order to contribute to the automation of both the fermentation and the maceration supervision, a dual-purpose optoelectronic system has been developed. It was devised to record both the refractive index n and the chromatic characteristics of the fermenting must. The former, closely related to the fermentation kinetics, is obtained through measurements of a laser beam displacement; whereas the latter, which is essential for the maceration, relies on absorbance measurements at discrete wavelengths in the visible spectrum. Additionally, the system measures the temperature, necessary to reference the data to the standard temperature of 20ºC. It comprises a frame that holds a laser diode, a PSD (position sensitive detector), three LED diodes, six photodiodes and a temperature sensor, plus some conditioning electronics and a data acquisition board.

A number of fermentations have been monitored off-line with the reported system, reaching a resolution of 0.0004 RIU (refractive index unit). Measurements are in good agreement with predictions derived from analytical calculations. Data have also been validated with a spectrophotometer, an areometer, a hand-held refractometer and a HPLC equipment (high performance liquid chromatography). Data show a slight but distinct increase in n during the last stage of the fermentation, which does not have a match in the density measurements and could therefore be well used as an alert to automatically detect the fermentation end.

8763-15, Session 4

Optical position feedback of 2D MOEMS mirrors

Andreas Tortschanoff, Marcus Baumgart, Dominik Holzmann, Martin Lenzhofer, Carinthian Tech Research AG (Austria); Thilo Sandner, Fraunhofer-Institut für Photonische Mikrosysteme (Germany); Andreas Kenda, Carinthian Tech Research AG (Austria)

Optical position feedback can provide accurate information about mirror deflection angles in the case of microscanners, which is important for most applications. In particular optical methods can be used with MOEMS devices, which do not have an intrinsic on-chip feedback.

A simple realisation uses the reflection from the backside of a MOEMS scanner. Previously, we have presented a compact device based on the accurate measurement of timing signals using fast differential photodiodes, which can be used with resonant scanner mirrors performing sinusoidal motion with large amplitude. While this approach provides excellent accuracy for high frequency scanners, it cannot be directly extended to arbitrary trajectories or static deflection angles.

Most recently, we have realized a new position sensing device applicable to arbitrary trajectories, which is based on the measurement of the position of the reflected laser beam with a quadrant diode. In this work, we present in much detail the characteristics of this device, showing first experimental results from the implemented device, but also theoretical considerations and optical simulations in order to analyze dependencies on resonance frequency and mirror dimensions. Accurate position feedback is the basis for closed-loop control of the MOEMS devices and we also realised a microcontroller based driver, capable of driving novel electrostatically driven MOEMS mirrors with optimal performance. For this, different control algorithms have to be used, depending on mirror parameters and expected trajectories.

Position feedback and the possibility of closed-loop control will significantly improve the performance of these devices.

8763-16, Session 5

Influence of fluid-structure interaction on microcantilever vibrations: applications to rheological fluid measurement and chemical detection *(Invited Paper)*

Isabelle Dufour, E. Lemaire, B. Caillard, H. Debéda, C. Lucat, Univ. Bordeaux 1 (France); Stephen M. Heinrich, Fabien J. Josse, Marquette Univ. (United States); Oliver Brand, Georgia Institute of Technology (United States)

At the microscale, cantilever vibrations depend not only on the microstructure's properties (geometry and materials) but also on the properties of the surrounding medium (density and viscoelastic properties). In fact, when a microcantilever vibrates in a fluid, the fluid offers resistance to the motion of the beam. The fluid loading can be interpreted as the sum of two forces: an inertial force and a viscous force. Thus, the study of the influence of the hydrodynamic force on the microcantilever's vibrational spectrum can be used to either extract the mechanical properties of the fluid or to optimize the use of microcantilever for chemical detection in liquid media:

The classical way to measure the rheological properties of fluids is either to use a viscometer or a rheometer. To overcome the limitations of these classical methods, an alternative method based on the use of silicon MicroElectroMechanical Systems (MEMS) will be presented. The method, which is based on the use of the analytical equations of the hydrodynamic force, allows the measurement on a wide frequency range of the complex shear modulus which characterize both the elastic and viscous behavior of complex fluids.

The classical way to use microcantilever in the dynamic mode for chemical detection in gas is to use the first transverse bending mode. In fact, the performance of microcantilevers excited in their standard out-of-plane dynamic mode drastically decreases in viscous liquid media. When immersed in liquid, in order to limit the decrease of both the resonant frequency (to maintain sensitivity) and the quality factor (to maintain the measurement noise), alternative vibration modes which shear the fluid rather than applying pressure have been studied and tested: these consist of in-plane vibration modes (lateral bending modes and elongation modes) instead of the classic out-of-plane vibration mode (transverse bending mode).

8763-17, Session 5

Comparison of quartz tuning forks and AlN-based extensional microresonators for viscosity measurements in oil/fuel mixtures

Javier Toledo Serrano, Tomás Manzaneque, Jorge Hernando García, Javier Vázquez, Univ. de Castilla-La Mancha (Spain); Abdallah Ababneh, Yarmouk Univ. (India); Helmut Seidel, Univ. des Saarlandes (Germany); Magín Lapuerta, José Luis Sánchez de Rojas Aldavero, Univ. de Castilla-La Mancha (Spain)

Monitoring the properties of liquids is of practical interest in many fields. In the case of the automotive industry, the in-situ monitoring of the lubricating oil is of utmost importance to determine its properties. For example, lubricants are subjected to dilution with diesel fuel as a consequence of late-injection processes, which are necessary for regenerating diesel particulate filters. This dilution can be determined by tracking the viscosity and density of the lubricant.

Resonant structures are playing an important role in the determination of the viscosity of liquids. Despite previous reports of structures with out-of-plane movement, the most promising approach is the use of

structures with in-plane vibration modes.

Here we report the use of two in-plane movement based resonators for the monitoring of oil dilution with diesel and biodiesel. One of the resonators is the millimeter-sized quartz tuning fork, working at 32.7 kHz. The second resonator is a state-of-the-art micron-sized AlN-based rectangular plate, actuated in the first extensional mode in the MHz range. Electrical impedance characterization was used to register the performance of the structures in liquid media. These measurements were completed with the development of low-cost electronic circuits to deduce the resonance frequency and the quality factor from both transient response and open loop frequency response; this allowed us the automated assessment of the viscosity of the fluids under investigation.

Our results demonstrate the performance of both resonators in oils up to 70 cP. The quality factor measured in lubricant SAE 15W40 at 40 ºC was 20 for the micro-resonator, and 12 in the case of the tuning fork. In addition, both devices allowed for the detection of the dilution of this lubricant with biodiesel with a resolution of 1%.

8763-18, Session 5

The concept of microfluidic microchemomechanical integrated circuits

Andreas Richter, Merle Allerdissen, Rinaldo Greiner, Andreas Voigt, Technische Univ. Dresden (Germany)

We report Labs on a Chip (LoC) that are able to process chemical rather than electronic information. These integrated circuits (ICs) are based on two special inventions: (a) the employing methods used in building electronic circuits. The microfluidic circuits consist of stacked and structured layers of special materials forming the microfluidic components. In microelectronics, this method to assemble circuits makes it possible to produce extremely powerful microprocessors containing more than 2 billion components, increasingly with continuously improved production techniques more and more components can be placed on a single chip. This development may now be expected for lab-on-a-chip technology as well. (b) Chemical transistors are the second invention. Instead of controlling electron flows, as in electronic transistors, they control liquid flows depending on the concentration of distinct substances – the chemical information. This capability enables the chemical transistors to process chemical information by evaluating whether a threshold concentration of the substance has been reached and therefore allowing or prohibiting the flow of the substance. Here, the chemical transistorsare used to process chemical control signals to facilitate a purely chemical chip control. This may sound complicated and a little bit crazy; but it is in fact very easy and effects an extremely improved performance of lab-on-a-chip technology. Electronic computer, control software and electromechanical control system necessary for the operation of former lab-on-a-chip systems can be completely dispensed with, since the chemical chip control is completely integrated in the circuit.

8763-502, Plenary Session Thursday

Biologically inspired large scale chemical sensor arrays and embedded data processing

Santiago Marco, A. Gutiérrez-Gálvez, Univ. de Barcelona (Spain) and Institute for Bioengineering of Catalonia (Spain); Anders Lansner, Royal Institute of Technology (Sweden); Dominique Martinez, LORIA (France); J. P. Rospars, Institut National de la Recherche Agronomique (France); Romeo Beccherelli, Istituto per la Microelettronica e Microsistemi (Italy); Alexandre Perera, Univ. Politècnica de Catalunya (Spain); Tim C. Pearce, Univ. of Leicester (United Kingdom); Paul Vershure, Univ. Pompeu Fabra (Spain); Krishna Persaud, The Univ. of Manchester (United Kingdom)

Biological olfaction outperforms chemical instrumentation in specificity, response time, detection limit, coding capacity, time stability, robustness, size, power consumption, and portability. This biological function provides outstanding performance due, to a large extent, to the unique architecture of the olfactory pathway, which combines a high degree of redundancy, an efficient combinatorial coding along with unmatched chemical information processing mechanisms. The last decade has witnessed important advances in the understanding of the computational primitives underlying the functioning of the olfactory system.

EU Funded Project NEUROCHEM (Bio-ICT-FET- 216916) has developed novel computing paradigms and biologically motivated artefacts for chemical sensing taking inspiration from the biological olfactory pathway. To demonstrate this approach, a biomimetic demonstrator has been built featuring a large scale sensor array (65K elements) in conducting polymer technology mimicking the olfactory receptor neuron layer, and abstracted biomimetic algorithms have been implemented in an embedded system that interfaces the chemical sensors. The embedded system integrates computational models of the main anatomic building blocks in the olfactory pathway: the olfactory bulb, and olfactory cortex in vertebrates (alternatively, antennal lobe and mushroom bodies in the insect). For implementation in the embedded processor an abstraction phase has been carried out in which their processing capabilities are captured by algorithmic solutions. Finally, the algorithmic models are tested with an odour robot with navigation capabilities in mixed chemical plumes.

8763-34, Poster Session Thursday

On a high potential variable flexural stiffness device

Markus Henke, Gerald Gerlach, Technische Univ. Dresden (Germany)

In today's markets there are great efforts in developing effective composite structures for lightweight constructions for nearly every engineering discipline. This concerns for example in aeronautics and the space sector, but also the automotive industry and energy harvesting applications. Classic composite materials can only slightly adapt to varying environmental conditions in because most materials, such as carbon or glass-fiber composites, show properties which are time-constant.

The contribution describes the development, the potential and the limitations of novel smart, self-controlling structures, which can adapt their mechanical properties to changing environmental conditions. These structures use a multi-layer approach, where it is possible to change the flexural stiffness by several magnitudes. As a prototype a layer stack of 20 anodized aluminum plates with a thickness 0f 0.5 mm is used and built up. The layers are braided together by an array of shape memory alloy (SMA) wires. Depending on the temperature and the corresponding contraction the wires can tightly clamp the layers so that they cannot slide against each other, due to friction forces applied in this way. In this case the multilayer acts as rigid beam structure with very high stiffness. If the friction-induced shear stress is smaller, than a certain threshold, the layers can slide over each other and the multilayer becomes compliant.

To control the friction forces between the layers the wires are heated by electrical current. This allows the control of the stiffness of the beam with regard to the natural transformation hysteresis curve of SMA wires.

8763-35, Poster Session Thursday

MEMS sensors for microscale piezoelectric metrology

Jenny Wooldridge, Andres Muniz-Piniella, Mark Stewart, Tamaryn A. V. Shean, Paul M. Weaver, Markys G. Cain, National Physical Lab. (United Kingdom)

A MEMS sensor has been developed for the determination of piezoelectric materials properties in small-scale systems. A vertical levitation comb drive actuator, manufactured at MEMSCAP with the MetalMUMPS process, applies a force to the test sample in the range of 1-33 µN, and the resulting electric displacement from the piezoelectric material is measured using a charge sensitive pre-

amplifier and lock-in technique, facilitating charge measurements down to 1x10-5 pC. The force output of the actuator was measured with capacitive micro-sensors from femtoTools, which were calibrated against a CSM Instruments Ultra Nanoindentation Tester using a Berkovitch tip. The system was tested against nine Pb(Zr1-xTix) O3 (PZT) ceramic cylinders and one Pb(Mg1/3Nb2/3)O3 - xPbTiO3 (PMN-PT) single crystal, with piezoelectric coefficients in the range of 70-1375 pCN-1. The PZT cylinders were 15 mm in length (either 3 or 6 mm in diameter) and the PMN-PT crystal was 3.4x2.0x4.1 mm3 in size. Contact was made to the MEMS through a 2mm diameter sapphire bead attached to the piezoelectric. The size of these preliminary test samples was large in comparison to the MEMS device, so that the measured coefficients could be compared to those obtained with macroscopic measurement methods with a Berlincourt meter and through impedance resonance techniques. The coefficients obtained with the MEMS device showed a good correlation (r=0.9997) with the values obtained with macroscopic techniques. With this new MEMS device, we have successfully miniaturised the metrology for the measurement of the direct piezoelectric effect to evaluate the functional quality of piezoelectric films in the rapidly expanding market of piezoMEMS applications.

8763-36, Poster Session Thursday

Optical device for precision topography of MOEMS by Moiré inteferometry

Saïd Meguellati, Smaïl Djabi, Univ. Ferhat Abbas de Sétif (Algeria)

The manufacturing of micro components is useful and necessary for eventual use in the field of MOEMS microtechnologies, but the inspection of the quality microfabrication process is required. The reduction of systems size, for a specific use, has become a necessity to the economy of matter, energy and volume, and consequently, the miniaturization of components is required. Characterisation and testing of these micro components requires adapted and increasingly powerful techniques of control. The accuracy of components geometry is the parameter which influences the precision of the function. Moiré topography is full-field optical technique in which the shape of object surfaces is measured by means of geometric interference between two identical line gratings. The technique has found various applications in diverse fields, from biomedical to industrial, scientific applications, and miniaturized instrumentation for space applications. In many industrial metrology applications, contactless and nondestructive shape measurement is a desirable tool for, quality control and contour mapping. This method of optical scanning presented in this paper is used for precision measurement deformation or absolute forms in comparison with a reference component form, of optical or mechanical micro components, on surfaces that are of the order of mm2 and more. The principle of the method is to project the image of the source grating on the surface to be inspected, after reflection; the image of the source grating is printed by the object topography and is then projected onto the plane of the reference grating to detect defects.

The optical device used allows the magnification dimensional surface up to 1000 times the surface inspected, which allows easy processing and reaches an exceptional nanometric imprecision of measurements. This measurement technique can be used advantageously to measure the deformations generated by constraints on functional parts and the influence of these variations on the function. It can also be used for precision dimensional control when, for example, to quantify the error as to whether a piece is good or rubbish. It then suffices to compare a figure of moiré fringes with another previously recorded from a piece considered standard, which saves time, money and accuracy. This method of control and measurement allows real time control; speed control and the detection resolution may vary depending on the importance of defects to be measured.

8763-37, Poster Session Thursday

A miniaturized linear shaker system for MEMS sensor characterization

Jörg Encke, Wilfried F. Hortschitz, Austrian Academy of Sciences (Austria); Andreas Kainz, Harald Steiner, Franz Keplinger, Technische Univ. Wien (Austria); Thilo Sauter, Austrian Academy of Sciences (Austria)

Motivation: Shaker Systems are widely used when characterizing the mechanical properties of MEMS inertial sensors [1, 2]. Commercially available systems offering the required frequency range might be to big in scale to be well suited for MEMS testing equipment like the Polytec MSA-400 vibrometer. They might also not be compatible for usage in a vacuum environment which is necessary for the investigation of damping effects in MEMS vibration Sensors [2].

Summary: A miniaturized, piezo driven shaker system is presented which is feasible for MEMS characterization in vacuum. It offers a broad frequency and amplitude range. The shaker is constructed out of one single peace of aluminum with a piezo-stack-actuator working in plane against four beam springs. It can easily be fabricated at low costs using a hand operated milling machine while being fully vacuum compatible up to 10-9 hPa . The systems characteristics are easily tuned to different applications as the first resonance frequency is given by the stiffness of the beam springs and the mass of the moving shaker table. The utilized piezo stack determines the maximum reachable amplitude for a given spring stiffness. FEM simulations have been carried out to design a flat transfer characteristic of the shaker up to 12 kHz and a amplitude range of sub nanometer up to 1 µm. The simulation based design was evaluated by laser vibrometer measurements which also show a good linearity between electrical excitation signal and output deflection amplitude. To account for sharp resonances introduced by any preexistent MEMS assembly, the resulting vibration amplitude of the MEMS structure can be levelled out by proper adjustment of the electrical excitation amplitude, e.g., with the help of a laser vibrometer. This technique allows studies on MEMS resonators featuring extreme dynamic range.

[1] W. Hortschitz, H. Steiner, M. Sachse, M. Stifter, F. Kohl, J. Schalko, A. Jachimowicz, F. Keplinger, and T. Sauter. An optical in-plane mems vibration sensor. Sensors Journal, IEEE, 11(11):2805 –2812, nov. 2011.

[2] M. Sachse, W. Hortschitz, H. Steiner, F. Keplinger, A. Jachimowicz, J. Schalko. A Middle Ear Microphone Design Based on the Physiology of the Human Ear. Eurosensors 2011, pages 595-598

8763-38, Poster Session Thursday

Controlled fabrication of advanced functional structures on the nanoscale by means of electron beam-induced processing

Johann Foucher, CEA-LETI (France); Sebastian W. Schmidt, Christian Penzkofer, Bernd Irmer, nanotools GmbH (Germany)

The controlled deposition of materials by means of electron beam induced processing (EBIP) is a well-established patterning method, which allows for the fabrication of nanostructures with high spatial resolution in a highly precise and flexible manner. Applications range from the production of ultrathin coatings and nanoscaled conductivity probes to super sharp atomic force microscopy (AFM) tips, to name but a few.

The latter are typically deposited at the very end of silicon or silicon-nitride tips, which are fabricated with MEMS technologies. EBIP therefore provides the unique ability to converge MEMS to nanoMEMS in a highly controllable way, and thus represents an encouraging opportunity to refine or even develop further MEMS-based features with advanced functionality and applicability.

In this paper, we will exemplary present and discuss two different application solutions, where we successfully applied EBIP to overcome dimensional and/or functional limitations.

We will present critical dimension (CD), “T-like-shape” AFM tips made from high density, diamond-like carbon (HDC/DLC) featuring total tip widths down to 15nm. Such CD-AFM tip dimensions are mandatory to fulfil ITRS requirements for the inspection of sub-28nm nodes, but are unattainable with state-of-art Si-based MEMS technologies today.

In the second part, we will present and discuss a cold field emitter (CFE) fabricated by means of EBIP technologies. Applying the EBIP approach allows for the production of nanoemitters, which are characterized by considerably enhanced imaging resolution

compared to standard thermal field emitters and stable operation properties at room temperature without the need for periodic cathode flashing – unlike typical CFEs.

Based on these two examples, we will outline the strong capabilities of the EBIP approach to further downscale functional structures in order to meet future demands in the semiconductor industry, and demonstrate its promising potential for the development of advanced functionalities in the field of nanoMEMS.

8763-39, Poster Session Thursday

Rotational micro actuator for microsurgery

Monika Leester-Schädel, Jan-Wilhelm Thies, Thomas Schubert, Stephanus Büttgenbach, Andreas H. Dietzel, Technische Univ. Braunschweig (Germany)

The implementation of innovative methods and concepts for microsurgery – especially in the context of endovascular and interventional treatment - require properly fitted and resized instruments. These surgical tools, such as micro-guiding systems, must be of the highest quality regarding reliability and accuracy while additional medical requirements for the application in the human body have to be fulfilled.

In this paper an innovative micro actuator system for controlling the rotational degree of freedom of surgery instruments is presented. The requirements for the actuator are as follows:

- maximum diameter 6 mm
- very low angular speed
- simple actuator principle, preferably not electrically driven
- low, but constant torque
- high positioning accuracy
- easy to integrate into an existing surgical device

The actuator's task is to rotate an SMA micro actuator which controls the radial deflection of a laser fiber in the course of a surgical resection [1].

The preceding evaluation of different actuator types has shown that a hydrostatic system using the surgical irrigation fluid as its driving power is most suitable for this application. From the possible hydrostatic motor designs, an annular gear motor in orbit setup (in short: Orbit Motor) has been chosen based on its suitability for micro manufacturing.

This challenge led to an innovative actuator design, which includes a rotor-integrated control for connecting the actor's individual positive-displacement chambers. To verify the functionality of the new design, a macro-model of the actuator was fabricated and tested. The obtained test results have already confirmed the functionality and show the actuator's exciting potential. Currently the macro-model is further resized and the micro fabrication process is being developed.

[1] Leester-Schädel, M.; Lesche, C.; Demming, S.; Büttgenbach, S.: SMA Micro Actuator for the controlled guidance of surgical resection instruments. ACTUATOR 2008, Bremen, Germany, pp. 511–514, 2008

8763-41, Poster Session Thursday

Integrated lenses in polystyrene microfluidic device

Yiqiang Fan, Huawei Li, Ian G. Foulds, King Abdullah Univ. of Science and Technology (Saudi Arabia)

This paper reports a new method for integrating microlenses into microfluidic devices for improved observation. Two demonstration microfluidic devices were provided using this new technique. The integrated microlenses were fabricated using a free-surface thermo-compression molding method on a polystyrene (PS) sheet which was then bonded on top of microfluidic channels as a cover plate, with the convex microlenses providing a magnified image of the channel for the easier observation of the flow in the microchannels.

With the increasing demand for miniaturized point-of-care systems, the integration of microfluidic and micro-optical systems is important. Microlenses have been fabricated through reflow, and thermo-compression molding and laser bumping. In our previous work, we presented a novel method of fabricating microlenses, which has the simplicity of using a single material like thermo-compression molding, but does not require a 3d-patterned master like previous methods. We have now integrated this free-surface thermo-compression molding technique with thermo-compression bonding of microfluidic devices to create lenses integrated in microfluidic systems.

The first device is an simple droplet generator fabricated for demonstration of the integrated lenses. Images taken using the microscope show the channel under the polystyrene microlens is obviously magnified. The second demonstrated device has a polystyrene microlens above the filter paper for the easy optical observation of the particle accumulation on the filter paper.

This study demonstrated a novel method for integrating microlenses with microfluidic devices. A simple and rapid free-surface thermo-compression molding process was used for the fabrication of polystyrene microlenses. The experimental results, show the microlens functioning to enlarge the images for easy observation of the flow in the microchannels. This integration method has potential application in point-of-care testing where integration of the micro-optical and microfluidic components is important.

8763-42, Poster Session Thursday

Miniaturized wireless passive sensor with polymer coated nanowire fabric for hydrocarbon detection

Sheng P. Zhang, Brad Leonhardt, Catherine Shipman, Praveen Pasupathy, Brian A. Korgel, John G. Ekerdt, Dean P. Neikirk, The Univ. of Texas at Austin (United States)

This paper describes development of a miniaturized wireless passive chemical sensor. The sensor uses a fringe field capacitor as a transducer integrated with a spiral inductor forming a resonant LC circuit. The fringe capacitor is formed from the self capacitance of spiral inductor traces. Resonant frequency is measured by interrogating the sensor using a non-contact reader coil. Polymer coatings combined with nanowire fabrics produce permanent change (chemical memory) when they selectively respond to aromatic and aliphatic hydrocarbons. Changes in the dielectric constant or thickness of the coatings lead to permanent resonant frequency change. The coatings are designed such that they do not respond to water or brine. Optimum sensor design (maximized Q and maximized coupling factor to the non-contact reader) in a fixed area is discussed. A distributed equivalent circuit incorporating multiple layer interdigitated capacitor model and spiral inductor model is developed to predict the resonant frequency when miniaturizing the sensor to sub-millimeter range. Successful sensor devices have been fabricated with either a polymer film alone or a polymer film encapsulating a nanowire fabric on top of polyimide passivation layer. The latter results in a dramatically improved resonant frequency shift in water when going through water-hydrocarbon-water exposure sequence, without constant monitoring in hydrocarbon. Completed, robust devices and polymer films have been successfully tested at temperatures of 120°C, in both brine and hydrocarbon, with post exposure measurement in both water and brine.

8763-43, Poster Session Thursday

Magnetic tunnel junction sensors with pTesla sensitivity for biomedical imaging

Luis Gameiro, Diana C. Leitao, Filipe Cardoso, INESC-MN (Portugal); Ricardo Ferreira, Elvira Paz, International Iberian Nanotechnology Lab (Portugal); Paulo P. Freitas, International Iberian Nanotechnology Lab (Portugal) and INESC-MN (Portugal); Susana Cardoso, INESC-MN (Portugal)

Biomedical imaging techniques such as magnetocardiography require highly sensitive magnetic sensors capable of detecting fields down to sub-picoTesla range in the low frequency range. Superconducting quantum interference devices offer nowadays the desired sensitivities with the inconvenient of working at temperatures at low temperatures,

having the necessity of cryogenic apparatus. An alternative relies on magnetoresistive sensors, in particular magnetic tunnel junctions (MTJ), where such specifications can be achieved at room temperature.

In this work we use MgO MTJ stack with the following structure: Si/SiO2(200)/Ta/CuN(50)/Ta(3)/CuN(50)/Ta(3)/Ru(5)/IrMn(7.5)/CoFe30(2)/Ru(0.85)/CoFe40B20(1)/Ta(0.21)/CoFe40B20(1.64)/MgO/CoFe40B20(3)/Ta(0.21)/NiFe(16)/Ta(10)/CuN(30)/Ru(7) (nm). The bulk material properties were characterized by CIPT prior to microfabrication yielding a tunneling magnetoresistance, TMR ~ 200 % and a resistance x area product RxA = 7.6 kΩ.µm2.

The MTJ stack was patterned into 3 different shapes (circle, square and rectangle) by optical lithography and ion milling etching, with areas ranging from 115 µm2 to 1500 µm2. Free layer magnetic stabilization is enhanced by 120 nm thick Co66Cr16Pt18 integrated permanent magnets (PM). To further improve the sensors sensitivities soft ferromagnetic flux guides (FG) composed of 600 nm thick sputtered Co93Zr16Nb3 were also included.

MTJs with integrated PM showed low coercivity (Hc < 1 Oe), linear transfer curves, with sensitivities up to ~ 200 %/mT.

Optimized detectivities of ~ 2000 %/mT could be achieved for sensors with 26x50 µm2 dimensions including both PM and FG. These sensors present a TMR ~ 206 % and a maximum sensitivity of 1860 %/mT. Noise characterization was performed with a bias voltage of 15 mV, giving a Hooge parameter of αH = 3.2x10-8 µm-2 and 1/f corner at 3 kHz. These values correspond to field detectivities of 49 pT at 10Hz and 3.5 pT at 100 kHz, therefore compatible with the end application.

8763-44, Poster Session Thursday

Hydrogel plug for independent sample and buffer handling in continuous microchip capillary electrophoresis

Dietmar Puchberger-Enengl, Technische Univ. Wien (Austria); Mireille Bipoun, Univ. Bremen (Germany); Martin Smolka, Technische Univ. Wien (Austria); Christian Krutzler, Integrated Microsystems Austria GmbH (Austria); Franz Keplinger, Technische Univ. Wien (Austria); Michael J. Vellekoop, Univ. Bremen (Germany)

For environmental monitoring systems a continuous operation mode of sensor systems is desirable. In order to obtain efficient field tests a multitude of different samples have to be processed with the least amount of external equipment. In microchip capillary electrophoresis most frequently electrokinetic sample injection is utilized because of its simple implementation. However, electrokinetic injection does not allow pressure driven sample handling. On the other hand, pressure driven injection suffers from low reproducibility of sample plug shape due to dead volumes much bigger than the used sample in the injector. Photopatterned hydrogel membranes have been utilized in microchip electrophoresis to preconcentrate biomolecules at the edge of the gel prior to the separation process [1].

In this contribution we present the use of a hydrogel plug to separate the sample from clean buffer to enable independent sample change and buffer refreshment. The device consists of a microfluidic channel with a quad-T injector and comprises insulated electrodes for capacitively coupled contactless conductivity detection (C4D). The inner double-T is occupied by the hydrogel, dividing the device into two microfluidic channels for sample and buffer liquid, respectively. UV curing polyethylene glycol diacrylate (PEG-DA), mixed with buffer is used to produce the fluidic barrier within the chip in a single step. A porogen (PEG) adjusts the pore size of the hydrogel to the size of analyte ions.

The sample is electrokinetically injected into the inner double-T through the gel and separated by a voltage between the second gel inlet and buffer outlet. By the blocking of disturbing flows by the gel barrier a well-defined ion plug is obtained. After each experiment, the sample can be changed and the separation channel flushed independently, allowing for a continuous operation mode. Fluorescent dyes (fluoresceine and rhodamine) are used to visualize the working principle. In a second step, inorganic ions, which are relevant for soil fertilization are separated and detected by the C4D electrodes.

[1] R. J. Meagher, N. Thaitrong, Microchip electrophoresis of DNA following preconcentration at photopatterned gel membranes, Electrophoresis 2012, 33, 1236–1246

8763-45, Poster Session Thursday

A new injection method for soil nutrient analysis in capillary electrophoresis

Martin Smolka, Dietmar Puchberger-Enengl, Technische Univ. Wien (Austria); Mireille Bipoun, Univ. Bremen (Germany); Georg Fercher, s::can Messtechnik GmbH (Austria); Andrzej Klasa, Univ. of Warmiñsko-Mazurski (Poland); Kaan Ozer, Integrated Microsystems Austria GmbH (Austria); Franz Keplinger, Technische Univ. Wien (Austria); Michael J. Vellekoop, Univ. Bremen (Germany)

We present a method for the direct injection of sample from a liquid reservoir, through a membrane-covered inlet into the separation channel of a capillary electrophoresis microdevice. Because we exchanged the sample channel for the reservoir, no mechanical component (e.g. pump) is needed for inserting the sample into the separation channel. This opens up the way for mobile application of soil analysis.

For sustainable agriculture, the cultivated soil must receive back what has been taken by the crop growth. However, excessive use of fertilizers causes high cost and can harm the soil conditions and the environment. Getting a lucrative yield in long term is therefore only achieved if information is retrieved on the soil nutrient concentrations. These values are commonly determined in laboratory measurements - a complicated and cost-intensive procedure. The realisation of an on-site device, making the soil testing feasible for farmers, could lead to an easily achievable demand driven fertilization, reducing environmental impact and costs spent for fertilizers.

As soil nutrient measurements are commonly performed on a soil solution (i.e. 5 g soil in 50 ml deionised water), a microfluidic chip is suitable for this purpose. The nutrients of interest are K, NH4, NO3 and PO4. Capillary Electrophoresis (CE) is used to separate the different sample components and the sample concentrations are measured with Capacitively Coupled Contactless Conductivity Measurement (C4M).

A highly crucial procedure in this measurement system is the sample injection into the buffer-filled separation channel. The injection of a reproducible volume demands for stable pressure conditions between the used liquid reservoirs. This is hardly achievable in a transportable on-site instrument. The application of a nanoporous membrane between injection channel and separation channel has shown to improve the reproducibility [1]. We have implemented such a filter directly at the inlet of the reservoir to the separation channel which allows pump-less injection. In our first experiments the highly reproducible detection of K, NH4 and NO3 has been successfully demonstrated down to concentrations of 20 µM.

[1] Z. Long, Z Shen, D. Wu, J. Qin, B. Lin, Integrated multilayer microfluidic device with a nanoporous membrane interconnect for online coupling of solid-phase extraction to microchip electrophoresis. Lab Chip, The Royal Society of Chemistry 2007, 7, 1819-1824

8763-46, Poster Session Thursday

Simulation and optimization of the magnetic field in an electroplated copper microcoils

Maher Matar, Alaaldeen T. Al-Halhouli, Stephanus Büttgenbach, Andreas H. Dietzel, Technische Univ. Braunschweig (Germany)

This work aims at simulating and optimizing the magnetic field intensity in different electroplated copper microcoil designs that can be integrated in a recently developed novel synchronous micropump [Al-Halhouli 2012]. The results of this study will be used in fabricating new optimized microcoil designs that may enhance the performance

of developed synchronous micropump (i.e., the maximum back pressures and flow rates).

The synchronous micropump concept depends on managing the movement of two magnets in an annular fluidic channel. Magnet rotation is achieved by sequentially activating a set of planar microcoils to repel or attract the first magnet (traveling magnet) through the channel, while the second one is anchored between the inlet and the outlet ports. At the end of each pumping cycle, the magnets exchange their anchored and traveling functions [Al-Halhouli 2012].

To achieve the maximum pressure and flow rate (highest performance) in such micropump, higher magnetic fields without exceeding the material temperature limitation are required. The stronger (higher) the magnetic fields that can be generated, the higher the hydraulic power that can the pump deliver.

This study presents an extensive numerical simulations using the commercial software package COMSOL and optimizations for the effect of the main microcoil parameters: coil wire width and height, the coil turns offset distance, the ratio of the Ferro-material core area to the –whole coil area, and number of coil turns on the generated magnetic field.

The main desired (analyzed) results are; the normal magnetic flux contours at the top (upper) surface of the coil -where the permanents rotates in the micro-pump channel-, the distribution of the magnetic field streams and the area averaging of the magnetic field intensity all over the micro-coil sector.

8763-47, Poster Session Thursday

Micro-fluorescent activated cell sorter (FACS) for isolation of genetically modified cells

Haifeng Shang, Kyung-A Hyun, Yonsei Univ. (Korea, Republic of); Kwon Soo Ha, Mi-Hye Kwon, Kangwon National Univ. (Korea, Republic of); Suho Ryu, Chulmin Joo, Hyo-Il Jung, Yonsei Univ. (Korea, Republic of)

In the past decade, the conventional fluorescent activated cell sorter (FACS) has played an important role in cell analysis and sorting as well as clinical diagnostics. Conventional FACS can just detect and separate the fluorescent particles/cells due to the existence of fluorescence triggers. As expression level of proteins of cells has closely relationship with diseases, it can be used as basis to diagnose the progressing degree of the diseases. For this reason, it is important to separate these cells depending on their protein expression levels. In this paper, we have developed a novel microfluidic device that could count and sort the genetically modified cells with various fluorescence intensities by using dielectriphoretic (DEP) force. Our proposed system consists of three main parts: sample focusing, detection and separation part. The operating principles can be summarized as four steps: firstly, fluorescent cells were induced into the microfluidic chip and were focused in the center of channel with proper width by using sheath flow. Secondly, a 532nm laser was used as light source to illuminate on fluorescent cells for exciting, while the optical signals were detected by a photomultiplier (PMT) and transformed into electrical signals. And then, with analysis of electrical signals by Labview programme, fluorescent cells were isolated into three outlets by a DEP force depended on their different fluorescence intensity levels automatically. At last, the purity was measured at 0.1•l/min sample flow rate, 5V voltage, and 800kHz frequency. Of these data for a simple collation and analysis, the purity value was up to 90%. As a result, we demonstrate that our integrated system is capable to count and isolate the genetically modified cells with various fluorescent intensity levels.

8763-48, Poster Session Thursday

Development of energy harvester system for avionics

Zdenek Hadas, Vojtěch Vetiška, Zdenek Ancik, Cestmir Ondrusek, Vladislav Singule, Brno Univ. of Technology (Czech Republic)

This paper deals with a development of energy harvesting system for avionics under European project ESPOSA. This system is used as a source of energy for a unit which can be used for wireless monitoring of an aircraft engine for small aircrafts. Health & Usage Monitoring Systems (HUMS) to reducing installation and maintenance cost is placed in the aircraft engine and an autonomous source of energy is required. There is several source of ambient energy in engine surroundings, which can be used for useful harvesting of energy. Significant sources of ambient energy in an engine area are mainly energy of mechanical vibrations and energy of thermal gradient. Both energy harvesting systems are developed in Brno University of Technology, however, this paper is focused on development of the system for energy harvesting from mechanical vibrations.

The used energy harvesting system consists of an electro-magnetic vibration energy harvester, power management and energy storage element. Nowadays several commercial power management circuits are available on the market. These commercial power management circuits provide a complete system for charging and protecting micropower-storage cells. The vibration energy harvester is a key element of the whole energy harvesting system and harvested power depends on a level and frequency of mechanical vibrations. However harvested output power significantly depends on behavior of the power management circuit with the energy storage element. It is caused by damping effects of harvested power in an electro-magnetic energy converter. Maximal electrical power is harvested when dissipated mechanical power inside the harvester and electrical power are in equilibrium. Therefore the energy harvesting system with commercial power management circuits have to be tested and verified measured results are used for the optimal redesign of the electro-magnetic vibration harvester. This developmental step is necessary for the design of the optimal vibration energy harvesting system and it will be described in this paper.

8763-49, Poster Session Thursday

Optimized energy harvesting from mechanical vibrations through piezoelectric actuators, based on a synchronized switching technique

Petros M. Tsampas, Ioannis Roditis, Vasilis A. Papadimitriou, Panagiotis Chatzakos, Innora Ltd. (Greece); Tat-Hean Gan, TWI Ltd. (United Kingdom)

Increasing demand in mobile, autonomous devices has made energy harvesting a particular point of interest. Systems that can be powered up by a few hundreds of microwatts could feature their own energy extraction module. Energy can be harvested from the environment close to the device. Particularly, the ambient mechanical vibrations conversion via piezoelectric transducers is one of the most investigated fields for energy harvesting. A new technique for optimized energy harvesting using piezoelectric actuators called “Synchronized Switching Harvesting” is explored. Comparing to a typical full bridge rectifier, the proposed harvesting technique can highly improve harvesting efficiency, even in a significantly extended frequency window around the piezoelectric actuator’s resonance. In this paper, the concept of design, theoretical analysis, modeling, implementation and experimental results using CEDRAT’s APA 400M-MD piezoelectric actuator are presented in detail. Moreover, we suggest design guidelines for optimum selection of the storage unit in direct relation to the characteristics of the random vibrations. From a practical aspect, the harvesting unit is based on dedicated electronics that continuously sense the charge level of the actuator’s piezoelectric element. When the charge is sensed, to come to a maximum, it is directed to speedily flow into a storage unit. Special care is taken so that electronics operate at low voltages consuming a very small amount of the energy stored. The final prototype developed includes the harvesting circuit implemented with miniaturized, low cost and low consumption electronics and a storage unit consisting of a super capacitors array, forming a truly self-powered system drawing energy from ambient random vibrations of a wide range of characteristics.

8763-50, Poster Session Thursday

Flexible piezoelectric microgenerators based on nanotextured ZnO films

Eleni Makarona, George Niarchos, George Voulazeris, Christos Tsamis, National Ctr. for Scientific Research Demokritos (Greece)

One of the key features for the next generation of portable wireless nanodevices and nanosystems (critical for sensing, medical science, environmental/infrastructure monitoring, defense technology, and even personal electronics and implantable devices) is for them to become battery-less and self-powered. Harnessing ambient energy from the environment and in particular seizing the effects of motion to provide power for these devices has been recognized as one of the most promising ways for real, sustainable and energetically autonomous devices. This work describes piezoelectric microgenerators developed onto flexible substrates and employing novel nanotextured ZnO films that are suitable for a variety of applications that can range from wearable devices to remote sensor nodes.

The devices presented in this work have been developed on Kapton substrates (formed to resemble 4"-wafers) and have as their core functional material nanotextured ZnO films [1,2] grown via a facile, low-cost, two-step chemical process that involves (i) the creation of a suitable seeding layer employing zero-gels, and (ii) the hydrothermal growth of the films themselves. The nanotextured films were sandwiched between lithographically patterned Al electrodes and the whole structure was encapsulated with PDMS. Output voltages achieved under instantaneous and sinusoidal external excitation reached up to 7V for devices of an area that did not exceed a few cm2. The present methodology –apart from its low-cost- is non-hazardous, environmentally-friendly and can be readily implemented to mass-fabrication, and has thus the potential to become the basis for the production of piezoelectric microgenerators for cost-efficient applications.

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8763-51, Poster Session Thursday

CMOS compatible low-frequency aluminium nitride MEMS piezoelectric energy harvesting device

Nathan M. Jackson, Rosemary O'Keeffe, Finbarr Waldron, Tyndall National Institute (Ireland); Mike O'Neill, Analog Devices Ireland Ltd. (Ireland); Alan Mathewson, Tyndall National Institute (Ireland)

Piezoelectric materials are widely used in various applications including sensors, actuators, and energy harvesting devices. Energy harvesting devices can be used to power autonomous wireless sensors that are placed in remote or difficult to reach areas, where replacing a battery is not practical or feasible. In this paper the authors present work on the fabrication and design of a CMOS compatible Aluminium Nitride (AlN) piezoelectric based MEMS cantilever structure for harvesting vibrational energy. In order for AlN to be piezoelectric it needs to be highly structured in the c-axis (002) crystal orientation. The deposition of highly structured AlN and its polarity is dependent on the underlying films and their crystal orientation. XRD rocking curve results from this paper show a highly oriented (002) AlN film with a FWHM value of 1.5°. Finite element modelling (FEM) of MEMS cantilever structures were used to determine the resonant frequency, stress, and estimated power to be harvested prior to fabrication. The MEMS cantilever structures were fabricated using standard MEMS fabrication techniques using SOI wafers. By optimising the AlN material deposition process and the stress values in the cantilever structures the authors were able to obtain a power density of 2.55 mW/ cm3/g2 for a single MEMS structure with 500 nm thick AlN. The cantilever structure had a resonant frequency of approximately 150 Hz. In this paper the authors also investigated methods to increase the bandwidth of the cantilever structures, by building an array of devices with slightly varying length masses.

8763-52, Poster Session Thursday

Comparison of low-power single-stage boost rectifiers for sub-milliwatt electromagnetic energy harvesters

Gyorgy Szarka, Bernard H. Stark, Stephen G. Burrow, Plamen Proynov, Univ. of Bristol (United Kingdom)

Energy harvesting could provide power-autonomy to many important embedded sensing application areas. However, the available envelope often limits the power output, and also voltage levels. This paper presents the implementation of an enabling technology for space-restricted energy harvesting: Four highly efficient, and fully autonomous power conditioning solutions are presented that are capable of operating at deep-sub-milliwatt levels with less than 1 Vpk AC input. Designs are contrasted, and their performance is compared experimentally, both in terms of their capability to periodically power sensing electronics, and also in their ability to extract power optimally from a kinetic, electromagnetic energy harvester.

The four complete systems, implemented using discrete components, include the power converters, the corresponding ancillary circuits with sub-10 µW consumption, start-up circuit, and an ultra-low-power shunt regulator with under-voltage lockout feature for the management of the accumulated energy. The systems differ in their power converter topology; all are boost rectifier variants that rectify and boost the generator's output in a single stage, thus reducing component count and improving efficiency at sub-1V input, when compared to the more commonly used two-stage designs. Experimental results are derived over a range of 200–1200 µW harvester output power, the system being powered solely by the harvester with no external power supplies. Component selection, and low-power design issues are addressed, and the performance is benchmarked against the maximum extractable power from the harvester under optimum load conditions. Experimental results show overall conversion efficiency, accounting for the quiescent power consumption, as high as 82% at 650 µW input, which remains in the 65–70% range even at 200 µW. Harvester utilisation over 90% is demonstrated in the sub-milliwatt range, resulting in peak overall system effectiveness of 73%. The results demonstrate significant improvement compared to the 50-60% conversion efficiency reported at several milliwatts in previous work.

8763-53, Poster Session Thursday

Load optimised piezoelectric generator for powering battery-less TPMS

David Blažević, Saša Zelenika, Ervin Kamenar, Univ. of Rijeka (Croatia)

In this paper a novel design of a Tire Pressure Monitoring System (TPMS) based on piezoelectric harvesting of kinetic energy produced by random vibrations of a vehicle's wheel is presented. Energy harvesting is the process of converting ambient energy into usable electric energy by employing different conversion mechanisms. In general, TPMS are gaining attention due to new EU legislative which is proposing that from the year 2014 each new vehicle is equipped with TPMS. These systems are very important when considering passenger safety (9% of accidents can be accounted to improper tire pressure) and vehicle efficiency (0.2 bar of under inflation causes 2% increase in fuel consumption, and a 25% decrease of tire lifetime). A piezoelectric conversion principle is used in the presented TPMS concept because of its design simplicity and high energy densities per device volume. On road experiments are performed in order to measure the frequencies and amplitudes of wheel vibrations. It is hence determined that the highest amplitudes occur in an unperiodic manner. The proposed prototype design consists of an inertial type (beam-mass system) energy harvester mounted on the

outside of the vehicle wheel. Initial tests are performed in laboratory conditions; after successful tuning and system set-up optimization, operation tests are performed on road. The energy obtained from the piezoelectric bimorph is managed by employing a control electronics which converts AC voltage to DC and conditions the output voltage to make it compatible with the load (sensor). The control electronics also manages the sleep/measure/transmit monitoring cycles so that the harvested energy is efficiently used. The system is finally successfully tested in real road conditions and a measurement cycle of approximately one minute is accomplished.

8763-54, Poster Session Thursday

Flat inductors for human motion energy harvesting

Juris Blums, Galina Terlecka, Ilgvars Gornevs, Ausma Vilumsone, Riga Technical Univ. (Latvia)

The human motion energy harvesting is under investigation. The up-to-now proposed devices for human motion energy harvesting are three-dimensional devices and are not suitable for integration into the clothing elements [1, 2]. The aim of this investigation: to develop electrodynamic human motion energy harvester that will consist only from flat elements and be integrable into the apparel. Main parts of the developed human motion energy harvester are flat, spiral-shaped inductors. Voltage pulses in such flat inductors can be induced during the motion of a permanent magnet along its. Such effects can be achieved during the relative motion of one part of apparel along the other. Due to the flat structure, inductors can be completely integrated into the parts of the clothes and it is not necessary to keep empty place for the movement of the magnet, as in usual electromagnetic harvesters. Due to the above-mentioned properties, the mean power density of developed harvester 0,7 mW/cm3 exceeds the values of it given for three-dimensional harvesters with cylindrical coil [2]. The prototype of the clothing, jacket with integrated electrodynamic human motion energy harvester with flat inductors is tested. The volume of the harvester in the jacket - 4,8 cm3, mass - 45 g and developed mean power during the walking with speed 6 km/h – 0,21 mW.

The theoretical model for the induction of the electromotive force due to the magnet's movement is created for the basic shapes (circle, rhombic, squared) of the inductive elements and the results (shape of voltage pulse, developed power and generated energy) of the calculations are in a good qualitative and quantitative coincidence with an experimental research.

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8763-55, Poster Session Thursday

Modeling, simulation and experimental testing of the MEMS thermoelectric generators in wide range of operational conditions

Zdenek Ancik, Radek Vlach, Ludek Janak, Brno Univ. of Technology (Czech Republic); Pavel Kopecek, UNIS, spol. s.r.o. (Czech Republic); Zdenek Hadas, Brno Univ. of Technology (Czech Republic)

A future and development of today's society strongly depends on an ability to utilize new sources of clean and renewable energy. Energy harvesting is independent branch and current trend in this area, which uses energy freely available in an environment. The one of prospective ways of energy harvesting is based on thermoelectric generating technology (TEG).

The aim of this paper is to examine the performances of thermoelectric generator based on microelectromechanical systems technology (MEMS) in wide range of operational conditions. The goal is to evaluate capability of this technology for a development of an independent energy source for aircraft applications. Complex overview of MEMS TEG properties obtained by computational modeling, simulations and experimental testing is utilized to define critical phenomena of MEMS TEG technology.

The computational modeling based on analytic and numeric approach is applied to complex mathematical description of MEMS TEG properties. The numerical model of MEMS TEG based on finite element methods (FEM) is created by the computational software ANSYS Thermo-electric module. The analytic approach is performed in the Matlab software.

The properties of two commercially available MEMS TEG modules are analyzed and experimentally tested (eTEG HV56 Power Generator module produced by Nextreme Thermal Solutions and a Thermogenerator package TGP-751 module produced by Micropelt). An electronically controlled heating unit is used for set the temperature of hot side of TEG. The cold side of TEG is considered as ambient temperature constituted by climatic chamber WKL 100 with temperature range from -70°C to +180°C. The results of the simulations and experimental testing are evaluated and compared.

On basis of the obtained results a capability of the MEMS TEG is judged as the independent source of energy for aircraft applications covering all range of the aircraft operational conditions. The results shown in this study are also essential for further design of modules cases, their mounting and positioning on an aircraft.

8763-56, Poster Session Thursday

Design and material aspects for thermoelectric energy harvesting devices in aircrafts

Alexandros Elefsiniotis, Nikolaos Kokorakis, Thomas Becker, EADS Deutschland GmbH (Germany); Ulrich Schmid, Technische Univ. Wien (Austria)

Greener, more power efficient technologies as well as cost reduction are driving forces in energy efficient systems. Energy autonomous wireless health monitoring systems can potentially reduce aircraft maintenance costs by requiring no conventional power supply or supervision and by providing information of the health of an aircraft without human interaction. Thermoelectric energy harvesting seems the best choice for aircraft related applications, since sufficient energy can be generated to power up a wireless sensor node. The general concept is based on an artificially enhanced temperature difference across a thermoelectric generator, which is created by attaching one side to the fuselage and the other side to a thermal mass, which, in this case, is a phase change material (PCM) [1]. In this work, a thermoelectric energy harvesting device is investigated varying systematically key parameters, such as container design and/or PCM, in order to further increase the overall efficiency. In detail, two different geometries and three different container materials are evaluated. As input and output parameters, the temperature profiles as well as the voltage of the thermoelectric generators (TEGs) are given. The output power and the total energy are determined by connecting a load resistor in parallel. Furthermore, the power to weight ratio for each combination is provided according to theoretical considerations and experimental tests done in a climate chamber mimicking a real flight profile. All in all, it can be summarized that the results are very promising so that a carefully selected combination of two different container designs shows a high potential to enhance the overall efficiency substantially.

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8763-57, Poster Session Thursday

A nano-power energy harvesting IC for arrays of piezoelectric transducers

Michele Dini, Matteo Filippi, Aldo Romani, Univ. degli Studi di Bologna (Italy); Valeria Bottarel, Giulio Ricotti, STMicroelectronics (Italy); Marco Tartagni, Univ. degli Studi di Bologna (Italy)

There is an increasing interest in energy harvesting for supplying low-power electronic microsystems. Much energy is spread in the environment in forms like vibrations, thermal gradients, electromagnetic radiation. Thus, multi-source power conversion is a viable solution to increase output power even though relatively unexplored. Generally, an important element for a power converter is the ability to provide a positive energy budget and high efficiency even in case of very weak and irregular power sources. In literature, IC and discrete implementations achieved this goal with intrinsic power consumptions of tens of uW/source, which limit the most aggressive applications.

This paper describes the design of a multi-source energy harvesting IC for arrays of independent piezoelectric transducers with an overall quiescent power consumption below 1 µW; the IC is suitable for almost any macro-scale piezoelectric transducer with no specific limitations. The proposed converter has been designed in a STMicroelectronics 0.32µm BCD technology and can manage up to 5 AC/DC channels (e.g. piezoelectric or electromagnetic transducers). The IC implements a boost converter based on synchronous electrical Charge extraction, which tracks vibrations amplitude. A single external inductor is time-shared among all transducers, and does not impact on overall system dimensions. Conflicts in accessing the inductor are handled by an arbiter, implemented with a fully asynchronous FSM for minimizing switching power. The designed converter is fully autonomous and suitable for battery-less operation; a passive conduction path is enabled during start-up and then cut off. Mainly due to subthreshold bias and energy saving techniques, the circuit draws an average quiescent current of 50 nA and additional 60 nA per channel, achieving the extremely low power consumption of 175 nW/source at 2.5 V. The area is 4.6 mm2 and the estimated conversion efficiency ranges between 70% and over 85%, obtained with ultra-low power synchronous rectification techniques.

8763-58, Poster Session Thursday

Design, fabrication and characterization of a very low frequency piezoelectric energy harvester designed for heart beat vibration scavenging

Mikaël Colin, Libor Rufer, Skandar Basrour, TIMA Lab. (France)

Current version of implatable cardioverter defibrillators (ICDs) and pacemakers consists of a battery-powered pulse generator connected onto the heart though electrical leads inserted through the veins. However, it is known that the long-term lead failure may occur and cause the dysfunction of the device. When required, the removal of the failed leads is a complex procedure associated with a potential risk of mortality [1,2]. As a consequence, the main players in the field of intracardiac implants are preparing the next generation of devices: miniaturized and autonomous leadless implants, which could be directly placed inside the heart (Fig 1). The idea of a stand-alone cardiac implant is not new and several approaches for powering the device have been suggested [3,4,5]. More recently, Karami [6] presented the simulation results of a piezoelectric energy harvester based on [3] and operating at 40Hz that could in theory power a cardiac implant with heart-induced vibrations. Deterre [7] presented an acceleration spectrum of the heart obtained by placing accelerometers inside several heart cavities (Fig 2). It appears that the heart vibration energy is rather localized at lower frequencies in the 15-30Hz-frequency band.

In this paper, we will discuss the frequency content of the heart vibration spectrum, and the dimensional restrictions in the case of a leadless pacemaker. In combination with the requirements in terms of useable energy, we will present a design study of a resonant piezoelectric scavenger aimed at powering such a device. In particular, we will show how the frequency-volume-energy requirement leads to new challenges in terms of power densities, which are to be addressed through implementation of innovative piezoelectric thick films fabrication processes. This paper also presents the simulation, fabrication and the testing of an ultralow frequency (15Hz) resonant piezoelectric energy harvester prototype (Fig. 3). Using both harmonic (50mg) and actual heart-induced vibrations, we obtained an output power of 60µW and 10µW respectively. Finally, we will place emphasis on the new constraint represented by the gravitational (orientation) sensitivity inherent to these ultra low frequency resonant energy harvesters (Fig.4).

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8763-59, Poster Session Thursday

A miniaturised autonomous sensor based on nanowire materials platform: the SiNAPS mote

Naser Koshro-Pour, Maher Kayal, Ecole Polytechnique Fédérale de Lausanne (Switzerland); Guobin Jia, Fritz Falk, Institut für Photonische Technologien e.V. (Germany); Erik Puik, Cees J. M. van Rijn, Nanosens B. V. (Netherlands); Adrian Nightingale, John C. de Mello, Imperial College London (United Kingdom); Nikolay Petkov, Yordan M. Georgiev, Tyndall National Institute (Ireland); Justin D. Holmes, Univ. College Cork (Ireland); Michael Nolan, Giorgos Fagas, Tyndall National Institute (Ireland)

A micro-power energy harvesting system based on core(crystalline Si)-shell(amorphous Si) nanowire solar cells together with a nanowire-modified CMOS platform for sensing hydrogen gas have been developed as components of dust-sized autonomous chemical sensor nodes. The mote system (SiNAPS) is supplemented by low-power electronics for power management and sensor interfacing, on a chip area of just 0.25mm2 and fabricated with 0.18µm CMOS process. We show that by direct charging of the target battery (e.g., NiMH microbattery or Li-ion thin-film battery) end-to-end efficiencies as high as 90% under AM1.5 illumination (80% under 100 times reduced intensity) are achievable. This requires matching the voltages of the photovoltaic module and the battery but circumvents maximum power point tracking. The photovoltaic response of single solar cells show efficiencies up to 10% under AM1.5 illumination and open circuit voltage, Voc, of 450-500mV. To match the battery's nominal voltage the miniaturised solar cells (~1mm2 area) are connected in series via wire bonding. A complete module of 12 cells delivers an open circuit voltage of 5.7V with a maximum output power of about 616µW at VMPP of 4.2V. The chemical sensor platform, also with a mm2 area, can detect hydrogen gas concentrations in the 100-100,000 ppm range and a broad temperature range using an extremely low power sensing interface circuit. By using Telran TZ1053 radio for wireless communication, the total average power consumption for the SiNAPS mote is less than 30µW to send one sample measurement every 10 seconds. The possibility of low-power miniaturised chemical sensors of liquid analytes through microfluidic delivery to surface functionalised silicon nanowires is also presented. The verified specifications of the various components and their proof-of-concept integration demonstrate the potential of further miniaturization and application of sensor nodes beyond the typical physical sensors, and are enabled by the nanowire materials platform.

8763-60, Poster Session Thursday

Optimal composition of bistable piezoelectric plates for maximised broadband energy harvesting performance

David N. Betts, Christopher R. Bowen, Hyunsun A. Kim, Univ. of Bath (United Kingdom); Daniel J. Inman, Univ. of Michigan (United States)

In this paper optimisation of a bistable piezoelectric-composite laminate combination for energy harvesting performance is presented. The arrangement of the device utilises the inherent bistability present in a specific family of asymmetric composite laminates to strain a piezoelectric layer bonded to the laminate. In the presence of mechanical vibrations 'snap-through' of the laminate between the two stable states leads to a large structural displacement and the generation of piezoelectricity. While many vibration based harvesting devices are often tuned to operate near resonance, such resonant devices are not easily scalable and performance falls significantly when attempting to harvest mechanical vibrations away from these frequencies. It has been demonstrated that due to the structural bistability of the asymmetric laminate, the presented device is effective over a wider range of frequencies with potential to generate power of the order of 25 mW across a broadband range of excitation frequencies. We develop an electrical-mechanical coupled dynamics model of the piezoelectric plate and apply to optimise for maximum electrical power output. Design variables considered include the geometry of the device, size and location of piezoelectric elements, and the load resistance of the harvesting circuit. The performance of optimal designs is examined experimentally for a range of vibration modes.

8763-61, Poster Session Thursday

Design, fabrication and characterization of a micromachined piezoelectric energy harvester excited by ambient vibrations

Ali Badar M. Alamin Dow, Univ. of Toronto (Canada); Achim Bittner, Ulrich Schmid, Technische Univ. Wien (Austria); Nazir P. Kherani, Univ. of Toronto (Canada)

With the continual drive to develop self-powered micro electro mechanical system (MEMS) devices vis-à-vis operational efficiency and safe operation enhancements, there is a need for autonomous energy harvesters. Autonomous energy harvesters are highly desirable as they eliminate the necessity of wiring and associated complexity, increase system performance, avoid battery replacement (where applicable) and related maintenance operations, and increase the mobility and portability of the system. Piezoelectric based vibrational energy harvesting technique is deemed the most promising approach for indoor/outdoor applications considering that vibrational sources are pervasive and accessible. Piezoelectric conversion is a very attractive and promising approach because of its high energy density, CMOS (complementary metal oxide semiconductor) compatibility with the use of aluminum nitride (AlN), adequate generated power level (order of 100 microwatts), and minimal microfabrication restrictions. A piezoelectric energy harvester consists of a piezoelectric film sandwiched between electrodes which are used to collect the generated power. When the piezoelectric material is subjected to mechanical vibrations, electrical energy is generated due to the induced stress in the material.

This research work presents the design, fabrication and characterization of micromachined piezoelectric energy harvester stimulated by ambient random vibrations utilizing AlN as a piezoelectric material. The device design consists of a silicon cantilever beam on which AlN is sandwiched between two electrodes, and a silicon seismic mass at the end of the cantilever beam. The generated electric power of the devices was experimentally measured at various acceleration levels. A maximum power of 34 μW was obtained at an acceleration value of 2g for the device which measure 5.6 x 5.6 mm2. Various unpackaged devices were tested and evaluated in terms of the generated power, resonance frequencies and at various acceleration values.

8763-62, Poster Session Thursday

Photovoltaic energy harvesting for smart sensor systems

Martin Kasemann, Albert-Ludwigs-Univ. Freiburg (Germany); Karola Rühle, Albert-Ludwigs-Univ. Freiburg (Germany) and Fraunhofer-Institut für Solare Energiesysteme (Germany); Karim M. Gad, Albert-Ludwigs-Univ. Freiburg (Germany); Stefan W. Glunz, Fraunhofer-Institut für Solare Energiesysteme (Germany)

Commercial photovoltaic cells used in energy harvesting applications suffer from low power conversion efficiencies below 10%, especially at low light intensities. High-efficiency cells, on the other hand, are typically optimized for the AM 1.5 sun spectrum at 1000 W/m2 light intensity, which is far away from the required operating range. This paper presents the general design rules for photovoltaic energy harvesters with special attention to the low intensity range. It infers design rules for different material classes like crystalline silicon, amorphous silicon and III-V photovoltaic cells and discusses the expected potential of the different technologies. Laboratory results for silicon cells with efficiencies of more than 15% at an intensity below 0.2 mW/cm2 (1/500th of the sun intensity) are analyzed. General routes for future development and commercialization are discussed.

8763-63, Poster Session Thursday

Parametrization of ambient energy harvesters for complementary balanced electronic applications

Yannick Verbelen, Abdellah Touhafi, An Braeken, Erasmus Univ. College Brussels (Belgium)

The specific technical challenges associated with the design of an ambient energy powered electronic system currently requires thorough knowledge of the environment of deployment, energy harvester characteristics and power path management. In this work, a novel flexible model for ambient energy harvesters is presented that allows decoupling of the harvester's physical principles and electrical behavior using a three dimensional function. The model can be adapted to all existing harvesters, resulting in a design methodology for generic ambient energy powered systems using the presented model. Concrete examples are included to demonstrate the versatility of the presented design in the development of electronic appliances on system level.

Finally, a work flow is presented to apply the proposed theory for maximum power point tracking (MPPT) of ambient energy powered electronic systems using multiple energy harvesters.

8763-64, Poster Session Thursday

Study of hybrid organic-inorganic thin films deposited by PECVD for gas sensors applications

Julien Piccot, Muriel Matheron, CEA Grenoble (France); Christophe Licitra, Nevine Rochat, Commissariat à l'Énergie Atomique (France); Julien El Sabahy, CEA Grenoble (France); Vincent Jousseaume, CEA-LETI (France)

Volatile organic compounds (such as benzene or toluene) are increasingly present in our environment and represent a significant risk for human healthcare. Then, it is necessary to be able to detect such gases even at low concentrations (few ppm to few ppb). Due to their excellent sensitivities, gravimetric sensors are good candidates for this type of detection. In order to be efficient, these sensors are functionalized using sensitive thin films. Indeed, the transducer should be coated with a chemically active layer whose function is to adsorb and concentrate target gases, optionally selectively and in a reversible manner.

In this work, we have investigated hybrid organic - inorganic materials

deposited using Plasma Enhanced Chemical Vapor Deposition (PECVD) for toluene detection. By varying the parameters of the PECVD deposition process, we have studied the influence of the chemical composition and structure of the thin films on the affinity to aromatic compounds in the gas phase. To this prospect, several physicochemical characterizations (Infrared spectroscopy, ellipsometry, contact angle, …) were performed. Then, the affinity of these organic-inorganic thin films toward aromatic compounds was investigated on Quartz Crystal Microbalance (QCM). This work demonstrates that organic-inorganic hybrid thin films obtained by PECVD are good candidates for the detection of aromatic compounds (such as toluene). High partition coefficient with toluene (K>5000) can be found by appropriately tuning the chemical composition and film microstructure.

8763-65, Poster Session Thursday

Zero power Humidochromic sensor based on polymeric photonic structures

Ioannis Raptis, National Ctr. for Scientific Research Demokritos (Greece); Margarita Chatzichristidi, Univ. of Athens (Greece); Isidora Georgaki, Athanasios Botsialas, Panagiotis Argitis, Nikolaos Papanikolaou, National Ctr. for Scientific Research Demokritos (Greece)

One-dimensional photonic crystals (1D-PC) are an excellent tool for rendering an incidence broad-band light source to a reflected narrow-band wavelength light. In the current study the development and characterization of 1-D PC using lithographic materials with the same casting solvent, surpassing that way the main limitation of polymeric PC, is introduced. Furthermore, the employ of patternable polymeric materials renders the 1-D PC adequate to be used as a narrow wavelength band source on a more complex device.

Two transparent polymer photoresists, poly(methyl methacrylate) (PMMA) and a negative epoxy-based chemically amplified resist (EPR), having an index contrast of ~0.11 in the visible range (nPMMA = 1.48 whereas nEPR = 1.59), were used for the fabrication of the 1D-PC. The alternating polymeric films were prepared via spin-coating from PGMEA based solutions, on glass substrate, followed by a post apply bake step at 110°C for 5min. The EPR resist was exposed at 254nm and post exposure baked (110°C for 5min) giving a crosslinked film. For the needs of the present study, polymeric film thickness was set to 100nm so that the reflectance peak is at ~600nm. The resulted thickness of each polymeric layer as well as the reflectance spectrum was measured with White Light Reflectance Spectroscopy [FR-Basic, Theta Metrisis]. The reflectance spectrum recorded for 5, 10 and 15 double layer stack is presented in fig. 1. The structure of the 1D-PC was confirmed by Secondary Ion Mass Spectrometry working in depth profiling mode. Variation of the CHO- and Sb- signals reflects multilayer structure with 20 alternating layers of PMMA (CHO- signal) and EPR (Sb- signal of the photoacid generator, PAG). C- and Si- signals, shown in fig. 2, confirm stability of the sputtering process and indicate the interface with the substrate.

8763-66, Poster Session Thursday

Investigation on the dielectric breakdown behavior of aluminum nitride thin films at different temperatures applying a time-zero approach

Michael Schneider, Achim Bittner, Ulrich Schmid, Technische Univ. Wien (Austria)

In MEMS (micro electromechanical system) devices, piezoelectric aluminum nitride (AlN) thin films are commonly used as functional material for sensing and actuating purposes. Additionally, AlN features excellent dielectric properties as well as a high chemical and thermal stability, making it also a good choice for passivation purposes. With those aspects and current trends towards minimization in mind, the dielectric reliability of thin AlN films is of utmost importance.

In this study, we present results on the transversal dielectric strength of 100 nm AlN thin films deposited by dc magnetron sputtering. The dielectric strength was measured using a time-zero approach, where the film is stressed using a fast voltage sweep up to the point of breakdown. The measurements were performed using different contact area sizes, different sweep speeds and temperatures. In order to achieve statistical significance, a couple of measurements were performed for each environment parameter set and the results analyzed using the Weibull approach.

The results show, that the breakdown field in positive direction increases with pad size and voltage ramp sweep speed, as expected. Furthermore, a decrease of the breakdown field with increasing temperature up to 598 K is observed with the mean field to failure following an exponential law typical for temperature activated processes. The activation energy was determined to 27 meV, allowing an extrapolation of the breakdown field towards even higher temperatures. In negative field direction no breakdown occurred, which is attributed to the MIS structure of the sample and hence, the increasing depletion layer forming in the silicon dominating the observed current behavior. The influence of the depletion layer is analyzed using different voltage ramp speeds.

8763-67, Poster Session Thursday

Interfacial adhesion between iron fillers and the silicone matrix in magneto-rheological elastomers at high deformations

Tobias Pössinger, CEA LIST (France); Christian Bolzmacher, Commissariat à l'Énergie Atomique (France); Laurence Bodelot, Nicolas Triantafyllidis, Ecole Polytechnique (France)

Magneto-rheological elastomers (MREs) not only alter their viscoelastic properties in response to an external stimulus but can also undergo very high deformation states. While the former effect is exploited in tunable vibration dampers the latter may be of interest in haptic devices. A large out of plane deformation can be introduced when the material is chosen appropriately. Using a coil or a permanent magnet matrix placed underneath the MRE surface, patterns can be displayed on the surface.

This work investigates as a first step to the realization of such a haptic MRE device the interfacial adhesion between the iron fillers and the silicone matrix in MREs at high deformations. Carbonyl iron powder with mechanically soft, spherical particles with an average size of 7.2 – 9.2 µm was mixed in a soft silicone matrix (Shore 00-30), degassed and cured under temperature. The presence of a homogeneous magnetic field up to 0.78T during curing allowed the formation of particle chains. In uniaxial tensile testing with engineering strains up to 170%, the static mechanical behavior of the samples with different particle quantities (10 – 80 wt%) lengthwise and crosswise to the particle alignment was characterized. Tensile tests of the samples under optical microscopy showed the effect of interfacial slipping and debonding between the two phases. To improve the interfacial adhesion, primers were applied to the iron particles in a second series of samples before the mixing and polymerization process. These samples were characterized and results compared to the untreated ones. An enhanced adhesion of the silicone matrix to the metal filler and an improved compatibility between the different phases resulting in a reinforced matrix and increased tear strength could be proven. Furthermore, images of the particle-matrix-interface realized with scanning electron microscopy showed a more elaborated interface compared to samples without primer additive. Based on these experimental results design guidelines are proposed to improve the performance of such composites at high deformation states.

8763-68, Poster Session Thursday

Investigations on the high temperature compatibility of various adhesion layers for platinum

Abdallah Ababneh, Ahmad N. Al-Omari, Yarmouk Univ. (Jordan); MySa Marschibois, Dara Feili, Helmut Seidel, Univ. des Saarlandes (Germany)

For microsystems operating at high temperatures platinum is a widely used metallization layer for Si-based devices [1] because it is relatively inert to oxygen. A difficulty when using Pt is its bad adhesion to silicon and silicon dioxide surfaces. Traditionally this problem is solved by using adhesion layers (typical thickness 10-20 nm) such as titanium (Ti) at the interface between Si and Pt.

Our purpose in this work is to find adhesion layers for Pt which are suitable at high temperatures up to 800°C. In this paper we investigated different adhesion layers, such as Ti, tantalum (Ta), aluminium nitride (AlN), aluminium oxide (Al2O3) and titanium oxide (TiO2). All films were deposited by using the sputter technique. SEM and FIB were applied to investigate the film morphology.

After annealing at 800°C, Al2O3 and TiO2 showed a dense oxide layer between Pt and Si. Apart from the formation of hillocks on the surface they seem to be suitable as adhesion layers for Pt at high temperatures.

Our investigations showed that AlN is not suitable as adhesion layer for Pt. Ti and Ta are also not suitable for high temperatures, diffusing strongly into Pt layers leading to the formation of oxide precipitates (TiOx or TaOx) in the Pt grain boundaries. In addition, the formation of crystallites (hillocks) on the surface was detected.

In the near future, the electrical resistance of the Pt-layers will be investigated.

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8763-69, Poster Session Thursday

2-2 composites based on [011]-poled relaxor-ferroelectric single crystals: piezoelectric anisotropy to hydrostatic response

Christopher R. Bowen, Univ. of Bath (United Kingdom); Vitaly Y. Topolov, Southern Federal Univ. (Russian Federation); David N. Betts, Hyunsun A. Kim, Univ. of Bath (United Kingdom)

In this paper the effect of crystallographic orientation on the piezoelectric anisotropy and hydrostatic piezoelectric coefficients of 2–2 parallel-connected single crystal (SC) / auxetic polymer composites is analysed for sensor, hydroacoustic and energy harvesting applications. The SC components examined are the relaxor-ferroelectric solid solutions of (1 – x)Pb(A1/3Nb2/3)O3–xPbTiO3 (A= Mg or Zn) and xPb(In1/2Nb1/2)O3–yPb(Mg1/3Nb2/3)O3–(1 – x – y)PbTiO3. The SC layers are poled along the perovskite unit-cell [011] direction and are characterised by two non-180deg domain types in the domain-engineered state with mm2 symmetry. The effective electromechanical properties and related figures of merit of the composites are determined using the matrix method [1]. The orientation of the domains in the SC layer are shown to have a significant influence on the effective piezoelectric coefficients d3j*, g3j*, squared figure of merit d33*g33*, electromechanical coupling factors k3j*, and hydrostatic analogs of these parameters. Large values of the effective parameters and inequalities |d33*/ d3j*|> 5 and |k33*/ k3j*|> 5 (j= 1 and 2) are achieved at specific orientations of the SC crystallographic axes and are due to anisotropy of its elastic and piezoelectric properties. The incorporation of auxetic polyethylene with a negative Poisson's ratio leads to a considerable increase of the hydrostatic parameters (dh*~ 2000 pC/N, dh*gh*~3 (GPa)-1, kh*~0.80, etc.). Advantages of these novel composites over conventional ceramic / polymer composites are to be taken into account for transducer, hydroacoustic and energy harvesting applications.

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8763-71, Poster Session Thursday

Simulation and characterization of silicon nanopillar-based nanoparticle sensors

Hutomo S. Wasisto, Stephan Merzsch, Andrej Stranz, Kai Huang, Andreas Waag, Erwin Peiner, Technische Univ. Braunschweig (Germany)

Nanopillar-based structures hold promise as highly sensitive resonant mass sensors for a new generation of aerosol nanoparticle (NP) detecting devices because of their very small masses. In this work, the possible use of a silicon nanopillar (SiNPL) array as a nanoparticle sensor is investigated. The sensor structures are created and simulated using a finite element modeling (FEM) tool of COMSOL 4 to study the resonant characteristics and the sensitivity of the SiNPL for femtogram NP mass detection. Instead of using 2D plate models or simple single 3D cylindrical pillar models, FEM is performed with SiNPLs in 3D structures based on the real geometry of experimental SiNPL arrays employing a piezoelectric stack for resonant excitation. In order to achieve an optimal structure and investigate the etching effect on the fabricated resonators, SiNPLs with different designs of cross-sections, sidewall profiles, lengths, diameters, pillar locations, and excitations are simulated and analyzed. To validate the FEM results, fabricated SiNPLs with a high aspect ratio of ~60 are employed and characterized in resonant frequency measurements. SiNPLs are mounted onto a piezoactuator inside a scanning electron microscope (SEM) chamber which can excite SiNPLs into lateral vibration. The measured resonant frequencies of the SiNPLs with diameters about 650 nm and heights about 40 µm range from 451.56 kHz to 458.21 kHz, which agree well with those simulated by FEM. By depositing different NPs (i.e., carbon, TiO2, SiO2, Ag, and Au NPs) on the SiNPLs, the decrease of the resonant frequency is clearly shown. Furthermore, the deflection of a SiNPL is enhanced by increasing the applied piezoactuator voltage. As intended to be used in workplace condition, the air flow parameters with controlled pressure and temperature are added to the SiNPL models by combining additional modules of multiphysics which can influence the sensor performances.

8763-72, Poster Session Thursday

Simulation, design and fabrication of a planar micro thermoelectric generator

Silvia Pelegrini, Univ. Federal de Santa Catarina (Brazil); Andrea Adami, Cristian Collini, Paolo Conci, Leandro Lorenzelli, Fondazione Bruno Kessler (Italy); André Pasa, Univ. Federal de Santa Catarina (Brazil)

Thermoelectric generators can be used to power electronic devices in situations where battery power is limited, powering from the grid is not practical or it is required to provide autonomous operation without maintenance or human intervention [1]. This study describes the design, simulation, and micro fabrication of a micro thermoelectric generator (µTEG) based on planar technology using constantan (CuNi) and copper (Cu) thermocouples deposited electrochemically (ECD) on silicon substrate. The present device configuration using thin films (900nm thickness) was selected because it can be manufactured into large area and also on flexible substrate, with low cost production, and can be used to exploit waste heat from equipments or hot surfaces in general, using the environment temperature and heat exchange by convection as cold side of the device. In the current implementation, the silicon structure has been designed and optimized with FE simulation in order to exploit the different thermal conductivity of silicon and air gaps to produce the maximum temperature difference on a planar surface. The results showed that a temperature difference of 10K across the structure creates a temperature difference of 5.3K on the thermocouples, thus providing a 53% efficiency of thermal distribution, depending on the heat transfer coefficients – h (W m-2 K-1), calculated trough of equations of the applied thermodynamics. Efficiency of module is investigated under different working condition, showing the dependence of module output on the external heat exchange (natural and forced convection), with a maximum generated potential of 13.3V/m2K and a thermoelectric efficiency of 5.9µW K-2 m-2. The experimental testing showed good thermoelectric efficiency in comparison with similar devices in the literature [2, 3].

[1] Thermo Life Energy Corp: www. PowerByThermoLife.com

[2] Glatz W et al. J MEMS (2009) 18 (3) 763–72

[3] Xie J et al. J MEMS (2010) 19 (2) 317–24.

8763-73, Poster Session Thursday

Advanced modeling of AlN-based micromachined energy harvesters driven by beta-emitting radioisotopes

Ali Badar M. Alamin Dow, Nazir P. Kherani, Univ. of Toronto (Canada); Ulrich Schmid, Technische Univ. Wien (Austria)

This work presents mathematical modelling of unimorph and bimorph AlN piezoelectric micromachined harvesters utilizing an energetic electron source - amenable to powering miniaturized devices such as MEMS (micro electro mechanical system) sensors. Tritiated silicon, as the energetic electron source, is appropriately aligned under a cantilever structure such that the emitted electrons are trapped by the collecting surface of the cantilever, thereby rendering it negatively charged while the electron emitting surface becomes positively charged. As a result, the attractive electric force causes the cantilever to bend towards the electron emitting surface until it makes contact and is discharged, and thus the cantilever snaps back. Tritium, which is immobilized within the silicon matrix, produces very low-energy decay betas and as such provides an artificial long-lived (12.3 years, corresponding to the half-life of tritium) vibrational source. Further, major advantages of tritium over other radioisotopes is that it is free of gamma-radiation and thus no special shielding requirements are needed. Moreover, tritium is readily immobilized within the silicon matrix using CMOS compatible processes. Thus, through the continuous charge-discharge sequences, vibrational cycles are generated in the piezoelectric cantilever. The resulting energy from the piezoelectric capacitor is rectified to provide electrical power to MEMS devices. Detailed electromechanical analysis and modelling of unimorph and series and parallel bimorph architectures are presented. The effect of damping ratio, air friction, generated electric power, output voltages, optimal load resistance as well as resonant frequencies for various gaps between the radioisotope source and the cantilever are analysed, calculated and validated against experimental findings. Very good agreement between the results of the analytical model and the available experimental findings is demonstrated, thus providing assurance for the optimization study of tritiated silicon radioisotope excited piezoelectric energy harvesters.

8763-74, Poster Session Thursday

Modeling methods of MEMS microspeaker, with capacitive working principle

David Tumpold, Manfred Kaltenbacher, Technische Univ. Wien (Austria); Christoph Glacer, Mohsin Nawaz, Alfons Dehé, Infineon Technologies AG (Germany)

The market for mobile devices like tablets, laptops or mobile phones is increasing rapidly. Device housings get thinner and energy efficiency is more and more important. Micro-Electro- Mechanical-System (MEMS) loudspeakers, fabricated in complementary metal oxide semiconductor (CMOS) compatible technology merge energy efficient driving technology with cost economical fabrication processes. In most cases, the fabrication of such devices within the design process is a lengthy and costly task. Therefore, the need for computer modelling tools capable of precisely simulating the multi-field interactions is increasing. The accurate modelling of such MEMS devices results in a system of coupled partial differential equations (PDEs) describing the interaction between the electric, mechanical and acoustic field. For the efficient and accurate solution we apply the Finite Element (FE) method. Thereby, we fully take the nonlinear effects into account: electrostatic force, charged moving body (loaded membrane) in an electric field, geometric nonlinearities and mechanical contact during the snap-in case between loaded membrane and stator. To efficiently handle the coupling between the mechanical and acoustic fields, we apply Mortar FE techniques, which allow different grid sizes along the coupling interface. Furthermore, we present a recently developed PML (Perfectly Matched Layer) technique, which allows to limit the acoustic computational domain even in the near field without getting spurious reflections. For computations towards the acoustic far field we us a Kirchhoff Helmholtz integral (e.g, to compute the directivity pattern).

We will present simulations of a MEMS speaker system based on a single sided driving mechanism as well as an outlook on MEMS speakers using double stator systems (pull-pull-system), and discuss their efficiency (SPL) and quality (THD) towards the generated acoustic sound.

8763-75, Poster Session Thursday

Experimental methodology to measure damping in microstructures by using the actuation force hysteresis curve

Giorgio De Pasquale, Aurelio Soma, Politecnico di Torino (Italy)

The study of damping in MEMS is crucial to predict their dynamic response and to estimate functional parameters such as switching time, release time and quality factor. Geometrical features (borders, perforations, anchors, etc.) complicate the airflow and make necessary the validation of simulated results. Fluid damping is the most relevant dissipation, followed by structural dissipations, thermo-elastic damping, anchor losses, surface effects and electric losses.

The damping coefficient of MEMS is generally derived from the peaks of the structural frequency response function (FRF) by using the so-called half power method, as literature testifies. The authors already experienced this method, both in air and with a vacuum chamber. Despite this experimental approach is widely used, it is affected by two main drawbacks: firstly, it requires highly precise and automated detection instruments (e.g. microscopes with embedded generator and control algorithm) to perform measurements in reasonably short time. Secondly, the damping coefficient can be calculated only at resonance without any information at other frequencies, by limiting the comprehension of nonlinear systems.

The alternative method presented here is based on the measurement of damping from the hysteresis cycle of the actuation force. This method applies in the time domain and allows conducting the measurement at any frequency and vibration amplitude. The effectiveness of this methodology on MEMS is proved by comparing the damping results on some MEMS samples with those provided by two alternative experimental strategies: the interpolation of the exponential decay of the structure response to a step force and the calculation of damping from the half power level of the FRF. The samples, designed by the authors, are gold microplates with square holes and elastic springs. The measurements are conducted by a laser vibrometer Polytech MSA500. The comparison shows good agreement among damping coefficients calculated with the different approaches (differences lower than 6%).

8763-77, Poster Session Thursday

A large deflection model of silicon membranes for testing intrinsic stress of MEMS microphones by measuring pull-In voltage

Florian Oesterle, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany); Alfons Dehé, Franz Fink, Harald Kuhn, Infineon Technologies AG (Germany); Robert Weigel, Alexander Kölpin, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany)

Mechanical parameters, especially mechanical stress of membranes used in silicon microphones strongly depend on the manufacturing process. As a result, deviations during this process can result in sensitivity variations of the microphone. Therefore, the stress should be well controlled within a certain tensile level. This paper describes a method to test devices electrically using the MEMS related pull-in phenomenon with respect to the mechanical compliance of microphone membranes for the purpose of detecting out of specification chips at an early stage within the manufacturing process instead of determination at a system functionality test after packaging.

Therefore, the adequacy for the intended use of the pull-in voltage and its dependency on varying tensile stress due to manufacturing tolerance is evaluated. A symbolic approach to the solution of large

membrane deflections as a result of all given geometry parameters and the applied voltage is nontrivial, since mechanical and electrical domain are directly coupled to one another. The approach of the model in this paper is to evaluate both mechanical restoring and electrostatic forces due to applied voltage separately. This uncoupling is done by using the resulting deflection profile of the circular membrane to calculate the electrostatic force independently from the mechanical one. The model will be verified with a fully coupled numerical simulation using the finite element software Comsol Multiphysics. Additionally, a smart method to include the influence of deflection dependent stray capacitances due to the highly perforated counter electrode in Comsol Multihysics is shown.

To prove both, the analytic model and the testing method itself, four DUTs out of a series production were packaged using varying process parameters to generate unequally stressed membranes. The semistatic capacitance characteristics up to the pull-in voltage of the DUTs are measured with an Agilent Impedance Analyzer. In addition to the good agreement of analytic and finite element results the paper shows an excellent suitability to take advantage of the pull-in phenomenon in order to measure process based variations in tensile stress of thin silicon membranes electrically.

8763-78, Poster Session Thursday

Analysis of local deformation effects in resistive strain sensing of a submicron-thickness AFM cantilever

Jonathan Adams, Georg E. Fantner, Ecole Polytechnique Fédérale de Lausanne (Switzerland)

Incorporating resistive strain-sensing elements into MEMS devices is a longstanding approach for electronic detection of the device deformation. As the drive for smaller devices scales dimensions down towards the sub-micrometre scale, the size of the strain-sensing element may become comparable to the size of the device itself. In this regime, the influence of the strain-sensing element on the mechanical behavior of the device cannot be neglected. We analyzed the performance of a submicron-thickness silicon nitride AFM cantilever with resistive strain-sensors in a Wheatstone bridge configuration. Using finite element simulation, we calculated the strain field in the sensor elements for a defined cantilever deflection. In particular, the thickness of the sensor element contributes to a local stiffening effect in the device structure. This effect lowers the strain in the local region at the sensor and reduces the resistance change of the sensor element. By varying the sensor geometry, we investigated strategies for increasing the strain in the sensor elements. Minimizing the thickness of the sensor elements reduces the local stiffening effect, but the effective reduction in sensor cross-sectional area increases their resistance and hence expected sensor noise. Alternatively, we varied the dimensions of each sensor element to maintain a constant cross-sectional area but maximize the strain in the sensor element. Through this approach, we expect a 4-fold increase in the magnitude of the output signal from the Wheatstone bridge without altering the resistance of the bridge. Our results provide an important consideration in the design geometry of resistive strain-sensing elements in MEMS devices.

8763-79, Poster Session Thursday

Magnetic circuit design for miniaturized magnetic shape memory alloy actuators

Christian Bolzmacher, Commissariat à l'Énergie Atomique (France)

Magnetic shape memory alloy (MSMA) is a relatively new kind of smart material. Upon application of a large magnetic field, it exhibits actuation strains up to 10% similar to thermal shape memory alloy (SMA) but shows significantly reduced response time in the millisecond range. Currently, application is restricted by the brittleness of the single crystal material, its nonlinear behaviour and the difficulty to generate and apply a magnetic field around 0.7T in order to exploit the full actuation potential.

The focus of this work is on the design of miniaturized magnetic circuits for bulk MSMAs. Various circuit designs are compared such as toroidal and series-parallel shapes. Analytical, numerical as well as equivalent circuit simulation is used to increase the magnetic field in a characteristic air gap where the smart material is placed. The implementation of permanent magnets is described to prestrain the smart material. Static as well as dynamic characterization results are given. Using the described magnetic circuits and 5M - MSMA rods with dimensions of 20x2.5x1mmμ^3 peak displacement of 0.8mm and a blocked force of 4.3N was obtained. Design guidelines for highly integrated miniaturized actuators are given.

8763-80, Poster Session Thursday

Exploiting infrared transparency of silicon for the construction of advanced MOEMS vibration sensors

Wilfried F. Hortschitz, Jörg Encke, Franz Kohl, Thilo Sauter, Austrian Academy of Sciences (Austria); Franz Keplinger, Harald Steiner, Andreas Kainz, Technische Univ. Wien (Austria)

The thermal noise of the seismic mass motion limits the resolution of typical micromachined vibration sensors. Its value can be adjusted by the size of the proof mass which is also representing a quantity for the inertial actuation input. By making use of a novel transduction concept, MOEMS vibration sensors featuring approximately twice as much mass per chip area are feasible while decreasing the technological efforts during fabrication. The devised sensor principle foresees the intensity modulation of a light flux propagating perpendicular through a micromachined aperture pair where one aperture is fixed to the encapsulation and the other one is deflectable due to inertial forces. Earlier attempts have employed optoelectrical transmitters and receivers operating at a wavelength where silicon is intransparent. Thus, openings in the silicon mass were necessary.

The now presented evaluation technique utilizes the transparency of silicon in the infrared region at wavelengths well above 1.1 µm. In contrast to the previously used optoelectronic components, a LED and a pin-diode made of InGaAs were integrated. This allows the use of thin-film metal apertures deposited on top of the silicon seismic mass instead of etched silicon windows.

Beside the increase in mass, this approach offers more design freedom and implies a reduced damping coefficient yielding an improved quality factor.

A proof of concept structure was fabricated and characterized together with a sensor operating on the preceding principle. The results show good agreement for the predicted behavior and parameters which were confirmed by FEM analysis considering the fabrication related underetching as well.

8763-81, Poster Session Thursday

A resonance-based solar element: a numerical model and mico/nano technology application

Pavel J. Fiala, Petr Drexler, Dusan Nespor, Brno Univ. of Technology (Czech Republic)

The authors propose an analysis of a model solar element based on the principle of a resonance system facilitating the transformation of the external form of incident energy into electrical energy. A similar principle provides the basis for harvesters designed to operate at lower frequencies, Jirků T., Fiala P. and Kluge M., 2010, Wen J. L., Wen Z., Wong P. K., 2000. In these harvesters, the efficiency of the energy form transformation can be controlled from the frequency spectrum of an external source.

Initial research studies in the field of mini- and micro-generators conceived as harvesters mainly examined the problem of exploiting a form of energy from the mechanical motion of a system, Stratton J. A., 1961, with special regard paid to possible utilization of the energy for feeding the electronic components of the moving system. The central issue in the part of the research related to this paper and chiefly solved in the WISE project (6-FP EU 2005-2008) was to develop an independent energy source Fiala P. and Drexler P., 2011,

for a temperature sensor (or other sensor types). The sensor has been tested in a EUROCOPTER helicopter, Jirků T., Fiala P. and Kluge M., 2010.

8763-82, Poster Session Thursday

Biomimetic MEMS sensor array for navigation and water detection

Oliver Futterknecht, Technische Univ. Wien (Austria); Mark O. Macqueen, Aramis Technologies (Malaysia); Salmah B. Karman, Univ. Kebangsaan Malaysia (Malaysia) and Univ. of Malaya (Malaysia); S. Zaleha B. M. Diah, Univ. Kebangsaan Malaysia (Malaysia); Ille C. Gebeshuber, Univ. Kebangsaan Malaysia (Malaysia) and Technische Univ. Wien (Austria) and Aramis Technologies (Malaysia)

The focus of this study is biomimetic concept development for a MEMS sensor array for navigation and water detection. The MEMS sensor array is inspired by abstractions of the respective biological functions: polarized skylight-based navigation sensors in honeybees (Apis mellifera) and the ability of African elephants (Loxodonta africana) to detect water. The focus lies on how to navigate to and how to detect water sources in desert-like or remote areas. The goal is to develop a sensor that can provide both, navigation clues and help in detecting nearby water sources. We basically use the information provided by the natural polarization pattern produced by the sunbeams scattered within the atmosphere combined with the capability of the honeybee's compound eye to extrapolate the navigation information. The detection device uses light beam reactive MEMS, which are capable to detect the skylight polarization based on the Rayleigh sky model. The actual challenge is to reduce the interference within the bandwidth of the visible light; therefore the focus lies on the UV part of the spectrum.

For water detection we present various possible approaches to realize the sensor. In the first approach, polarization is used: moisture saturated areas near ground have a small but distinctively different effect on scattering and polarizing light than less moist ones. Modified skylight polarization sensors (Karman, Diah and Gebeshuber, 2012) are used to visualize this small change in scattering. Application of this technique near ground indicates water sources near the ground surface. The second approach is inspired by the ability of elephants to detect infrasound produced by underground water reservoirs, and shall be used to determine the location of underground rivers and visualize their exact routes.

Reference:

Karman S.B., Diah S.Z.M. and Gebeshuber I.C. (2012) "Bio-inspired polarized skylight-based navigation sensors: A review", Sensors 12(11), 14232-14261.

8763-83, Poster Session Thursday

Simulation and design optimization of transparent heaters for spectroscopic micro cells

Henning Völlm, Jonathan Herrmann, Dara Feili, Helmut Seidel, Univ. des Saarlandes (Germany); Reinhard Maier, Volker Häublein, Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany); Heiner Ryssel, Fraunhofer-Institut für Integrierte Systeme und Bauelementetechnologie IISB (Germany) and Friedrich-Alexander-Univ. Erlangen-Nürnberg (Germany)

In several fields of miniaturized analytical systems micro cells or chambers are used. For example for spectroscopic applications like the central cell for chip scale atomic clocks [1] a dedicated temperature of the inner cell surfaces is needed. The minimal temperature is important for the behaviour of the principal function and the homogeneity within the cell influences the overall power consumption. Therefore an optimized transparent heater structure is necessary to heat the cell with a minimum amount of energy to a specific lower temperature limit. Transparent heaters have the capability to be used on optical windows. Heating directly on the optical windows is necessary to avoid the condensation of alkali atoms on the optical ports. In this work indium-tin- oxide (ITO) as a transparent conductive thin film is used. Different heating approaches are simulated by finite element analysis in COMSOL Multiphysics. First the modelling concept is proved by investigations on simple heating bars. Proved by good agreement with real existing heating bars we investigated several structures which promise to provide more uniform temperature profiles.

First results show that meander based structures provide temperature distribution with slightly higher temperature values in the middle of the heated area. Detailed analysis discovers a heat accumulation with a maximum effect in the middle of the structure. This becomes a dominant effect due to the low temperature conductivity of the substrate. To compensate this phenomenon we modified the width of the wire at a given thickness by a length dependent formula as introduced by [2]. This leads to a wire shape like a muscle which results in a variation of the current density and hence the heat generation is adapted. Thus the heat distribution becomes more uniform. The combined result of an optimised arrangement and wire shape shows the best homogeneity of the temperature profile.

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8763-84, Poster Session Thursday

Flip chip packaging of piezoresistive barometric pressure sensors

Tobias Waber, Hochschule München für Angewandte Wissenschaften (Germany); Wolfgang Pahl, Matthias Schmidt, EPCOS AG (Germany); Gregor Feiertag, Hochschule München (Germany); Stefan Stufler, EPCOS AG (Germany); Rainer Dudek, Fraunhofer-Institut für Elektronische Nanosysteme (Germany); Anton Leidl, EPCOS AG (Germany)

Piezoresistive pressure sensors are used in many applications e.g. automotive, medicine and consumer electronics. Barometric pressure sensors are now widely used in navigation systems and mobile phones. For these devices the size of the pressure sensors must be further decreased. It is also important that the sensor chips are packaged with ultra-low stress. Up to now most pressure sensor chips for barometric pressure have been packaged using a soft adhesive and wire bonding. However, it is difficult to achieve a very small package size and height with wire-bonding type packages. For other electronic components flip-chip packaging is used for highly miniaturized packaging. However, standard flip chip packaging is not suited for piezoresistive pressure sensors because of the rather high stress induced on the sensor chip by the package. So we have developed a low stress flip-chip package with springs between the sensor chip and a ceramic cavity housing. The under bump metallization (UBM) on the sensor chip side was optimized to further decrease the packaging stress.

In a standard flip chip package the different coefficients of thermal expansion (CTE) of chip and substrate and strong mechanical coupling by the solder bumps would lead to stress in the sensor chip which is not acceptable for piezoresistive pressure sensors. To overcome this problem we have developed a new ultra low stress flip-chip packaging technology. In this technology first an UBM is patterned on the sensor wafer. As the next step solder bumps are deposited. After wafer-dicing the chips are flip-chip bonded on springs within a ceramic cavity.

As a source of residual stress we identified the UBM and the solder bump on the sensor chip. Different CTEs of the silicon chip and the UBM/solder lead to creep strain in the aluminum metallization between UBM and chip. As a consequence a temperature hysteresis can be measured which is shown in Figure 1 (see upload).

As can be seen the actual measurement at a certain temperature depends on the previous temperature conditions. Here the external pressure is 1000 hPa.

In this contribution we will explain how the temperature hysteresis of about 2 hPa could be reduced by modifying the chip layout. Changes are the thickness of the chip, the depth of the cavity or smaller

diameters of the UBM. In Figure 2 (see upload) the current status (sep 2012) is shown.

The hysteresis was reduced under 1 hPa by changing the thickness and the cavity depth.

8763-85, Poster Session Thursday

A lorentz force actuated magnetic field sensor with capacitive read-out

Michael Stifter, Technische Univ. Wien (Austria) and Austrian Academy of Sciences (Austria); Harald Steiner, Andreas Kainz, Franz Keplinger, Technische Univ. Wien (Austria); Wilfried F. Hortschitz, Integrated Microsystems Austria GmbH (Austria); Thilo Sauter, Austrian Academy of Sciences (Austria)

We present a novel design of a resonant magnetic field sensor with capacitive read-out permitting wafer level production. The device consists of a single-crystal silicon cantilever manufactured from the device layer of an SOI wafer. Cantilevers represent a very simple structure with respect to manufacturing and function. On the top of the structure a gold lead carries AC currents that generate alternating Lorentz forces in an external magnetic field. If the cantilever is actuated, the free end oscillation depends on the eigenfrequencies of the structure. Particularly, the specific design of a U-shaped structure provides a larger force-to-stiffness-ratio than standard cantilevers. The electrodes for detecting cantilever deflections are separately fabricated on a Pyrex glass-wafer. They form the counterpart to the lead on the freely vibrating planar structure. The wafers are mounted on top of each other. A custom SU-8 bonding process on wafer level creates a gap which defines the equilibrium distance between sensing electrodes and the vibrating structure. Additionally to the capacitive read-out, the cantilever oscillation was simultaneously investigated with laser Doppler vibrometry through proper windows in the SOI handle wafer. Advantages and disadvantages of the asynchronous capacitive measurement configuration are discussed quantitatively and presented by a comprehensive experimental characterization of the device under test.

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8763-86, Poster Session Thursday

Mid-infrared rib waveguide absorption sensors based on Si

Ventsislav M. Lavchiev, Johannes Kepler Univ. Linz (Austria); Peter Irsigler, Ursula Hedenig, Thomas Grille, Infineon Technologies Austria AG (Austria); Bernhard Jakoby, Johannes Kepler Univ. Linz (Austria)

We present a silicon (Si) based infrared (IR) absorption sensor which is suitable for integration into a miniaturized sensor system. The sensor is designed to operate in the wavelength region around λ=5 µm. We particularly discuss the design, the modeling and the optical characterization of the used materials. The sensor operates as a single-mode Si waveguide (WG) on low refractive index Si3N4 membrane. The single-mode requirement for the WG is needed to avoid losses due to imperfections on the WG walls causing redistribution of the carried energy among the different modes. The waveguide interacts with the sample by means of the evanescent field which extends into the sample. This sensor configuration is not only compatible to the Si technology, but can also be realized on a single chip. In addition, the principle of operation is not limited to a single wavelength: by changing the waveguide dimensions, it can be applied to a broad spectral range. Thus, by its dimensions, performance and Si-compatibility, the sensor is expected to overcome previously published devices.

The single-mode requirements lead to WG dimensions of 2 µm width x 600 nm height for an operation at λ=5 µm, which are verified by 3D simulations. For those parameters, the WG will support one transverse electric (TE) mode and one transverse magnetic (TM) mode. Efficient guidance is only obtained for the fundamental TE and TM modes. As an example, it is shown that mode TE1 is a non-guided mode. The experimentally obtained WG dimensions are 605 nm height and 2 µm width. In our paper we discuss issues with the design, the material characterization and first experimental results obtained with the recently fabricated prototypes.

8763-87, Poster Session Thursday

MEMS sensors for mm-range displacement measurements with sub-nm resolution

Vladimir T. Stavrov, AMG Technology Ltd. (Bulgaria); Vencislav M. Todorov, Techproject Co. (Austria); Assen Shulev, Institute of Mechanics, Bulgarian Academy of Sciences (Bulgaria); Chavdar Hardalov, Technical Univ. of Sofia (Bulgaria)

It is challenging to provide adequate conditions and experimental set-up for displacement measurements in mm-range with nm/sub-nm resolution. It is even more complex to perform such measurements in static mode. In order to satisfy the needs for a simple, reliable, and cost-effective tool for displacement measurements in mm-range with nm/sub-nm resolution, test MEMS sensors with sidewall embedded piezoresistors have been prototyped. To investigate in details the parameters and characteristics of the test sensors, an experimental set-up has been developed and demonstrated. In order to decrease the thermal noise influence on to the sensor a special Lock In amplifier has been developed and implemented. MEMS device has been bonded directly on the low-noise amplifier PCB. The mechanical set-up provides dual axial approach and testing capabilities of 10 µm with resolution of 0.1 nm. Sensitivity of 0.05nm in static displacement mode has been demonstrated.

After detailed characterization of the test MEMS, in order to achieve mm displacement sensing range, an application specific all-silicon MEMS sensor has been developed. Having the same structure of the sensing element as the test one but with integrated differential springs, the application specific sensor has successfully demonstrated sensing range of 1mm.

In near future possible MEMS layout optimizations could extend the displacement sensing range up to 5mm.

8763-88, Poster Session Thursday

Detection of bad indoor environment with a miniaturized gas sensor system

Jochen Huber, Fraunhofer-Institut für Physikalische Messtechnik (Germany); Jürgen Wöllenstein, Albert-Ludwigs-Univ. Freiburg (Germany)

The refurbishing to an energy efficient standard leads to tight buildings and affects the indoor climate. In case of refurbishing the inhabitants or users are not adapted to this new situation. The air quality is often degraded due to the lack of exchange with the outdoor environment. People in Europe spend more than 90 % of their time indoors. Diseases and bad health are affected by bad indoor air quality. An indication parameter for bad indoor environment is the concentration of so called volatile organic compounds (VOC). VOCs are the sum of organic gases and are mostly present in very small concentrations (single molecules to ppb/ppt range). We used semiconducting metal oxide gas sensors (MOX) for VOC detection and classification. Yet small concentrations of VOCs are difficult to detect. To solve this, we developed a miniaturized measurement

system with two units to detect smallest amounts of VOCs with MOX sensors. One of the units is a preconcentration chamber, that operates by thermal adsorption of VOC gases by cooling down a highly porous polymer adsorbent with a Peltier element. Fast heating by inverse conduction of the Peltier element leads to desorption of the VOC gases which can be detected now in higher concentrations in the second unit.

To differentiate between the different VOC gases, pattern recognition with different MOX sensors was performed. The system allows to detect smallest amounts of VOC gases and to distinguish between types of VOCs due to the pattern measurement with various gas sensors. Due to its small dimensions the system can be easily integrated in sensor networks. The gas measurement setup allows recognizing bad indoor environment and mold built-up in its beginning helping to start counteraction. By pattern recognition the origin of bad indoor environment can be estimated.

8763-89, Poster Session Thursday

Noise as diagnostic tool for quality and reliability of thick-film pressure sensors

Petr Sedlak, Vlasta Sedlakova, Jiri Majzner, Josef Sikula, Brno Univ. of Technology (Czech Republic); Marina Santo Zarnik, Darko Belavic, Jožef Stefan Institute (Slovenia)

Due to stochastic nature of the matter, physical processes in materials are considered to be stochastic, and they reveal as fluctuation of measurable quantities macroscopically.Users generally require minimizing impact of fluctuations on measurements in order to achieve maximal signal-to-noise ratio. However, fluctuation mechanisms can also give useful pieces of information about defects in a sensor. Thus, we provided an investigation of Low-Temperature Co-fired Ceramic (LTCC)-based ceramic pressure sensors (CPSs) by using the low frequency noise measurements to get information about quality and reliability of these sensors.

Investigated CPSs contain four functional thick-film resistors (0.8 x 0.8 mm2) connected in the Wheatstone bridge printed on the ceramic diaphragm. Special test specimens containing thick film resistors of different sizes including four thick-film resistors (0.8 x 0.8 mm2) connected in the Wheatstone bridge were made for the case study by using different thick-film materials and technology variants. The contributions of single resistors connected in the bridge to the total noise of the bridge were evaluated.

Besides the influence of processing technology and materials on the noise level of the LTCC-based piezoresistive CP, we have found the correlation between the noise level and the stability of sensors offset voltage, and the presence of the structural defects in the functional resistors. Wrinkle type defects, cracks and other imperfections increase the noise level of the investigated sensor. Low frequency noise measurements show its potential to serve as a method for the determination of defects closed in the sample volume and on the resistor/substrate interface. We found that low-frequency noise may identify

- a fracture in membrane of pressure sensor, when a level of noise spectral density is higher in order of 3 to 6 than a standard level of noise voltage,

- significant defects in printed resistors, when a level of noise spectral density is higher in order of 1 to 2 than a standard level of noise voltage,

- structural defects, which are responsible for long-term stability of a sensor, in the functional resistors, when a level of noise spectral density is higher for 50% up to 100% than a standard level of noise voltage.

8763-90, Poster Session Thursday

A FPGA-based measurement system with QCM for real-time fluctuation-enhanced gas sensing

Petr Sedlak, Marek Vondra, Josef Sikula, Vlasta Sedlakova, Jiri Majzner, Brno Univ. of Technology (Czech Republic)

Due to stochastic nature of the matter, physical processes in materials are considered to be stochastic, and they reveal as fluctuation of measurable quantities macroscopically. These fluctuations are usually called noise, since they are assumed to be unwanted and distracting components, which do not carry any information. Users generally require minimizing impact of fluctuations on measurements in order to achieve maximal signal-to-noise ratio. However, fluctuation mechanisms can also give useful pieces of information about chemical and physical processes in a sensor. In our previous papers, we suggested a model adsorption-desorption noise in quartz crystal microbalance (QCM) on the basis of experimental study that showed influence of adsorption of detected matter on frequency fluctuation of QCM sensor.On the basis of the model and experimental results (frequency change and its second statistical moment), the time for capture of detected-matter molecule was estimated, and may give additional information about processes on the active layers.

We developed a measurement system, whose core is FPGA. The system contains two oscillator circuits (for QCM and a reference quartz crystal), a frequency mixer, and FPGA, which besides instantaneous frequency and noise spectral density of frequency fluctuations give us information about time of molecule capture. Experiments were provided on QCMs whose electrodes were deposited by polypyrrole using Matrix Assisted Pulsed Laser Evaporation. This material is suitable for construction of QCM humidity sensors. In the case of our samples, the change of relative humidity from 35 % RH to 71 % RH causes a change of resonant frequency (Δf) in the range 2100 Hz. Our experiments were done in Binder environmental test chamber.

8763-91, Poster Session Thursday

Optical-thermal actuation of silicon cantilevers: modelling and experimental investigation

Fei Jiang, Adrian J. Keating, Mariusz Martyuink, Dilusha K. Silva, Lorenzo Faraone, John M. Dell, The Univ. of Western Australia (Australia)

This paper reports the modeling and experimental investigation of optical-thermal excitation of silicon cantilevers. In this work, silicon cantilevers were fabricated using SOI starting wafers having dimensions of 15 µm wide, thickness of 0.26 µm, and lengths from 50 to 120 µm. Standard processing resulted in cantilevers exhibiting significant upward bending due to anchor effects. An Ar+ plasma treatment of a narrow strip of the cantilever near the anchor on the cantilever side results in flat cantilevers. In order to investigate the effect of the laser modulation frequency (λ=405 nm) and position on the temperature at the anchor edge and displacements at the tip of the cantilever, transient thermal ANSYS simulations and a steady-state static thermal-mechanical ANSYS simulations for both types of cantilever were undertaken using a structure consisting of silicon device layer, SiO2 anchor layer and silicon substrate with a modified material model used for the region exposed to the Ar+ plasma. Measured dynamic properties for both types of cantilever were obtained using an optical driving signal with pulsed modulation and frequencies provided by a 405 nm diode laser with a 2.9 µW/µm2 peak laser power. The 30 µm diameter laser spot was located along the longitude direction of silicon cantilever. Simulation results correlate well with experimental observation, including: 1) for untreated silicon cantilevers, the maximum displacement is observed when the laser beam was located half an optical beam diameter away from the anchor on the silicon suspended cantilever side; 2) for silicon cantilevers with an Ar+ plasma treatment, it is clear that the maximum of displacement amplitude occurs when the laser source is located at half a beam diameter away from the Ar+ plasma treatment area at the cantilever tip side.

8763-92, Poster Session Thursday

MEMS-based silicon cantilevers with integrated electrothermal heaters for airborne ultrafine particle sensing

Hutomo S. Wasisto, Stephan Merzsch, Andreas Waag, Erwin Peiner, Technische Univ. Braunschweig (Germany)

The development of low-cost and low-power MEMS-based cantilever sensors for possible application in hand-held airborne ultrafine particle monitors is described in this work. The proposed resonant sensors are realized by silicon bulk micromachining technology with electrothermal excitation, piezoresistive frequency readout, and electrostatic particle collection elements integrated and constructed in the same sensor fabrication process step of boron diffusion. Built-in heating resistor and full Wheatstone bridge are set close to the cantilever clamp end for effective excitation and sensing, respectively, of beam deflection. Meanwhile, the particle collection electrode is located at the cantilever free end. A 300 µm-thick, phosphorus-doped silicon bulk wafer is used instead of silicon-on-insulator (SOI) as the starting material for the sensors to reduce the fabrication costs. To etch and release the cantilevers from the substrate, inductively coupled plasma (ICP) cryogenic dry etching is utilized. By controlling the etching parameters (e.g., ion energy, ion density, and duration), cantilever structures with thicknesses down to 10 - 20 µm are yielded. In the sensor characterization, the heating resistor is driven by an ac sine voltage of 2 V generated from a waveform generator. As the resistor is heated, it generates thermal waves which expand through the silicon cantilever. The thermal waves will induce thermal expansion and further cause mechanical bending strain in the out-of-plane direction. Based on the piezoresistive conversion, the output signals of cantilever deflection can then be read by a multimeter and stored into a PC. A resonant frequency of 114.08 ± 0.04 kHz and a quality factor of 1302 ± 267 are measured in air for a fabricated rectangular cantilever (500x100x13.5 µm3). Owing to its low power consumption of a few milliwatts, this electrothermal cantilever is suitable for replacing the current external piezoelectric stack actuator in the next generation of the miniaturized cantilever-based nanoparticle detector (CANTOR).

8763-93, Poster Session Thursday

Design and fabrication of a 5 MHz ultrasonic phased array probe with curved transducer

Julia Fischer, Thomas Herzog, Susan Walter, Henning Heuer, Fraunhofer-Institut für Zerstörungsfreie Prüfverfahren (Germany)

Within the field of ultrasonic testing it is very important to match the probe to the test object, not just concerning the acoustic properties but also the shape. Present solutions are not yet satisfactory. In the non-medical field probes for curved test objects usually have a corresponding delay wedge. With this comes an increase in energy loss due to additional interfaces. This can be avoided by manufacturing a probe with a curved front. The objective was to develop a technology to apply the curvature to the composite material and the matching layer.

A 5 MHz, 16-element phased array probe with a curved (concave) transducer using a 1-3 composite as active material was designed and fabricated. The composite was fabricated with the dice-and-fill method. The backing, a filled epoxy resin, was poured into a convex mold. After curing the backing was bonded with the curved side down onto the transducer's back using an especially designed tool to make sure the parts stay in place during the process and are bonded properly.

The backing could successfully be bonded so that the curvature was transferred from it to the transducer and the matching layer. A coax cable was then bonded to the transducer and the whole stack could be placed in a housing and backfilled. After curing it was ready to be tested.

The finished probe was tested on a steel half circle with the corresponding radius and on the Olympus PAUT test piece. Good results could be obtained. Three boreholes with a diameter of 1 mm and a distance of 5 mm to one another could be detected and resolved.

8763-94, Poster Session Thursday

MEMS pressure sensor with maximum performances by using novel back-side direct-exposure concept featuring through glass vias

Ha-Duong Ngo, Technische Univ. Berlin (Germany); Klaus-Dieter Lang, Technical Univ. Berlin (Germany); Mathias Fritz, Fraunhofer-Institut für Zuverlässigkeit und Mikrointegration (Germany); Biswajit Mukhopadhyay, Technical Univ. Berlin (Germany); Piotr Mackowiak, Technische Univ. Berlin (Germany)

Design, fabrication, and characterization of novel MEMS pressure sensors with new back-side-direct-exposure packaging concept are presented. The to be measured pressure is acting on the back-side of silicon membrane, thus generates a much smaller stress concentration in silicon substrate than by the acting on the front side as it is the case in common pressure concepts used on the market. This smaller stress concentration is increasing the robustness and stability of the sensor while keeping the sensitivity at the same level. The new sensor concept is also featuring a vertical contact through the glass (TGV – Through Glass Via) bonded on the front side of silicon wafer and allows mounting of the sensor, for example on a board for pressure measuring. By avoiding disturbing wires, this novel packaging concept allows fabrication of small devices and therefore is ideally suited for many applications, where accurate and high resolution pressure measurements are needed. The active area of the sensor on front-side, including implanted area and metal leads, are completely sealed and located in vacuum. Hence it will allow long term stable device behaviour.

In many applications, the pressure peaks in the measurement systems is very high. These high pressures can lead to membrane failure due to the silicon breakage and limits the over pressure of the sensors. In common pressure measurement systems, due to the front side bond wires and acting pressure, complex and expensive packaging concepts by using media separation (steel membrane and liquids) are needed. The sensors presented herein avoid both these drawbacks due to the integration of through-glass vias and back side exposing.

The silicon pressure sensor developed consists of a square diaphragm with four p-type piezoresistors (Wheatstone bridge). Membrane dimensions are optimized by FEM-analysis, resulting in a diaphragm area of 64000 µm^2 and a thickness of 50 µm. In compare to the standard front-side-exposing concept, the novel back-side-exposing concept shows a three time lower stress by keeping the sensitivity at the same level. Chip size is 2,5x2,5 mm2. Standard 390µm thick wafers and KOH etching method are used to obtain a uniform diaphragm thickness. A schematically cross-section of the sensor shows all employed material layers and provides information about the fabrication process. Sealed TGVs are realized by ultrasonic drilling and printing of lot paste to fill the vias to make contact to the bond pads on the front side of silicon wafers. Cavity into glass for membrane deflection is realized by hydrogen fluoride etching.

Prototypes of the sensors have been fabricated. Figure 3 shows a silicon chip on a preliminary TO8 package with bond wires to test the sensor function. Burst test has shown a three times higher breakage pressure with the new concept. Exhaustive testing procedure is on-going to characterize the fabricated sensors. Important sensor parameters (sensitivity, TCO, TCS, drift) will be determined and presented hopefully in the final paper and at conference.

8763-95, Poster Session Thursday

Stacked PZT linear arrays for high intensity ultrasound transducers

Rico Schumann, Thomas Herzog, Susan Walter, Henning

Heuer, Norbert G. Meyendorf, Fraunhofer-Institut für Zerstörungsfreie Prüfverfahren (Germany)

The performance of the separate elements in phased array ultrasound transducers has a high importance in materials testing. This work describes the development of a manufacturing technique for one dimensional ultrasound arrays (linear arrays) with significantly higher amplitudes of the sending signal compared to conventional linear arrays.

The aperture and the width of the elements of linear arrays are limited by the used method for the excitation of the transducer and the reconstruction algorithms (e.g. sampling phased array). Therefore possible technologies for the stacking of several PZT layers were investigated to increase the sending signal. A technique based on adhesive bonding of poled PZT ceramics and thin copper foils was developed. Furthermore different adhesives, partly with filling powders, were compared in terms of their processability and their influence on the transducer behaviour. The choice of the adhesive as well as the choice of the type and amount of filling powders showed a high influence on the total capacitance. A variation of the specific adhesive and powder mixture could be used to increase the capacitance and therefore to match the electrical impedances of the sensor to the impedance of used hardware. The electrical interconnection was realised by connecting the thin copper layers of the PZT stack to a customised, metallised damping body. The metallisation on the damping body was structured like the PZT stack and could additionally be used to connect the single coax cables that lead to the connector.

Linear array transducers with 32 elements and a working frequency of 1.5 MHz were manufactured using our stacking technique. The amplitude of the sending signal could be increased by 3 times compared to transducers with a monolithic PZT sensor and the capacitance could be increased by 2.5 times.

8763-96, Poster Session Thursday

From nature to MEMS: towards the detection limit of crickets' hair sensors

Ahmad Dagamseh, Yarmouk Univ. (Jordan)

Crickets exploit the air-motion, using highly sensitive mechanoreceptor hairs, to detect approaching spiders. The high sensitivity of these hairs enables perceiving tiny air movements which are only just distinguishable from noise (as low as 30 μm/s [1]. This forms our source of inspiration [2] to design sensitive arrays made of artificial hair sensors for flow pattern observation i.e. Flow camera.

The realization of high-sensitive hair sensor requires designs with low thermal-noise to match the detection limit of crickets' hairs. Here we investigate the damping factor (R) in our artificial hair sensor using different models as it is the source of the thermo-mechanical noise in the mechanical system.

We estimate the damping factor in our hair sensor using the physical structure of the hair sensor, the quality factor of the hair system and the shift in resonance frequency. The results show that the damping factor estimated in air is in the range of 1x10-12 N.m/rad.s-1 compared to 1x10-14 N.m/rad.s-1 in vacuum. The crickets have R = 5x10-14 N.m/rad.s-1. In our artificial hair-sensor, the threshold flow velocity resulting from the thermo-mechanical noise is in the range of 52 μm/s, bordering the threshold flow-amplitude of crickets. In normal operation conditions the crickets are still 100 times more sensitive than our hair sensor. Table 1 summarizes the damping factor in the hair using different methods.

In conclusion, the thermal noise will influence the design of high sensitivity hair sensors. In this abstract we studied the thermal noise in our artificial hair sensor resulted from the squeeze film damping. Mathematical models supported with experimental results were performed to estimate the damping coefficient originated from the hair-shaft and membrane geometry and will be investigated further to be presented in our conference contribution.

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8763-97, Poster Session Thursday

Counting line detectors with one monolithically integrated readout circuit: two applications

Thomas Lohse, Peter Krüger, Henning Heuer, Fraunhofer-Institut für Zerstörungsfreie Prüfverfahren (Germany); Martin Oppermann, Technische Univ. Dresden (Germany); Hannes Torlee, Fraunhofer Institut für Photonische Mikrosysteme (Germany); Norbert G. Meyendorf, Fraunhofer-Institut für Zerstörungsfreie Prüfverfahren (Germany)

The developed direct converting X-ray line detectors offer a number of advantages in comparison to other X-ray sensor concepts. Direct converting X-ray detectors are based on absorption of X-rays in semiconductor material, which leads to a generation of charge carriers. By applying high bias voltage charge carriers can be separated and with this the arising current pulse can be assessed by suitable readout ICs subsequently. The X-ray absorber itself is implemented as a diode based on GaAs to use it in the reverse direction. It exhibits low dark currents and can therefore be used at room temperatures. The GaAs-absorber has a structured top electrode designed on variable bonding and high breakdown voltages.

The implemented GaAs-absorber exhibits a pixel size of 100 μm while the readout integrated circuit (IC) features fast dead-time-free readout, energy discrimination by two individually adjustable thresholds with 20 bit deep counters and radiation-hard design on chip level. These properties guarantee the application as fast and thus sensitive line detector for imaging processes as well as for spectroscopic analysis. The latter application is realized by evaluating the penetration depth of X-rays using reconstructive algorithms. As an example, emission spectrum of X ray tubes is determined thereby. Another advantage of the imaging line detector is the cascadability of several sensor modules with 1024 pixels each. This property ensures that the 102.4 mm long sensor modules can be concatenated virtually with arbitrary length gap-lessly.

The readout ICs hitting radiation dose can be further minimized by implementing constructive steps to ensure longer lifetime of the sensor module. Additionally, reliability investigations of used epoxy adhesives with regard to their resistivity against X-radiation were realized. Results of shear tests as well as of the analysis using SEM, EDX and FTIR are presented and discussed. Furthermore, first results using the line detector are introduced.

8763-98, Poster Session Thursday

Design strategies of opto-mechanical micro oscillators for the detection of the ponderomotive squeezing

Antonio L. Borrielli, Istituto dei Materiali per l'Elettronica ed il Magnetismo (Italy) and Gruppo Collegato di Trento (Italy); Enrico Serra, Univ. degli Studi di Trento (Italy) and Gruppo Collegato di Trento (Italy); Francesco Saverio Cataliotti, Univ. degli Studi di Firenze (Italy) and European Lab. for Non-Linear Spectroscopy (Italy) and Istituto Nazionale di Fisica Nucleare (Italy); Francesco Marin, European Lab. for Non-Linear Spectroscopy (Italy) and Istituto Nazionale di Fisica Nucleare (Italy) and Univ. degli Studi di Firenze (Italy); Francesco Marino, European Lab. for Non-Linear Spectroscopy (Italy) and Istituto Nazionale di Fisica Nucleare (Italy) and CNR-ISC (Italy); Antonio Pontin, Giovanni A. Prodi, Istituto Nazionale di Fisica Nucleare (Italy) and Univ. degli Studi di Trento (Italy); Michele Bonaldi, Istituto Nazionale di Fisica Nucleare (Italy)

and Istituto dei Materiali per l'Elettronica ed il Magnetismo (Italy)

The interaction of the radiation pressure with micro-mechanical oscillators is earning a growing interest for its wide-range applications (including high sensitivity measurements of force and position) and for fundamental research (entanglement, ponderomotive squeezing, quantum non-demolition measurements).

In this contribution we describe the fabrication of a family of opto-mechanical devices specifically designed to ease the detection of ponderomotive squeezing and of entanglement between macroscopic objects and light. These phenomena still elude observation, due to the overwhelming effects of classical noise sources of thermal origin with respect to the weak quantum fluctuations of the radiation pressure. Therefore, a low thermal noise background is required, together with a weak interaction between the micro-mirror and this background (i.e. high mechanical quality factors).

The device should also be capable to manage a relatively large amount of dissipated power at cryogenic temperatures, as the use of a laser with power up to a ten of mW can be useful to enhance radiation pressure effects.

In the development of our opto-mechanical devices, we are exploring an approach focused on relatively thick silicon oscillators with high reflectivity coating. The relatively high mass is compensated by the capability to manage high power at low temperatures, owing to a favourable geometric factor (thicker connectors) and the excellent thermal conductivity of silicon crystals at cryogenic temperature. We have measured at cryogenic temperatures mechanical quality factors up to10^6 in a micro-oscillators designed to reduce as much as possible the strain in the coating layer and the consequent energy dissipation. This design improves an approach applied in micro-mirror and micro-cantilevers, where the coated surface is reduced as much as possible to improve the quality factor. The deposition of the highly reflective coating layer has been carefully integrated in the micro-machining process to preserve its low optical losses: an optical finesse of F= 6x10^4 has been measured in a Fabry-Perot cavity with the micro-resonator used as end mirror.

8763-99, Poster Session Thursday

Measurement of the 1/f noise of lateral actuated MEMS with sidewall piezoresistors

Vladimir T. Stavrov, AMG Technology Ltd. (Bulgaria); Thilo Sauter, Institute for Integrated Sensor Systems (Austria); Philipp Philippov, Technical Univ. of Sofia (Bulgaria)

MEMS devices with sidewall embedded piezoresistors have been prototyped for current study. Measurement of the 1/f noise of these devices has been described in present paper. In view of the low impedance of the piezoresistors, a modified sample conditioning and pre-amplification setup was employed and the complete arrangement was kept in a thermostatted housing at 30 °C. The 1/f and the 1/(Δf) noise signals are fully correlated as the underlying mechanism, i.e. the modulation by conductivity fluctuations, is the same for both phenomena.

The bias voltage of each resistor ranges from zero to V_{pp} and the related device currents contain 1/f noise due to the DC bias in conjunction with conductivity fluctuations. Accordingly, the AC bias results in 1/Δf noise centred about the frequency of the sinusoidal. The spectrally resolved analysis of the 1/f and down-converted 1/Δf noise signals was then established with two instances of a digital Lock-in amplifier capable of mHz operation. As both lock-in amplifiers have been locked to a common reference signal, the spectral analyser keeps any correlation between the two channels.

Measurements of the current noise were done over the frequency range 0.0625 Hz to 2.048 kHz and measurement resolution of about 10^{-18} V^2/Hz is determined by the selected correlator averaging period in conjunction with the total noise of the instrumentation channels. To enable a direct comparison with metal-film resistor technology, sidewall piezoresistors have been replaced by 1 kΩ metal-film resistors for several measurement runs.

The crossover of the 1/f noise of a full bridge of piezoresistors and their thermal noise will appear below 10 Hz for a bias voltage smaller than 1V. This is, to our best knowledge, among the best 1/f noise performances for lateral piezoresistors.

8763-100, Poster Session Thursday

Modular high frequency eddy current sensor system and image preprocessing algorithms for CFRP testing

Martin H. Schulze, Henning Heuer, Norbert G. Meyendorf, Fraunhofer-Institut für Zerstörungsfreie Prüfverfahren (Germany)

Carbon fiber based materials (CFRP) are used in many lightweight applications in aeronautical, automotive, machine and civil engineering application. By the increasing automation in the production process of CFRP laminates a manual optical inspection of each resin transfer molding (RTM) layer is not practicable. Due to the limitation to surface inspection, the quality parameters of multilayer 3 dimensional raw material cannot be observed by optical systems. The Imaging Eddy-Current (EC) NDT is the only suitable inspection method for non-resin materials in the textile state that allows an inspection of surface and hidden layers in parallel. The HF-ECI method has the capability to measure layer displacements (misaligned angle orientations) and gap sizes in a multilayer carbon fiber structure.

For evaluation process the EC-imaging device named EddyCus® MPECS was developed to measure in 2D single sensor setup. To inspect raw carbon fiber materials during production process the setup needed to be adapted to use eddy current array (ECA) sensors. By the usage of a special multiplexer unit it is possible to variate the sensor orientation and thus the sensor sensibility.

ECA Sensors were designed as a stackable device to use them gapless for an advised width of about 2.5 meters. The defect classification was done by 2D-FFT with adapted preprocessing algorithms.

In the paper first results of the performance of this new sensor system were presented.

8763-101, Poster Session Thursday

MEMS pressure sensor fabricated by advanced bulk micromachining techniques

Gabriel Vanko, Institute of Electrical Engineering (Slovakia); Peter Hudek, Johann Zehetner, Fachhochschule Vorarlberg (Austria); Jaroslav Dzuba, Institute of Electrical Engineering (Slovakia); Pavlina Choleva, Fachhochschule Vorarlberg (Austria); Martin Vallo, Ivan Rýger, Tibor Lalinsky, Institute of Electrical Engineering (Slovakia)

This work is motivated by the need for a new material basis for pressure and strain sensors operating at elevated temperatures. The proposed solution takes advantage of excellent piezoelectric properties of III-N compounds, especially gallium nitride (GaN) based heterostructures. In addition to other common used piezoelectric materials, they have some important advantages: (1) the direct compatibility with high electron mobility transistors (HEMTs); (2) the high mechanical stability of epitaxial films with the integrability into micro(nano)-electro-mechanical systems (M(N)EMS); (3) the possibility to operate at high temperatures due to their ability to preserve their piezoelectric properties in wide temperature range.

We present the design and implementation of a MEMS pressure sensor with an operation potential under harsh conditions at high temperatures (T = 300 – 800 °C). The sensor consists of a circular HEMT (C-HEMT) integrated on a circular AlGaN/GaN membrane. The deflection of the circular membrane due to an external loading (pressure) is in-situ sensed from the changing of the 2DEG conductivity [1] or from the accumulated piezoelectric charge [2] of the C-HEMT. In this design concept the piezoresistive and piezoelectric effect of AlGaN/GaN heterostructure is used to sense the pressure under static and/or dynamic conditions.

Key and highly topical issue in advanced process technology of

MEMS sensors is the SiC-bulk micro-(nano)machining issue for creating membrane and/or cantilever beam structures necessary for the verification of the all possible multi-functional sensing principles.

The originality of our MEMS sensors design concept is supported by a new SiC bulk micromachining treatment. The process sequence is based on a specifically tuned laser ablation technique combined with selective reactive ion etching (SRIE), which allows defining 3D micromechanical membranes and/or cantilevers in SiC bulk substrates. In the first process step, the bulk of the SiC backside is ablated down near to the interface of the AlGaN/GaN heterostructure. Subsequently, the SRIE technique etches the residual (~ 10-20 µm thick) SiC away down to the AlN etch-stop layer.

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8763-102, Poster Session Thursday

Industrial use of a cantilever-based microprobe for the characterization of tribological surfaces

Thomas Frank, Lutz Döring, Stefan Völlmeke, CiS Forschungsinstitut für Mikrosensorik und Photovoltaik GmbH (Germany); Steffen Reich, CiS Forschungsinstitut für Mikrosensorik und Photovoltaik GmbH. (Germany)

Industrially produced work pieces often have in addition to the quality assurance process for determining surface properties such as roughness and waviness other properties that are commonly referred to as the friction and wear properties, so called tribological parameters. The knowledge of the wear properties of a work piece surface and its optimization can help to save energy and resources, both during production and during the conditions of use. In addition to the well known methods for the subsequent surface treatment such as lapping and honing recently, the primary shaping rotary milling method for producing surfaces with tribologically active components are examined.

The optical discovery of such surfaces is possible, but no parameters are directly accessible. Even complex image processing routines fail here. The tactile measurement with conventional stylus measuring machines proves to be too slow. The weight of the probe, which is typical with a few grams and therefore the inertia of the probe in such a conventional dynamic measuring operation, becomes as a limiting factor. Maximum sampling rate is thus determined by the dynamic properties of the probe and is less than 500 microns / s. The objective of a high measurement speed can only be achieved with a microprobe MEMS device with a weight of only a few micrograms.

The high resonance frequency of about 3 ... 5 kHz of those cantilever-based sensors allows a very high measurement speed up to about 10 mm/s. At the same time such a probe has a resolution in the vertical deflection of typically 2 nm. The monolithic integrated tip can be used for long time. In initial measurements of more than 50 meters without significant changes to the stylus tip geometry were observed. The robustness of the sensor and its signal to the effects of light and temperature changes, as well as against electro smog, dust and process auxiliaries such as drilling oils allow the use under production conditions, such as directly in the working area of a machining centre.

The current paper provides comprehensive information on the use of such a cantilever-based sensor. Furthermore the first measurement results taken from real structures are presented.

8763-103, Poster Session Thursday

Chemical microsensors based on hydrogels with adjustable measurement range

Willi Haas, Johann W. Bartha, Wolf-Joachim Fischer, Andreas Richter, Technische Univ. Dresden (Germany)

This work presents polymeric microsensors for the monitoring of alcohol contents in aqueous solutions. The inexpensive sensor device is partially built by polymers. The housing consists of (100) Si substrate, whereas the sensitive material is poly(N-isopropylacrylamide) (PNIPAAm). The acquisition of the sensor data is realized by a non-contact light barrier. The output answer of this light barrier is strong linear. The continuous sensor signal observed by the light barrier is the deflection of an elastic membrane, which is caused by the swelling or deswelling of the stimuli-responsive hydrogel. To achieve an electronic adjustment of the sensor's measurement range we use a controlled double-sensitivity of hydrogel. By controlling the temperature of the temperature-responsive hydrogel PNIPAAm the phase transition concentration is precisely adjustable to the required value. The electrothermic control interface is based on a Peltier element.

The response time of the sensors is in the lower minute range and therefore fast enough for the most of applications. The average sensor resolution for measurements of ethanol is ca. 20mV/wt-%. Further improvements are possible.

8763-104, Poster Session Thursday

Self-aligned single-mask fabrication process for electro-thermal microactutors using ICP-RIE

Ali Badar M. Alamin Dow, Univ. of Toronto (Canada); Adel B. Gougam, Masdar Institute of Science & Technology (United Arab Emirates); Nazir P. Kherani, Univ. of Toronto (Canada)

Advances in the miniaturization of semiconductor devices have been made possible by new methods of microfabrication techniques. These advances have stimulated the birth of Micro Electro Mechanical Systems (MEMS) technology which enable the fabrication of a wide variety of sensing and actuating devices at microscopic dimensions . In MEMS technology, a well controlled etching process is critical for the fabrication of structures with specific geometry and properties. Hence, in recent years significant research has been underway to develop advanced dry etching technologies to produce 3D high-aspect ratio vertical structures so as to overcome the classical limitations of the wet etching technique. Reactive ion etching (RIE) can achieve a higher degree of anisotropic etching which allows for larger feature density. Moreover, one derivative technique of RIE, inductively coupled plasma (ICP) etching, is capable of producing features with high aspect ratio as high as 90:1. Taking advantage of the notching effect when making a structure from silicon on insulator (SOI), structure release without the use of HF acid has been demonstrated . Since the notching effect was aspect ratio sensitive, HF free structure release is only possible for features up to a certain aspect ratio.

We report on the development of a self-aligned single-mask process for the fabrication of released and movable MEMS devices. ICP-RIE was used to realize the structures directly out of single crystal silicon. Applying side wall passivation, controlling the ratio of ion flux and radical flux, smooth etching profile can be achieved with high aspect ratio. No wet etching process is required to release the structures as is the case with SOI wafers. This approach overcomes the stiction limitation associated with wet etching and yields good thickness uniformity over the entire structure. Electrothermal microactuators with integrated microgrippers were designed, fabricated and characterized.

8763-105, Poster Session Thursday

Fabrication of an array like freeform molding tool for UV-replication using a step and repeat process

Jens Dunkel, Frank C. Wippermann, Andreas Brückner, Andreas Reimann, Andreas Bräuer, Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany)

Artificial compound eye cameras are the most prominent approach of next generation wafer level cameras for consumer electronics.

The image quality of compound eye cameras can be increased significantly by the use of refractive freeform arrays (RFFA) instead of conventional microlens arrays. Due to the non-symmetric freeform surface profile of the single lenslets, these arrays provide further degrees of freedom in optical design and hence an improved resolution and a high optical fill factor. In order to address low cost and high volume markets, the fabrication technology of these elements is based on a wafer level UV-replication process. Therefore, a replication tool on wafer level is needed, which is subsequently replicated into a UV-curing polymer using a modified mask aligner. Established micro fabrication technologies such as reflow of photoresist do not permit the fabrication of RFFA structures. We propose a method for the fabrication of these elements on wafer scale, based on a step and repeat process using a modified Nano imprint stepper for the first time. Hereby, a single refractive freeform array (RFFA), fabricated by an ultra-precision diamond machining process, is transferred into PDMS in a first step. This element is used as a stamp in the subsequent step and repeat process to replicate a single RFFA several hundred times on a substrate to obtain the final wafer level molding tool. In order to prove the concept, we fabricated a typical design of a RFFA consisting of 135 single lenslets with a pitch of 480 µm and a maximum sag height of 25 µm in Ormocer on a substrate with a diameter of 220 mm. The surface quality of the fabricated structures was characterized with a white light interferometer. Inevitably occurring surface deviations in the process chain due to material shrinkage effects, as well as the endurance of the PDMS stamps, are discussed.

8763-106, Poster Session Thursday

Fabrication of double-sided micro structured mechanical sensors based on SU-8 resist using a new micro molding process

Alexa Oerke, Stephanus Büttgenbach, Andreas H. Dietzel, Technische Univ. Braunschweig (Germany)

Advances in micro and nano fabrication technologies for MEMS require high-level measurement techniques with regard to sampling and sensitivity. For this purpose at the Institute of Microtechnology (IMT) highly sensitive piezoresistive 3D force sensors based on SU-8 polymer have been developed. In this paper we present an improved micro fabrication process for a double-sided micro structured design. The sensors are produced by multilayer processing techniques such as UV lithography and coating methods. The double-sided micro structured design of the SU-8 polymer demands a photoresist application method which simultaneously features a top side structuring and a casting from a mold. We use a new micro molding process to meet the demands.

The sensor design consists of a boss-membrane. The micro fabrication technology is described, focusing on the development of the molding structure for shaping of the bottom side and a capable release process for the detachment of the molded structures.

The fabrication process of the SU-8 mold layer is optimized to fabricate molding structures with heights from a few µm up to 350 µm. Therefore different SU-8 formulations, namely with classification numbers 5, 25, 50, and 100, have been used. The fundamental limitations for the mold design result from the lithography process, which defines the smallest lateral resolution, and from the characteristics of a molding process, e.g. the impossibility to realize an undercut. To allow for reliable release, the molding structures have to be coated with a sacrificial layer. A silicon nitride is deposited onto the substrate with an accompanying monitoring of the deposition temperature during the PECVD process.

The technical capabilities of this innovative molding process of SU-8 will allow for more freedom in the design of MEMS elements and therefore will provide an excellent development potential not only for mechanical sensors but also for new microsystems of all kinds.

8763-107, Poster Session Thursday

Multilayer micromachined bandpass filter for L/S band satellite communication systems

Abdul Qader Ahsan Qureshi, Fondazione Bruno Kessler (Italy); Luca Pelliccia, Univ. degli Studi di Perugia (Italy); Sabrina Colpo, Jacopo Iannacci, Fondazione Bruno Kessler (Italy); Paola Farinelli, Univ. degli Studi di Perugia (Italy); Benno Margesin, Fondazione Bruno Kessler (Italy)

This paper presents the design and fabrication of a 2nd order L/S band filter used as a test vehicle for the development of a fabrication technology for micromachined cavity microwave filters in order to preliminary explore all the technological constraints on a simpler structure. The multilayered 2nd order pseudo-elliptic L/S band filter is based on λ/4 TEM mode resonators which are patterned on a very thin dielectric layer. For convenience 500 µm thick Si wafers have been used which limits the simulated unloaded Q factor of the 2nd order L/S band filter to about 200. The test structures presented here amount to the more sophisticated 4th order filters in an extended technological concept (i.e. 1500 µm thick Si wafer and two additional modules) but still based on similar resonating elements aiming to replace the existing bulky metallic waveguide filters installed in many satellite transceivers.

A five mask fabrication process is employed for the realization of the elements of said filter which is based on three modules. Module A and B are fabricated on the same wafer while module C which served as ground is fabricated on a separate wafer. A 2 µm high sealing ring is etched on the back of module A and B by DRIE while cavities and through silicon via (TSV) are etched by TMAH. All internal surfaces of the modules are plated with gold. The surface mounting compatibility of the filter is obtained by adopting vertical via holes to connect the external feeding lines (e.g. microstrip or coplanar) with the filter resonators. Such a transition separates the input/output from the filter input/output coupling mechanism. The final wafers are diced and specimens are vertically stacked and bonded through thermocompression bonding. The overall filter dimensions are 48x20x1.5 mm3.

The full article will include complete RF characterization of the devices.

8763-108, Poster Session Thursday

Contour and flexure-actuated in-plane modes of AlN-based piezoelectric vibrating MEMS

Victor Ruiz, Tomás Manzaneque, Jorge Hernando García, Univ. de Castilla-La Mancha (Spain); Abdallah Ababneh, Yarmouk Univ. (Jordan); Martin Kucera, Technische Univ. Wien (Austria); Ahmad N. Al-Omari, Yarmouk Univ. (India); Achim Bittner, Ulrich Schmid, Technische Univ. Wien (Austria); Helmut Seidel, Univ. des Saarlandes (Germany); José Luis Sánchez de Rojas Aldavero, Univ. de Castilla-La Mancha (Spain)

Nowadays there is an increasing interest in the use of the in-plane modes of vibrating MEMS structures [1]. Under the proper design, such modes are characterized by higher quality factors than out-of-plane modes, what results in a better resolution for mass sensing applications, as well as the possibility of liquid parameter monitoring in high viscous media [2, 3, 4].

The structures used in this study have a piezoelectric film for sensing and actuating, which allows lower driving voltages and currents than for electrostatic or thermal actuation. We followed two different approaches for the design of a wide variety of in-plane vibrating structures: contour modes and flexure-actuated modes. Regarding the contour modes [4], the structure vibrates at frequencies determined by its edge dimensions. These modes include the extensional one but also other dilation-type and diagonal-shear modes. In this case, plates with different anchors were used. In the

flexure-actuated modes, a plate is displaced by the lateral bending of the flexures which also support the suspended structure. Serpentine flexures of several periods, in combination with square plates, were used for the flexure-actuated approach. For both cases, the top metal layout was optimized for an efficient actuation of the mode of interest following the procedure outlined in Ref. 5.

We combined optical and electrical techniques to fully characterize the structures. For the electrical characterization, impedance measurements allowed us to determine two important figures of merit of each mode: the quality factor and the motional resistance, which is related to the amplitude of the conductance peak. Besides, with the help of a speckle pattern-based interferometer, we were able to recognize the shape of the modes. A quality factor as high as 6000 and a motional resistance as low as 300 Ohm were obtained for an extensional contour mode in air.

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8763-109, Poster Session Thursday

Pressure dependence of the quality factor of piezoelectrically driven AlN/Si-microcantilevers

Abdallah Ababneh, Ahmad N. Al-Omari, Yarmouk Univ. (Jordan); HuaCheng Qiu, Univ. des Saarlandes (Germany); Tomás Manzaneque, Jorge Hernando García, José Luis Sánchez de Rojas Aldavero, Univ. de Castilla-La Mancha (Spain); Achim Bittner, Ulrich Schmid, Technische Univ. Wien (Austria); Helmut Seidel, Univ. des Saarlandes (Germany)

Resonant microcantilevers play an important role in several applications, such as mass sensing [1], atomic-force microscopy (AFM) [2], and pressure monitoring [3]. In this paper, silicon cantilevers with piezoelectrically active AlN top layers were fabricated and analyzed. The dimensions of the cantilever are about 1000 µm x 250 µm x 20 µm. AlN with a thickness of 1000 nm is reactively sputtered from an Al-target with good piezoelectric coefficients [4]. The cantilevers were electrically characterized in a vacuum chamber within a pressure range from normal atmosphere down to 5x10-3 mbar. Two different modes were detected and analyzed. The first bending mode has a frequency of 19.5 kHz and a quality factor of 470 at atmospheric pressure. This value increased continuously to 985 at 1x10-1 mbar, where it reaches its maximum due to the dominance of intrinsic losses at lower pressures, whereas fluidic losses dominate at higher pressures. The corresponding resonant frequency increased from 19.5 kHz at atmospheric pressure to 19.573 kHz at 5 mbar.

The second bending mode was detected at 117.264 kHz. The quality factor is 570 at atmospheric pressure and increases continuously to 1275 at 1x10-1mbar. Similarly to the first mode, the quality factor reaches its maximum at this pressure. The corresponding resonant frequency was also changed from 117.264 kHz at atmospheric pressure to 117.630 kHz at 5 mbar. Other cantilever geometries and higher resonating modes are currently being investigated.

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8763-110, Poster Session Thursday

Microgalvanic nickel pulse plating processes for the production of thermal actuators

Wolfgang Hansal, Happy Plating GmbH (Austria); Harald Steiner, Technische Univ. Wien (Austria); Rudi Mann, Martina Halmdienst, Happy Plating GmbH (Austria); Johannes Schalko, Franz Keplinger, Technische Univ. Wien (Austria)

Nickel is often used in the micro fabrication because of its fatigue resistance and its mechanical properties. It is used for instance for thermal actuators, microgripes, or RF-switches [1]-[3]. The defined electrodeposition of the nickel matrix is crucial for the properties and functionality of the thermal actuators. Micro galvanic processes are the basis of this electrodeposition, and require knowledge of the electrochemical fundamentals as well as numerical electrochemical process simulation for adjustment. Especially realization of high aspect ratios requires the use of sophisticated plating techniques such as pulse reverse deposition.

The electrochemical fundamentals for tailoring the micro galvanic process were determined by a comprehensive set of electrochemical experiments. For complete and homogenous structure filling at high aspect ratios (>3:1), reverse pulse technology has been necessary. The pulse plating process was adjusted by using the results of electrochemical numerical simulation routines, visualizing the (local) potential field and the current field line distribution as a function of the applied electrochemical parameters. Compact, completely void free structures could be obtained applying the developed pulse plating process to the structured wafers. The electrodeposited material has been nickel for stability and hardness reasons. Stress measurements revealed a nearly stress free deposits.

MEMS structures were designed to convert the thermal expansion of the material into an in-plane deflection and deposited using the developed pulse plating process. Two bent beam actuators are arranged facing each other, and connected to a lever. The lever ratio increases the deflection of the bent beams to a reasonable range of several micrometers. A special designed measurement setup, consisting of a sealable chamber, a Peltier element with a temperature control unit, and an optical microscope is used to measure these deflections at different temperatures. Additional, finite element simulations are carried out to determine the thermal expansion coefficient of the plated Nickel.

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8763-111, Poster Session Thursday

Control of cavitation density through gas and acoustic uniformity in a proximity megasonic pre-bond cleaning system

Donald Dussault, Eric Liebscher, ProSys, Inc. (United States);

Frank Fournel, CEA-LETI (France); Viorel Dragoi, EV Group (Austria)

The increased complexity of microelectronic and sensor applications that have emerged over the past decade have driven the wafer bonding process to mature as a production technology for both MEMS and 3D stacked die manufacturing. The use of CMOS device wafers has restricted the types of viable bonding processes to low temperature fusion bonding, adhesive bonding and metal bonding. Due to the specific requirements of CMOS technology the allowed bonding processes had to be adapted in order to fulfill the specific CMOS-compatibility demands, significantly challenging the legacy cleaning processes of record.

A pre-bond cleaning process was developed utilizing a unique large area proximity type Megasonic transducer. This cleaning process was investigated for PRE (particle removal efficiency) as well as particle neutrality. These tests yielded higher values then those achieved with the process of record. Subsequently, this process was integrated into an industrial volume low temperature fusion bonding process and enabled higher bonding yields.

Current work describes development, testing and operational verification of a process fluid management devise used in conjunction with the wide area proximity Megasonic transducer. Megasonic enhanced processing is possible through the creation of cavitations in the process fluid exposed to sound. The eventual implosion of the cavitation releases a micro jet stream (shock wave) that is actually responsible for the particle cleaning, structure damage, or process enhancement observed in a Megasonic process.

In addition to acoustic field uniformity, Process fluid characteristic control is critical to the uniformity and density of cavitation and represents an important cleaning process control item. We will describe the calculation, measurement and verification of this process characteristic control with both laboratory and production equipment results.

8763-112, Poster Session Thursday

Surface damage monitoring using electro-magnetic sensors

Seok-Jin Kwon, Korea Railroad Research Institute (Korea, Republic of)

The wheel is an important part of an express train because it supports the weight of the train while maintaining contact with the rail. Damages to the wheel occur because of the following reasons: 1) high vertical stress on the region in contact with the rail; 2) thermal stress due to brake friction; and 3) nonmetallic inclusions in the row metal. These damages affect the safety of an express train. Therefore, nondestructive testing (NDT) and the maintenance of the wheel must be conducted regularly.

This paper presents the applicability of electro-magnetic technique to the detection and sizing of defects in wheel. Under the condition of continuous rolling contact fatigue the damage of wheel has continuously monitored using the applied sensor. It was shown that the usefulness of the applied sensor was verified by twin disc test and the measured damaged sizes showed good agreement with the damaged sizes estimated by electro-magnetic technique.

8763-113, Poster Session Thursday

Formation of a deposit on workpiece surface in polishing nonmetallic materials

Yuriy D. Filatov, V. Bakul Institute for Superhard Materials NASU (Ukraine); Guy Monteil, Institute FEMTO-ST (France); Volodymyr I. Sidorko, Oleksandr Y. Filatov, V. Bakul Institute for Superhard Materials NASU (Ukraine)

The quantum-mechanical description of scattering of wear particles in the tool–workpiece contact zone in the process of polishing has provided an explanation of the oscillatory structure of scattering of tool wear particles on debris particles and on wear particles and has made it possible to calculate the total and differential scattering cross-sections. Based on ab initio computations, relationships have been established between the differential cross-section of scattering of wear particles on debris particles and on wear particles and the scattering angle for various regions of the contact zone. It has been found out that the differential cross-section of scattering of wear particles on debris particles as well as on wear particles is maximum when the scattering angles are close to zero and 180° in the central regions of the contact zone. The probability of scattering of a flow of wear particles in the central regions of the tool–workpiece contact zone is shown to be much higher than that in the peripheral regions. The value of the differential cross-section of the forward scattering of wear particles on debris particles is the most significant in the central region, (7.0 Tb/sr) and greatly exceeds the value of the differential cross-section of scattering of wear particles on wear particles (0,3 Tb/sr). The above-mentioned difference is almost 200-fold and observed in a narrow circular region—3 mm in radius and 0.5–1.0 mm wide—on the tool working surface.

The mechanism of localization of the deposit fragments on the workpiece surface has been described, which permits determination of boundaries of the circular zone where individual deposit fragments are located. The theoretically calculated dimensions of the zone agree well with experimental data. Deposit fragments on workpieces of molten basalt, glass, quartz, and natural stone have been experimentally examined.

8763-114, Poster Session Thursday

A closed-loop system for frequency tracking of piezoresistive cantilever sensors

Hutomo S. Wasisto, Qing Zhang, Stephan Merzsch, Andreas Waag, Erwin Peiner, Technische Univ. Braunschweig (Germany)

A closed loop circuit capable of tracking resonant frequencies for MEMS-based piezoresistive cantilever resonators is developed in this work. The proposed closed-loop system is mainly based on a phase locked loop (PLL) circuit. In order to lock onto the resonant frequency of the resonator, an actuation signal generated from a voltage-controlled oscillator (VCO) is locked to the phase of the input reference signal of the cantilever sensor. The VCO can provide a direct readout and a high stability of frequency. In addition to the PLL component, an instrumentation amplifier and an active low pass filter (LPF) are connected to the system for gaining the amplitude and reducing the noise of the cantilever output signals. The LPF can transform a rectangular signal into a sinusoidal signal with voltage amplitudes ranging from 5 to 10 V which are sufficient for a piezoactuator input (i.e., maintaining a large output signal of the cantilever sensor). To demonstrate the functionality of the system, a self-sensing silicon cantilever resonator with a built-in piezoresistive Wheatstone bridge is fabricated and integrated with the circuit. The resonators are realized using a silicon bulk micromachining process. A piezoactuator is utilized for actuating the cantilever into resonance. Implementation of this closed loop system is used to track the resonant frequency of a silicon cantilever-based sensor (i.e., 2750x100x50 μm3) resonating at 9 kHz under a cross-sensitivity test of ambient temperature. The changes of the resonant frequency are interpreted using a frequency counter connected to the system. From the experimental results, the temperature sensitivity and coefficient of the employed sensor are 0.3 Hz/°C and 31.9 ppm/°C, respectively. The frequency stability of the system can reach up to 0.07 Hz. The development of this system will enable real-time nanoparticle monitoring systems and provide a miniaturization of the instrumentation modules for cantilever-based nanoparticle detectors.

8763-115, Poster Session Thursday

Simulation of thick film PZT actuators with interdigitated electrodes

Mohanad Mohammed Zaki, Sandy Zähringer, Norbert Schwesinger, Technische Univ. München (Germany)

Using the commercial COMSOL Multiphysics® software package,

this paper treats the topic of simulating the mechanical response of thick film piezoelectric ceramics (lead zirconate titanate, PZT) using the finite element method.

The poling and actuation are done using single-sided interdigitated electrodes (IDEs) fabricated on the ceramic; this requires using high electric fields on the order of a few kV/mm.

Simulations relating to actuators utilizing IDEs based on piezoelectric ceramics consider thin film structures where nonlinearities are absent but they play an important role in thick film soft piezoelectric ceramics [1]. The non-linear behavior leads to an amplification of the piezoelectric mechanical coupling factor d_33 depending on the strength of the applied field [2].

The simulation model used accounts for nonlinearities in the piezoelectric coupling coefficients thus enabling the optimization of the response of the actuators.

In addition, the simulation enables probing the piezoelectric response modes and their effect on the resulting deformation which for the chosen ceramic are d_31, d_33 and d_15.

Two different IDE designs were simulated, a unique star-shaped electrode [3] that exhibits a bidirectional deformation and a ring-shaped electrode design exhibiting a unidirectional deformation

To validate the results of the simulation, the electrodes are fabricated on top of a 100µm thick soft piezoelectric ceramic provided by Johnson Matthey (VIBRIT 1334).

Measurements are on the way using a laser vibrometer and a white light interferometer.

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8763-116, Poster Session Thursday

Vacuum packaging of MEMS sensors

Jae Hong Park, Tae Hyun Kim, Woo Choong Kim, Myeongho Song, Eunmi Park, Hee Yeoun Kim, Kwyro Lee, National Nanofab Ctr. (Korea, Republic of)

We will address a methodology for design, fabrication, and analysis of MEMS based infrared sensor array packaging.

Also, ultimate type of wafer level packaging will be introduced in a view point of design factors and structural differences compared with on-going metal packaging.

8763-19, Session 6

Flexible hot-film anemometer arrays for flow measurements on curved structures

Tobias T. Beutel, Martin Schwerter, Monika Leester-Schädel, Andreas H. Dietzel, Stephanus Büttgenbach, Technische Univ. Braunschweig (Germany)

In this work, the design, fabrication and characterization of a new type of AeroMEMS hot film sensor arrays is presented. The arrays are micro-fabricated on flexible polyimid foil (PI), which was either ready-made or custom-made in a spin-on process. Onto this PI layer apart from the typically used Nickel, a variety of materials for the sensing element has been selected in order to trim the sensor’s behavior. In addition to that, the wiring of the sensor can be made of copper or gold. The electroplated copper is up to 2 µm thick, for high-power operation during measurements in water. The much thinner magnetron sputtered gold wiring is used for precise measurements in wind tunnels.

It is a unique characteristic of these arrays that their total thickness can be scaled from 5 to 52 µm. This is essential, because the maximum sensor thickness has to be adapted to the various thicknesses of the boundary layers in different flow experiments. With these sensors we meet the special requirements of a wide range of fluid mechanics. For example, the extremely flat hot film anemometer does not affect the flow, what is essential in today’s active flow control experiments.

The entire development, starting from theoretical investigations is described. Further, the micro-fabrication is explained, including all typical processes e.g. photolithography, diffusion, sputtering techniques and wet-etching. The wet-etching of the sensing element is described precisely, because the resulting final dimensions are critical for the functional characteristics.

The result of these steps is a wide knowledgebase of how to fabricate flexible arrays with well-defined properties. There is no commercial supplier, offering sensor arrays with thicknesses down to 5 µm. But these are necessary to enable new kinds of measurements within the boundary layer of fluids, because the efforts to be made for installation of these sensors are considerably reduced.

8763-20, Session 6

Microthermal sensors for determining fluid composition and flow rate in fluidic systems

Andreas Schütze, Christian Kiefer, Bastian Schmitt, Univ. des Saarlandes (Germany)

The analysis of fluid mixtures with regard to their composition over a wide concentration range is still a major challenge. Such sensors are required, for example, for Direct Methanol Fuel Cells (DMFC) for determining the concentration of methanol in water, for SCR systems determining the mixture of urea in water but also for water contamination in oil. A simple and low cost measurement method can be realized using a microthermal sensor to determine the thermal capacity and thermal conductance of the fluid mixture. In this sensor a short heat pulse with a duration of a few tenth of a second is introduced into the fluid mixture and the resulting temperature increase is measured. This principle results in an almost linear dependence of the temperature increase on the methanol content in water. The sensitivity was determined at S = 0.12 K/vol% for methanol in water for a heat pulse of 0.5 sec duration and a heater power of 60 mW for the concentration range 0 to 20 vol%.

By integrating additional temperature sensors in front and behind the microheater the flow rate of the liquid flowing across the sensor can be determined. We are investigating both a differential anemometer approach and a time-of-flight flow measurement with the goal of determining the liquid composition and flow rate simultaneously. The measurement principle is studied by multiphysics simulations and experimental evaluation of microsensors with heater and temperature sensors sputtered on polyimide foil. Microfluidic measurement cells with integrated seals are realized by rapid prototyping. The sensors will be optimized for both low cost and low power consumption in order to allow integration of the sensors in miniaturized DMFC systems.

8763-21, Session 6

A high thermal resistance MEMS-based Pirani vacuum sensor chip

Florian Dams, Rupert Schreiner, Fachhochschule Regensburg (Germany)

The performance of thermal conductivity vacuum gauges can be improved by a well-designed geometry. The lower measurement range limit is determined by the thermal conduction heat losses through the supporting structures and the size of the active sensing area. The upper measurement range is limited by the distance of the heated element to the cold reference plane. Silicon based MEMS-technology gives the possibility to fabricate both sensing structures with suitable areas out of low thermal conductive materials and narrow gaps in order to extend the measurement range in both directions.

In this work we present a micromachined process to fabricate high thermal resistance sensor structures. The rectangular sensitive areas range from 400 to 1500µm in length and are 250µm in width. The sensing area is supported by four beams with 200 to 400µm in length and 30 to 60µm in width. The whole element is structured out of low thermal conductive PECVD-siliconnitride films with 1µm in thickness. The electrical nickel heater is completely embedded in the silicon nitride layer for protection against aggressive gases. For a proper thermal insulation from the Si-substrate both the sensitive area and the support beams are anisotropically underetched by TMAH. By this way a free-supporting sensor structure with a gap to the substrate of 150µm is formed.

Chips with different geometries were characterized concerning their properties as thermal-conductivity vacuum sensors. The sensor chips were studied in a constant temperature operating mode where the temperature of the sensitive area was held constant by a self-balancing bridge circuit. The required electrical heating power was measured in an embedded system. For an optimized thermally insulated structure and a temperature rise of 20K to ambient 20µW heating power in the high vacuum regime and 50mW at atmospheric pressure were necessary. The average solid state thermal resistance of the sensing device is in the order of 1E6 K/W, resulting in a total measuring range of the vacuum sensor chip of 8 orders of magnitude from 1E-5 to 100mbar.

8763-22, Session 6

Microfluidic low cost calorimeters for biological and chemical applications

Martin Jaegle, Fraunhofer-Institut für Physikalische Messtechnik (Germany); Jürgen Antes, Fraunhofer-Institut für Chemische Technologie (Germany)

Thermal analysis or calorimetry is a widely used technique for obtaining both qualitative and quantitative information about thermal transitions associated with a particular material or process. However, the range of potential applications for calorimetry is far wider as every chemical and physical process is characterised by the change of its energetic state. Calorimetry is therefore a universal analytical method for investigating thermal effects resulting from chemical or biochemical reactions and/or changes in physical states.

Moreover calorimetry does not require any labelling or immobilization of the reactants and is therefore also an attractive methodical approach of detecting biochemical interactions without employing fluorescent markers. However, commercially available classical calorimeters require an unfavourable large test volume and thus a relatively huge amount of test substance. Hence, these calorimeters are not suitable for biochemical or screening applications. These problems can be overcome by applying miniaturised calorimeters containing micro fabricated thermopile chips. Such devices have many significant advantages when applied to biochemical and screening applications including low cost, small sample consumption and fast response times.

Here, we present the development of a low cost thermopile chip. Low cost thermopile chips capable of analyzing small quantities of samples that are easy to use, have fast response times, and good operational stability are needed in many biochemical, chemical and clinical diagnostic applications. To fit a wide range of applications the thermopile chip and the microfluidic device is developed modularly. The device structure can be adapted easily to enable a wide variety of other standard calorimeter operations. DSC, DTA, reaction calorimeters, and “lab on a chip” concepts are possible for single measurements as well as for high throughput characterization. First results will be shown for selected chip layouts.

8763-23, Session 7

Electromagnetic microactuators *(Invited Paper)*

Stephanus Büttgenbach, Alaaldeen T. Al-Halhouli, Marco Feldmann, Volker Seidemann, Andreas Waldschik, Technische Univ. Braunschweig (Germany)

High precision microactuators have become key elements for many applications of MEMS, e.g. for positioning and handling systems as well as for microfluidic devices. Electromagnetic microactuators exhibit considerable advantages such as high forces, large deflections, low input impedances and thus, the involvement of only low voltages. Most of the magnetic mi-croactuators developed so far are based on the variable reluctance principle and use soft magnetic materials. Since the driving force of such actuators is proportional to their volume, they require structures with rather great heights and aspect ratios. Therefore, the develop-ment of new photo resists, which allow UV exposure of thick layers of resist, has been es-sential for the advancement of variable reluctance microactuators. On the other hand, hard magnetic materials have the potential for larger forces and larger deflections. Hybrid integra-tion of permanent magnets, electroplating of hard magnetic materials and polymer magnets, in which micro particles of hard magnetic material are suspended in a polymer matrix, have been used to fabricate permanent magnet microactuators.

In this paper we give an overview of sophisticated electromagnetic microactuators which have been developed in our laboratory in the framework of the Collaborative Research Cen-ter “Design and Manufacturing of Active Microsystems”. In particular, concept, fabrication and test of variable reluctance micro stepper motors, of rotating synchronous micromotors and of microactuators based on the Lorentz force principle will be described. Special empha-sis will be given to applications in lab-on-chip systems.

8763-24, Session 7

Thermal design of a tristable electromagnetic linear microactuator with high displacement and low actuation force for mass storage applications

Xin Xu, Ha-Duong Ngo, Piotr Mackowiak, Technische Univ. Berlin (Germany)

This paper reports on thermal design of a micro linear tristable actuator with an integrated sensor platform. On the basis of theoretic analysis and previous works, a novel design for the set-up of the one-axis actuator is proposed, in which electromagnetic driving is used, and the actuator will be hold only with permanent magnet forces on the end. It consists of a rotor carrying the movable structure to which the actuated component is connected mechanically and electrically. Springs with low stiffness in the plane of actuation but high stiffness in all other directions connect the movable structure to the rotor frame. Conducting paths are situated on the springs to provide electrical connectivity on the movable structure. For contacting, power supply and the reading of the two on the sensor chip placed micro sensors, six conductors need to be located on the micro mechanical spring system designed for currents up to 100mA.

In order to confirm the thermal stabilization by working under strong current on micro spring, a thermal analysis is made. Though the thermal FEA of microstructures is very challenging, the essential convection coefficient is calculated with help of a CFD-Simulation of a 2D finite element

A 3D finite element modeling is presented in brief theoretical analysis, modeling and simulation of temperature distribution were done for the realized micro actuator. Simulations of temperature distribution in the realized actuator were done taking into account the thermal-mechanical deforma by working under named current. In order to underlay the thermal measurement results the FEM model is shown. The obtained simulation and experimental results are graphically presented, compared and analyzed.

The thermal stabilization of a tristable linear electromagnetic actuator is presented. The measured maximum temperature of the spring and the conductor is 57,7°C. The average temperature of the sensor platform is 37°C. However the infrared camera in combination with the microscope optics does not offer enough local and temperature resolution caused by the complex background of the slider and needs to be optimised by manufacturer.

8763-25, Session 7

Highly sensitive thermal actuators for temperature sensing

Harald Steiner, Technische Univ. Wien (Austria); Wilfried F. Hortschitz, Austrian Academy of Sciences (Austria); Michael Stifter, Austrian Academy of Sciences (Austria) and Technische Univ. Wien (Austria); Franz Keplinger, Technische Univ. Wien (Austria); Thilo Sauter, Austrian Academy of Sciences (Austria)

Thermal actuators are broadly used for instance as microgrippers. Many of them rely on resistive heating elements and are locally heated up to several hundred degrees Celsius [1].

We present a thermal actuator which is completely passive. Only the temperature of the surrounding environment is used to deflect the tip of the actuator. State of the art actuators show sensitivities in the range of 0.01 µm/°C up to 0.17 µm/°C [1]-[3]. Our goal was to increase these sensitivities, and get reasonable deflections already in the temperature range of several ten degrees, in order to enable its use as a temperature indicator.

The presented actuator consists of two symmetrical bent beam stacks. Each bent beam stack consists of 6 beams in parallel. The stacks are coupled facing each other and only slightly shifted along the mirror axis. Both stacks are connected to a lever beam. Due to the thermal expansion of the material, the tip of the lever moves up- and downwards perpendicular to the mirror axis. The MEMS is built up of galvanic deposited Nickel, and is manufactured in a multi-project-wafer-run, offered by Europractice.

Finite element simulations were carried out for design considerations prior to the manufacturing of the device. The simulations were used to optimize the design regarding to the sensitivity and the maximum mechanical stress to be expected. The stress level needs to be lower than the yield strength of the material, to prevent plastic deformation and therefore irreversible tip deflections. It also limits the overall sensitivity of our design.

First results of the device with 400 µm long bent beams show a linear behavior and a sensitivity of 0.5 µm/°C, in a temperature range of -30°C up to +40°C.

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8763-26, Session 8

Design of high-efficiency vibration energy harvesters and experimental functional tests for improving bandwidth and tunability

Aurelio Soma, Giorgio De Pasquale, Politecnico di Torino (Italy)

This paper introduces the results of design and experiments on devices for harvesting energy from the vibrations of machines and vehicles usable for supplying sensors. The conversion strategies considered are piezoelectric and magnetic-inductive. The main contribution of this research is the empirical evaluation of different technical solutions applied to the harvester prototypes for improving their performances in terms of efficiency and for optimizing the duty cycle of the autonomous sensing system.

The power spectral density (PSD) diagram of the operative field subjected to random vibrations provides the necessary information for the preliminary dimensioning of the transducer. The PSD also provides the distribution and amplitude of resonance peaks in the frequency domain, which are generally induced by coupled vibration modes of the machine. The small variation of dimensional parameters allows tuning the harvester on the actual driving resonance: active tuning systems are conceivable with increasing of energy consumption for their activation. Finally, the bandwidth amplification represents another source of efficiency improvement for very distributed PSDs and can be obtained with specific dynamic strategies. The dynamic response of the harvester can be modified by acting on the oscillating masses and on suspensions stiffness; in coupled systems (e.g. magnetic inductors) the dynamic and electric properties are strongly dependent, introducing relevant complications in the design optimization. Satisfactory results have been achieved in the lowering of resonance frequency by using levitating magnetic suspensions and in the increasing of Q-factor by studying the fluid flows around the movable parts. The experimental validation of every tentative design solution allows reducing the uncertainties about the benefits and drawbacks of the current layout respect the results provided by simulations, whose accuracy is sometimes extremely rough for mechanical-electrical-magnetic-fluidic coupled systems. Output power values of 10mW (5.7Hz, 1.4g) and 115mW (3.2Hz, 0.2g) were obtained for piezoelectric and inductive harvesters respectively.

8763-27, Session 8

Fabrication of vertical nanowire resonators for aerosol exposure assessment

Stephan Merzsch, Hutomo S. Wasisto, Andrej Stranz, Technische Univ. Braunschweig (Germany); Peter Hinze, Thomas Weimann, Physikalisch-Technische Bundesanstalt (Germany); Erwin Peiner, Andreas Waag, Technische Univ. Braunschweig (Germany)

Vertical silicon nanowire (SiNW) resonators are designed and fabricated in order to assess exposure to aerosol nanoparticles (NPs). Firstly, the SiNWs constructed in aligned arrays are designed and simulated using finite element modeling (FEM) to approximate their operating resonant modes. To realize SiNW arrays, nanolithography and inductively coupled plasma (ICP) deep reactive ion etching (DRIE) at cryogenic temperature are utilized in a top-down fabrication of SiNW arrays which have high aspect ratios (i.e., up to 34). For nanolithography process, a resist film thickness of 350 nm was applied in a vacuum contact mode to serve as a mask. A pattern including various diameters and distances for creating pillars was used (i.e., 400 nm up to 5 µm). In dry etching process, the etch rate was set high of 1.5 µm/min to avoid underetching. The etch profiles of Si wires can be controlled aiming to have either perpendicularly, negatively or positively profiled sidewalls by adjusting the etching parameters (e.g., temperature and oxygen content). The wire pitch can also affect the wire profiles due to resulting variations in exchange of educts and products while etching. Moreover, to further miniaturize the wire, multiple sacrificial thermal oxidations and subsequent oxide stripping are used yielding SiNW arrays of 650 nm in diameter and 40 µm in length. In the resonant frequency test, a piezoelectric shear actuator is integrated with the SiNWs inside a scanning electron microscope (SEM) chamber (~2 x 10-7 kPa). The observation of the SiNW deflections are performed and viewed from the topside of the SiNWs to reduce the measurement redundancy. Having a high deflection of ~10 µm during its resonant frequency of 452 kHz and a low mass of 31 pg, the proposed SiNW is potential for assisting the development of a portable aerosol resonant sensor.

8763-28, Session 8

Quality factor enhancement for resonant MEMS applying an analogue feedback circuit driven by a lock-in amplifier

Martin Kucera, Technische Univ. Wien (Austria) and AC^{2}T research GmbH (Austria); Franz Hofbauer, Technische Univ. Wien (Austria); Tomás Manzaneque, Victor Ruiz, Univ. de

Castilla-La Mancha (Spain); Achim Bittner, Technische Univ. Wien (Austria); José Luis Sánchez de Rojas Aldavero, Univ. de Castilla-La Mancha (Spain); Ulrich Schmid, Technische Univ. Wien (Austria)

Most recently [1], a quality factor enhancement circuit was presented using a digital control loop instead of an analogue circuitry for piezoelectric driven, resonantly excited MEMS cantilevers. When applying the first approach, software controls the measurement equipment and the read out of measurement data, as well as the setting of new values. To extract a frequency response, several frequencies have to be measured and for each frequency several hundred of iterations are necessary to reach steady state condition in order to emulate the behaviour of an analogue feedback circuit. Therefore, a major drawback of this digital control realized in LabView is the huge amount of data being exchanged between LabView and external equipment, causing a long duration of each iteration step. In this work, an analogue circuit is presented, providing faster feedback, by replacing the digital communication. For this purpose, an analogue multiplier IC AD734 from Analog Devices is used in combination with the auxiliary output of the in X-Y mode working lock-in amplifier HF2LI providing the measured conductance value to realize the positive feedback. Since the high speed auxiliary output is used in this configuration, the feedback duration per iteration is minimized to almost the lock-in time constant of the low-pass filter. This leads to an enormous saving in measurement time without any loss in accuracy of the data.

In the final paper, an electronic circuit of the analogue feedback circuit will be presented. Furthermore, the concept will be described in detail together with measurements of a self-sensing and self-actuated aluminium nitride cantilever performed in air. These promising results, however, will stimulate further research activities to optimize the performance of resonant excited cantilevers.

[1] M. Kucera et al., “Lock-in Driven Quality Factor Enhancement with Parasitic Effect Compensation of a Self-Actuated Piezoelectric MEMS Cantilever,” presented at IEEE Ultrasonic Symposium 2012.

8763-29, Session 8

Multi-modal vibration based MEMS energy harvesters for ultra low power wireless functional nodes

Jacopo Iannacci, Massimo Gottardi, Enrico Serra, Roberto Di Criscienzo, Fondazione Bruno Kessler (Italy); Antonio L. Borrielli, Istituto Nazionale di Fisica Nucleare (Italy) and Consiglio Nazionale delle Ricerche (Italy); Michele Bonaldi, Istituto Nazionale di Fisica Nucleare (Italy) and Istituto dei Materiali per l’Elettronica ed il Magnetismo (Italy)

Vibration based MEMS energy harvesters have emerged in recent years as a key enabling solution for energy autonomous wireless (sensor) nodes and networks. Interest of the research community towards miniaturization of vibration energy converters was initially scarce, due to low power levels achievable with such structures. Nonetheless, progressive reduction of consumption requirements for ultra low power electronics and, on the other hand, increasing demand for integration and miniaturization, brought MEMS energy harvesters back in the limelight.

In this work we address optimization of the mechanical transfer function and energy conversion characteristics of vibrational MEMS harvesters, focusing on mechanical behavior of resonant structures. In particular, the multi modal approach is followed by the authors in order to extend devices’ range of operability. As it is well known, in vibration based harvesters maximum energy conversion is achieved for vibrations corresponding to the structure’s resonant frequency. This makes MEMS energy harvesters operable in a very narrow frequency range. Nonetheless, it is possible to increase the number of resonant frequencies (i.e. modes) sensed by the mechanical vibrating structure, indeed extending energy conversion on a broader range of operability, regardless of the particular conversion mechanism employed (piezoelectric, electromagnetic, electrostatic).

In the full paper we will present a comprehensive study of the multi modal approach, based both on analytical and FEM (Finite Element Method) modeling and validated against experimental data, aiming to the synthesis of optimized concept designs of broad band MEMS vibration energy harvesters, to be then manufactured and experimentally tested. Aspects related to the simulation of energy conversion will be also addressed, in order to establish a design and optimization flow that enables to interface the simulation of device’s electromechanical characteristics together with active electronics for energy extraction, storage and utilization, the latter aspects being of particular importance in the realization of energy autonomous and energy aware wireless systems.

8763-503, Plenary Session Friday

Micro- and nanoscale thermoelectrics: an overview over basic concepts and recent advances

Markus Winkler, Fraunhofer-Institut für Physikalische Messtechnik IPM (Germany); Martin Jaegle, Fraunhofer-Institut für Physikalische Messtechnik (Germany); Xi Liu, Christian-Albrechts Univ. zu Kiel (Germany); Jan Koenig, Harald Boettner, Fraunhofer-Institut für Physikalische Messtechnik (Germany); Lorenz Kienle, Christian-Albrechts-Univ. zu Kiel (Germany)

Micro- and nanostructuring thermoelectric materials have opened new fields for the applications of thermoelectricity. Micro-thermoelectrics are a general variant of thermoelectrics to enable special applications like localized cooling and small-scale energy harvesting to power autonomous sensor systems. In contrast, nano-thermoelectrics is a term generally applied to the art of nanostructuring materials, aiming at an increased figure of merit ZT and thus an improvement in device efficiency.

In the talk recent advances in the field of micro-thermoelectrics are presented. Furthermore, the theoretical principles and concepts behind nanostructured materials will be elucidated. This will be followed by selected examples of the application of nanostructuring in thermoelectric materials research and device fabrication. Results reported previously in literature as well as recent results obtained within our group will be presented, illustrating the diversity of thermoelectric material research.

8763-30, Session 9

All-silicon micro-force sensor for bio applications

Vladimir T. Stavrov, AMG Technology Ltd. (Bulgaria); Assen Shulev, Institute of Mechanics, Bulgarian Academy of Sciences (Bulgaria); Vencislav M. Todorov, Techproject Co. (Austria); Ilia R. Roussev, Institute of Mechanics, Bulgarian Academy of Sciences (Bulgaria)

In this paper we present design, prototyping, calibration and testing of a micro-force sensor sufficient for injection of biological cells. It is an axial all silicon piezoresistive Micro Electro-Mechanical System (MEMS). A CAD model allows studying initially the behavior of such a mechanical system. The design is adapted to allow the sensor to operate also in fluids when submerged. The layout of the all-silicon force sensor is illustrated and discussed. A prototype made by recently developed technology for manufacturing of MEMS devices with sidewall embedded piezoresistors is investigated. Calibration of the sensor is realized by means of an experimental set-up including capacitive micro force sensor and piezo driven translational stage. It has been found that the prototyped sensor provide large working range with sub-micro-newton resolution. Functionality of the all-silicon micro-force sensor for bio-applications is verified by penetration of a Xenopus Leavis Oocyte cell’s membrane. The measured force profile and interpretation of the results with respect to the sensor’s construction are also given.

8763-31, Session 9

Efficient nanoparticle filtering using bioinspired functional sufaces

Sebastian Busch, Manuel Ketterer, Albert-Ludwigs-Univ. Freiburg (Germany); Xenia Vinzenz, Christian Hoffmann, Institut fur Bioprozess- und Analysenmesstechnik e.V. (Germany); Jürgen Wöllenstein, Albert-Ludwigs-Univ. Freiburg (Germany)

Today we feel for many reasons that the pollution of our environment with unconsciously released nanoparticles is steadily increasing. In recent years, a number of studies have revealed more and more adverse health effects of both naturally occurring and anthropogenic airborne nanoparticles – a commonly known example is the fine dust in the exhaust gas of vehicles. Exhaust gas from diesel engines contains a large quantity of possibly harmful nanoparticles. Yet also current filtering techniques come to their limitations concerning the elimination of fine particles in the nanometer size range. Many studies have already reported a connection between the increasing prevalence of respirable dust in the environment and the frequency and the degree of hypersensitivity reactions in humans. At the same time, an increasing number of people suffers from allergies, e.g. against pollen. First hints have now been given that agglomerates of fine dust sticking on pollen surfaces render them more aggressive against the human immune system.

Our aim is to investigate the principle of adherent surfaces of biological microparticles, in a first step different pollen species, and to transfer the gained knowledge about their surface structure and functionality into a technology providing an artificial, functionalized superstructure, which offers an efficient filtering method for airborne particles, e.g. particulate matter. In detail, we examined three pollen species for their potential as biological model regarding their surface structure and biochemical composition. The surface structures were mimicked on silicon wafers using wet etching processes. The biochemical composition was investigated with Raman spectroscopy. As a first approximation, the surfaces were functionalized with polyelectrolyte layers using dip-coating, and were characterized with IR spectroscopy. Furthermore the layers were tested for their stability at different flow velocities in a wind tunnel. Using standard nanoparticle dust, the surfaces were evaluated for their ability to efficiently capture the particles, depending on flow velocity and surface functionalization.

8763-32, Session 9

Hydrogel-based labs-on-a-chip

Merle Allerdissen, Stephan Klatt, Andreas Richter, Technische Univ. Dresden (Germany)

A microfluidic platform containing one or more laboratory functions is called a lab-on-a-chip (LOC). Due to their small size and their capability for parallel processing, LOCs in general reduce fabrication costs, operating time, the reagent consumption and the required sample volume. Thus, they offer a large number of potential applications for various fields, especially in the areas of biology, chemistry and medicine.

In order to realize LOCs, in recent years many different technologies and approaches have been developed. Here, we present LOCs based on the stimuli-responsive hydrogel Poly(N-isopropylacrylamide) (PNIPAAm). Stimuli-responsive hydrogels are three-dimensional networks that are able to change their volume significantly in response to small changes of various environmental parameters. PNIPAAm, for example, is a temperature-sensitive hydrogel. Heated in a swelling agent above its lower critical solution temperature (LCST), it reversibly changes from a swollen to a shrunken state and thereby exhibits a volume change in the order of 90%. Since the LCST of PNIPAAM depends, inter alia, on the specific alcohol concentration in the swelling agent, not only switchable components like micropumps or microvalves, but also valves with an appointed threshold value, so-called chemostats or chemical transistors, can be realised.

PNIPAAm can be synthesised and cross-linked via photo-patterning. On the one hand, this allows to achieve hydrogel patterns with very defined dimensions, on the other hand, a direct integration of the active elements into the microchip even during the fabrication process is possible. The performance of such a microfluidic component primarily depends on its network structure and the design parameters of channel structure and valve. We investigate obtainable properties of photo-linked PNIPAAM gels and show their application for different fluidic operations on a LOC like fluid transportation, metering, valving and mixing.

8763-33, Session 9

A low complexity wireless microbial fuel cell monitor using piezoresistive sensors and impulse-radio ultra-wide-band

Marco Crepaldi, Alessandro Chiolerio, Tonia Tommasi, Diana Hidalgo, Giancarlo Canavese, Istituto Italiano di Tecnologia (Italy); Danilo Demarchi, Fabrizio C. Pirri, Istituto Italiano di Tecnologia (Italy) and Politecnico di Torino (Italy)

Microbial Fuel Cells (MFCs) are energy sources which generate electrical charge thanks to bacteria metabolism. Although functionally similar to chemical fuel cells (both including reactants and two electrodes, and anode and cathode), they have substantial advantages, e.g. 1) operation at ambient temperature and pressure; 2) use of neutral electrolytes and avoidance of expensive catalysts (e.g. platinum); 3) operation using organic wastes. An MFC can be effectively used in environments where ubiquitous networking requires the wireless monitoring of energy sources. We then report on a simple monitoring system for MFC comprising an ultra-low-power Impulse-Radio Ultra-Wide-Band Transmitter (TX) operating in the low 0-960MHz band and a nanostructured piezoresistive pressure sensor connected to a discrete component digital read-out circuit. The sensor comprises an insulating matrix of polydimethylsiloxane and a condutive filler i.e. silver nanoparticles. Pressure modulates the mean distance between particles, i.e. the current flow. The read-out circuit encodes pressure as a pulse rate variation, with an absolute sensitivity to the generated MFC voltage. Pulses with variable repetition frequency can encode battery health: the pressure sensor can be directly connected to the cells membrane to read excessive pressure. A prototype system comprises two MFCs connected in series to power both the UWB transmitter which consumes 40uW and the read-out circuit. The two MFC generate an open circuit voltage of 0.8±0.1V. Each MFC prototype has a total volume of 0,24L and is formed by two rectangular Plexiglas chambers (anode and cathode) separated by a cation exchange membrane. The anode chamber is filled by a buffer solution 0.1M (Na2HPO4 and NaH2PO4), glucose 60g/L, beer yeast 100g/L and methylene blue (1.22 g/L). The cathode is filled by 6.58g/L potassium ferricyanide and 0.1M buffer solution. The paper reports on the prototype and measurements towards a final solution which embeds all functionality within a MFC cell.

8764-1, Session 1

A 2.5 Gb/s low-voltage CMOS fully-differential adaptive equalizer

Erick Guerrero Rodriguez, Cecilia Gimeno, Concepcion Aldea, Santiago Celma-Pueyo, Univ. de Zaragoza (Spain)

Plastic optical fiber has become one of the most preferred choices, more than copper cables, for low-cost high-speed communications because it is lighter, reliable and cheaper. However, it has the same limitation in bandwidth which can cause, along with other factors, to increase the bit error rate. Therefore, adaptive equalization is mandatory in order to reach multi-gigabit transmissions over POF links. On the other hand, continuous-time equalizers can be used, as a good trade-off for low-power high-speed applications, requiring less complexity and smaller area than discrete-time or purely digital approaches.

Continuous-time equalizers proposed in literature are based on conventional degenerated differential pair [1-2]. Unfortunately, their gain and zero are strongly coupled, which supposes a serious drawback for tuning purposes. Furthermore, low-voltage supply severely limits its dynamic range. To overcome these, the proposed system is formed by a fully-balanced equalizer based on a split-path topology, whose crossed-feedback reduces considerably the common-mode gain, obtaining a high CMRR. Further, the gain and high-frequency boosting can be orthogonally controlled.

As the spectrum of a PRBS can be represented by a sinc2(x) function, it can be split into its low and high-frequency components to determine if the signal is under or over-compensated [3]. Then, as the ratio of any two frequencies is fixed, that is it can be expressed as PH/PL=const, a control signal can be generated by means of the difference PH-PL•const, where PH and PL are the low and high-frequency components, respectively, and adjust the boost accordingly.

The proposed equalizer was implemented in a standard 0.18-µm CMOS technology. The total power consumption is 17.3-mW and it is aimed for multi-gigabit applications, targeting 2.5-Gb/s. The signal BW is improved from 100-MHz to 1.8-GHz for a 50-m length POF. It was fed with 1-V as a test bench to demonstrate its applicability to shorter technology

8764-2, Session 1

Reducing flicker noise up-conversion in a 65-nm CMOS VCO in the 1.6-to-2.6 GHz band

Andrea G. Bonfanti, Federico Pepe, Carlo Samori, Salvatore Levantino, Andrea L. Lacaita, Politecnico di Milano (Italy)

The demand of larger tuning ranges for the voltage-controlled oscillator (VCO) in newest communication standards can lead to unacceptable phase noise performances of traditional voltage-biased topologies, which allow to avoid further noise and power dissipation due to tail current generation but on the other hand they suffer from a large degradation of the 1/f^3 phase-noise component. In the next few years, 4G cell phones will integrate traditional cellular standards and WiMAX. Since the latter requires a low integral phase noise of the local oscillator performing signal (de)modulation, the 1/f^3 phase-noise component of the VCO can easily result into intercarrier interference. In this paper, the flicker noise up-conversion mechanisms involved in voltage-biased oscillators are investigated, yielding design guidelines and presenting a new improved topology for its mitigation. In this work, the noise analysis is performed in the framework of Hajimiri's Impulse Sensitivity Function (ISF) and the presence of cyclostationary noise sources is fully taken into account. In particular, an orthogonal decomposition of the 1/f^3 phase-noise is carried out, highlighting the different generation mechanisms of its components, the latter eventually linked to circuit parameters. The prototype voltage-biased VCO features a digitally-controlled negative-gm and has been implemented in a 65-nm CMOS technology. The oscillator covers the 1.6-2.6 GHz band to serve for both 4G and WiMAX 2.5-GHz operation modes. The proposed VCO architecture consists on a segmented transconductor which provides the proper value of negative-gm to ensure a low 1/f noise up-conversion over the whole tuning range without impairing the 1/f^2 phase-noise performances. The proposed phase-noise model is validated by means of experimental measurements. A reduction of about 10dB of the flicker-induced phase noise is achieved. Another advantage of the proposed topology is a reduced sensitivity to voltage supply variations, as low as 20MHz/V over the entire tuning range.

8764-4, Session 1

Energy harvesting with piezoelectric applied on shoes

Enrico Camilloni, Mirko Carloni, Marco Giammarini, Massimo Conti, Univ. Politecnica delle Marche (Italy)

In the last few years the continuous demand of energy saving has brought continuous research on low-power devices, energy storage and new sources of energy. Energy harvesting is an interesting solution that captures the energy from the environment that would otherwise be wasted.

The work presents an electric-mechanical model of a piezoelectric transducer in a cantilever configuration. The model has been characterized measuring the acceleration and the open circuit voltage of a piezoelectric cantilever subjected to a sinusoidal force with different values frequency and subject to an impulsive force.

The model has been used to identify the optimal position in which the piezoelectric cantilever has to be placed on a shoe in order to obtain the maximum energy while walking or running.

As a second step we designed the DC-DC converter with an hysteresis comparator. The circuit is able to give energy to switch on a microprocessor for the amount of time long enough to capture and store the information required.

The first application considered is the acquisition of the acceleration in different positions in the foot during running or walking.

The complete system has been implemented, installed on a shoe and used in a 10 Km running competition.

Future developments will consider the use of a low power wireless transceiver to connect the energy harvesting sensor to a smartphone using ANT+ protocol.

8764-5, Session 1

A 1.2 V low-power OpAmp for integrated lock-in amplifiers

Maria Valero, Santiago Celma-Pueyo, Nicolás Medrano-Marques, Univ. de Zaragoza (Spain); Belen Calvo, Cecilia Gimeno, University of Zaragoza (Spain)

The growing demand for long-life autonomous portable equipment is driving the current trend towards low power design. Wireless sensor networks (WSN) with smart sensors are examples. They need to have very longtime battery lifetimes since in most cases it is not possible to recharge or replace batteries frequently.

Taking the right acquisition of sensor measurements can be difficult when the sensor output signals are very small compared to the noise level. An interesting possibility is the use of lock-in amplifiers (LIAs). Although LIAs are widely employed in instrumentation, only a few integrated versions can be found in the literature. Nevertheless, most of them operate in dual supply mode and with power consumption of mili-watts. In this way, it is necessary to re-design all the building blocks of the LIA in single supply operation compatible with the power requirements of battery-operated sensor nodes in WSN.

A low-power rail-to-rail class AB operational amplifier (OpAmp) suitable for integrated lock-in amplifiers is presented. It has been designed in a standard 0.18µm CMOS technology. For a 1.2V single supply and 68.6?W power consumption, simulations shows a 81dB open loop gain, 60º phase margin, 26.7MHz unity gain frequency (no load), 75dB CMRR and 30.7V/µs slew-rate (10pF load). To

demonstrate its feasibility, a compact and reliable LIA making use of the proposed OpAmp has been designed, targeting sensor signal conditioning in embedded wireless applications.

The proposed LIA, designed in a low-cost 0.18µm CMOS process, takes into account restrictions due to single supply. With 1.2V single supply and 135µW power consumption it recovers signals up to 1 MHz with errors below 2.6% for noise signals of the same amplitude as the signal of interest, showing very promising results with both a reduction in voltage supply and power dissipation respect to previously reported LIAs, without compromising signal recovery capability.

8764-33, Session 1

Rectennas design using DG-MOSFETs

Raúl R. Rodríguez del Rosario, IUMA (Spain); Benito B. González Pérez, Javier A. García, IUMA (Spain) and Univ. de Las Palmas de Gran Canaria (Spain)

In this paper we consider SOI technology to develop RFIDs for ultra wide band (UWB). To do this, we investigate the feasibility of designing rectennas with Double Gate MOSFETs (DG-MOSFETs), and evaluate its performance in a wide frequency range.

Firstly, the drain current of undoped D-MOSFETs is modeled through explicit and ongoing source and drain charges, Qs and Qd.We have incorporated to the compact model the parasitic capacitances of the transistors:Cgs, Cgd and Cds. Explicit expressions for Cgs and Cgd, depending on Qs and Qd, have been obtained. In the case of the drain to source capacitance, Cds, a well-known analytical expressionis used from literature, which depends on the total drain charge, QD.

In the rectenna under consideration, gate and drain terminals of both DG-MOSFETs are shorted (Vgd = 0V). Thus, the Cgd capacitance does not need to be included in the large signal model; the drain current of transistors only depends on the drain to source voltage, Vds, which is also the case of the capacitances Cgs and Cds.

The compact model of DG-MOSFETs has been implemented in ADS, with Verilog-A. Thus, RFID rectennaswere electrically simulated, validating the results by numerical simulations with Sentaurus Device. A sinusoidal input signal of 1V amplitude is assumed for the rectenna, which implies the drain to source voltage of DG-MOSFETS ranges between ?1.5 V.

For the different transient simulations, varying the transistor geometry, it has been observed that for the frequency range covered by the UWB, the proposal rectenna with DG-MOSFET efficiently rectified RF energy. The rectified voltage of our rectennahas been compared with that of a similar rectenna with conventional N-MOSFETs: a 58% higher DC voltage can be extracted with the DG-MOSFETs.Therefore, it is possible to use SOI technology for implementing RFIDs.

8764-6, Session 2

FPGA-based implementation for steganalysis: a JPEG-compatibility algorithm

Eric Gutierrez-Fernandez, Marta Portela-García, Celia López-Ongil, Mario Garcia Valderas, Univ. Carlos III de Madrid (Spain)

Steganalysis is a process to detect hidden data in cover documents, like digital images, videos, audio files, etc. This is the inverse process of steganography that is the used method to hide secret messages. The widely use of computers and network technologies make digital files very easy-to-use means for storing secret data or transmitting secret messages on internet. Depending on the cover medium used to embed the data, there are different steganalysis methods. In case of images, many of the steganalysis and steganographic methods are focused on JPEG image formats, since JPEG is one of the most common formats.

One of the main important handicaps of steganalysis methods is the processing speed, since it is usually necessary to process huge amount of data or it can be necessary to process the on-going internet traffic in real-time. In this paper, a JPEG steganalysis system is implemented in an FPGA in order to speed-up the detection process with respect to software-based implementations and to increase the throughput. In particular, the implemented method is the JPEG-compatibility detection algorithm that is based on the fact that when a JPEG image is modified, the resulting image is incompatible with the JPEG compression process.

The developed system includes all the required steps in hardware, like calculating the DCT (Discrete Cosine Transform) coefficients, the quantization matrix and checking the compatibility condition. Experiments have been performed with a set of JPEG images with and without hidden data. Obtained results show the correct behaviour of the implemented tasks with enough precision, and that the throughput is increased in two orders of magnitude with respect to software implementations. Pipelining and parallelizing techniques have been applied in order to accelerating the algorithm execution. Many of the generated blocks can be applied to implement other steganalysis methods with JPEG cover images.

8764-7, Session 2

Implementation of scalable video coding deblocking filter from high-level SystemC description

Pedro P. Carballo, Omar Espino, Romen Neris, Pedro Hernández, Tomasz M. Szydzik, Antonio Nunez, Univ. de Las Palmas de Gran Canaria (Spain)

This paper describes key concepts in the design of a deblocking filter (DF) for a H.264/SVC video decoder. The DF supports QCIF and CIF video formats with temporal and spatial scalability. The design flow starts from a SystemC functional model and has been refined using high-level synthesis methodology to RTL microarchitecture. The process is guided with performance measurements (latency, cycle time, power, resource utilization) with the objective of assuring the quality of results of the final system. The functional model of the DF is created in an incremental way from the AVC DF model using OpenSVC source code as reference. The design flow continues with the logic synthesis and the implementation on the FPGA using various strategies.

The final implementation is chosen among the implementations that meet the timing constraints. The DF is capable to run at 100 MHz, macroblocks are processed in 6,500 clock cycles what produces a throughput of 130 fps for QCIF format and 37 fps for CIF format. The proposed architecture for the complete H.264/SVC decoder is composed of an OMAP 3530 SOC (ARM Cortex-A8 GPP + DSP) and the FPGA Virtex-5 acting as a coprocessor for DF implementation. The DF is connected to the OMAP SOC using the GPMC interface.

A validation platform has been developed using the embedded PowerPC processor in the FPGA, composing a SoC that integrates the frame generation and visualization in a TFT screen. The FPGA implements both, the DF core and a GPMC slave core. Both cores are connected to the PowerPC440 embedded processor using LocalLink interfaces. The FPGA also contains a local memory capable to store information necessary to filter a complete frame and to store a decoded picture frame. The complete system is implemented in a Virtex5 FX70T device.

8764-9, Session 2

Network-on-chip emulation framework for multimedia SoC development

Garbí Singla, Félix B. Tobajas Guerrero, Valentín De Armas, Univ. de Las Palmas de Gran Canaria (Spain)

Current tendencies of consumer electronics have envisaged multiprocessor System-on-Chip (SoC) as a promising solution for high performance embedding systems, and, in this scenario, Network-on-chip communication paradigm is considered as a way to improve on-chip communication efficiency. In this paper, a NoC based SoC emulation framework is designed and implemented on a low-cost FPGA device. The main objective of this work is the design and implementation of a prototyping platform with a NoC-

based interconnection topology, which provides a demonstrator for the implementation of multimedia applications. The emulation platform will allow evaluation, comparison, and verification of different aspects of a NoC design for SoCs. The proposed emulation platform consists of different types of functional IP blocks (microprocessors, memory blocks, peripherals, additional blocks, etc.) interconnected through a NoC infrastructure. In order to provide a low-cost solution, the platform design is restricted to use a single FPGA, resulting in a low-scale SoC due to the limited resources available in the FPGA device. However, the proposed design may be scalable and replicated in large scale FPGA or multi-FPGA devices to increase emulation performance. Additionally, a design flow based on different commercial EDA tools is presented, and functional blocks integration process is discussed in detail due to problems experienced at this stage. The platform is fully implemented on a Xilinx Spartan-6 LX45T FPGA and special attention is given to verification and floorplanning stages. Finally, various multimedia applications with real-time requirements are executed on the NoC-based SoC platform. The performance results are analyzed according to the type of application, as well as the number of processors required.

8764-10, Session 3

Protocol-level noise analysis of networked systems based on simulation/analytical approach

Massimo Conti, Giovanni Battista Vece, Eros Mazza, Univ. Politecnica delle Marche (Italy)

Reliability and noise tolerance represent important requirements for digital networked systems, especially in critical working conditions. These issues mostly concern the communication tasks between the network nodes, which are usually implemented on the basis of formal protocol rules. A challenging target for a reliability analysis is to provide comprehensive evaluations and acceptably accurate results. However, the current complexity of many networked systems entails relevant limitations to this possibility.

In this paper we present a novel system-level methodology for noise analysis of digital networked systems. In our research we have defined a simulation/analytical approach entirely based on the protocol specifications and capable to address a fast and comprehensive study of the reliability properties. The proposed methodology is illustrated through a case study on the MOST 150 protocol, which is currently used to realize multimedia networks in automotive contexts.

8764-11, Session 3

A simulation technique to compute phase noise induced from ciclostationary noises sources in RF oscillators

Andrea G. Bonfanti, Federico Pepe, Salvatore Levantino, Carlo Samori, Paolo Maffezzoni, Andrea L. Lacaita, Politecnico di Milano (Italy)

Noise analysis of electrical oscillators has attracted large interest in the last decade, mainly triggered by the wide diffusion of radio frequency (RF) applications. Unfortunately, most commercially-available simulators do not allow to grasp a complete understanding of the phase-noise generation mechanism. Thus, ad hoc simulations may be required to optimize the performances of designed circuits. The proposed calculation technique is simple to implement and provides the designer a deep insight into the phase-noise generation mechanism for both stationary and cyclostationary sources, thus resulting a powerful tool to perform an optimum design in RF applications. In this work, the noise analysis is carried out in the framework of the Hajimiri's model, based on the Impulse Sensitivity Function (ISF). To illustrate the proposed method, we start from calculating the oscillator response to sinusoidal current perturbations, eventually leading to a description of the impulse phase response in the frequency domain. This computation can be implemented by means of a combination of Periodic Steady State (PSS) and Periodic Transfer Function (PXF) analyses, available in most commercial RF circuit simulators. Hence, we describe a computational algorithm to extract the modulating functions of the cyclostationary sources by means of a transient simulation. The proposed simulation method has been implemented for the calculation of 1/f^2 phase noise and has been verified on two oscillator topologies, namely a current-biased LC tuned and a three-stage ring oscillator, where all devices are described by BSIM4 models with parameters of an existing 65-nm CMOS technology process. A comparison with the results of the SpectreRF Periodic Noise (PNOISE) analysis firmly confirms the validity of the proposed computation method.

8764-12, Session 3

An IOMMU for hardware-assisted full virtualization of heterogeneous multicore SoCs

George Kornaros, Kostantinos Harteros, M. Astrinaki, I. Christoforakis, Technological Educational Institute of Crete (Greece); Marcello Coppola, M. D. Grammatikakis, STMicroelectronics (France)

Hardware virtualization is a major challenge in embedded virtualization. The key to improving resource utilization in a virtualized system is to allow maximum possible resource access operations to perform natively with minimal intervention by the virtual machine monitor, while at the same time ensuring protected operation among different virtual machines' address space. A novel I/O Memory Management Unit component (IOMMU) is architected to enable mapping of virtual addresses from multiple devices to the correct VM's physical memory locations, offering enhanced protection, scatter-gather functions on distributed memory organizations, high performance supported by a configurable TLB and an integrated lightweight hardware monitoring unit to facilitate dynamic system optimizations.

This new IOMMU is designed in a modular way supporting address translation along with protection functionality. IOMMU ensures device isolation by safely mapping a device to a particular guest without risking the integrity of other guests. Additionally, the IOMMU is designed to provide an increased amount of security in scenarios without virtualization; with the aid of the IOMMU, the operating system is able to protect itself from malicious device drivers by limiting a device's memory accesses and managing the permissions of peripheral devices.

Through focusing on efficient hardware-assisted full virtualization for multicore SoCs the design of the IOMMU is decomposed into modular blocks. Internally, the main controller dispatches internal commands and performs IOMMU component management. An I/O translation look-aside buffer allows acceleration of page translation of incoming addresses by avoiding expensive remote loading of page table entries. The page table walker sub-unit is responsible to access system memory and performs address translation in case of an IOTLB cache miss. The IOMMU device table sub-unit contains configuration data for each device in order to provide proper protection for incoming translation requests. Finally, the monitoring unit includes agents that provide custom circuitry for monitoring events related to internal IOMMU activity and interface transactions. These agents facilitate estimation of key performance metrics: memory access latency, throughput and resource utilization in order to optimize the performance and usage of IOMMU resources.

8764-13, Session 3

Effective properties of multi-phase anisotropic systems

Vladimir V. Shchennikov, Institute of Metal Physics (Russian Federation); Sergey V. Ovsyannikov, Univ. Bayreuth (Germany); Natalia V. Morozova, Igor V. Korobeynikov, Institute of Metal Physics (Russian Federation); Vsevolod V. Shchennikov Jr., Institute of Engineering Science (Russian Federation)

The approach is considered for calculation of electrical, thermal and mechanical properties of anisotropic multi-phase systems

basing on the model of orderly orientated inclusions with variable 3D –configuration [1]. The model allows receiving simple algebraic equations for the properties depending on the several impacts (e.g. electrical, thermal, and magnetic fields as in Hall effect and Nernst-Ettinsghausen effects) orientated along the different axes of coordinate [2]. Some powerful relations may be obtained using the model, for example, the relation between Seebeck effect on the one hand and thermal and electrical conductivities on the other hand for two-phase systems with arbitrary anisotropy [1]. The using of the present model as well as other ones is considered for real systems. The widely used simplest approximation for inclusions configuration as randomly distributed spheres of identical sizes was shown to be incorrect for electrical and mechanical properties of some isotropic multi-phase systems [2]. The using of the model for isotropic systems is discussed. Recent applications of the approach for consideration of thermo-electrical and mechanical properties in the real systems are presented and the potential for it usage for any kind of multi-phase technical systems is discussed.

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8764-14, Session 4

A low-cost PSoC architecture for long FFT

Pietro Angelo Lomoio, Pasquale Corsonello, Univ. della Calabria (Italy)

Fast Fourier Transform is widely used in wireless communications, image processing, signal analysis and radar systems. In such applications, it is often required the transformation of long series by using fixed-point arithmetic. A system-level implementation of FFT architecture for long data series is presented. It exploits opportunities provided by the newest programmable System-on-Chips (PSoC) to face such intensive algorithms whenever a tradeoff between resolution and a cost is of major concern.

The proposed strategy relies on a balanced partitioning of computational effort between an embedded ARM processor and a single FFT core of size N*. Such core on-the-fly reconfigures its twiddle look-up-table and data access criterion to accomplish the required computation.

A low-cost SRAM is used to accommodate the large amount of input data, intermediate complex results and overall output of FFT of size N = N* x N*. Whereas pre-calculated twiddle coefficients are stored in an external flash memory, thus saving internal memory resources of the PSoC.

An on-purpose designed arithmetic data-path performing high-precision operations and the smart exploitation of internal RAM blocks as cache memory allow a good accuracy and performance to be reached.

The embedded controller is purposely programmed to allow the high-level management of algorithm and the correct flow of data among peripherals, without need of extra control logic. It transfers bursts of N* values from external RAM towards FFT core in PSoC fabric, along with a set of coefficients taken from external flash memory containing all the N/2 twiddle factors. The proposed architecture can be easily run-time reconfigured, in order to change input data length.

8764-15, Session 4

High speed Radix-4 soft-decision Viterbi decoder for MB-OFDM UWB system

Guixuan Liang, Jorge Portilla, Teresa Riesgo, Univ. Politécnica de Madrid (Spain)

In this paper, a 64 state soft decision Virterbi Decoder (VD) system by using a high speed radix 4 add compare select (ACS) architecture is presented. The proposed VD system can support different data rate (from 53.5 Mbps to 480 Mbps) for multiband orthogonal frequency-division multiplexing (MB-OFDM) ultra-wideband (UWB) system when implemented onto the FPGA board.

The proposed VD employs efficient two stages Radix 4 architecture, which is responsible for calculating two steps of 64 stage Radix 4 branch metrics (BM) within one clock cycle. The branch metrics are calculated using a uniform distance measurement algorithm, which equal to the symbol itself when compared to logis-0 and equal to its one’s complement when compared to logic-1. By employing the modified Modulo Normalization algorithm, in this work it is possible to use only a 10-bits memory block to restore each of the 64 state metrics, with the advantage of avoiding errors caused by overflow during the updating process for state metrics, and simplifying the comparator circuit of the ACS unit. The Two Pointer Even Algorithm, which is considered to be very simple and more hardware-efficient than the register exchange algorithm, is used for tracing back the survivor sequence and output the decoded data stream.

3-bit soft decision input sequences are used for gathering the experimental results. The sampling frequency of the MB-OFDM UWB system is 528 MHz, by using the proposed two stages Radix 4 VD architecture we can process 4 input signals in parallel within one clock cycle, therefore only 132 MHz operating frequency is needed for the proposed VD system. This will dramatically reduce the dynamic power consumption for real hardware implementation. Final results from an FPGA implementation show that the proposed VD architecture can support a maximum working frequency of 144 MHz on Xilinx XUPV5-LX110T Evaluation Platform, with an error rate of only around 4%.

8764-17, Session 4

A comparative study of continuous-time analog adaptive equalizers

Carlos Sánchez-Azqueta, Santiago Celma-Pueyo, Univ. de Zaragoza (Spain)

In modern high-speed data communications systems, the limited bandwidth of the channel results in inter-symbol interference (ISI) at the received signal, which has to be compensated by equalization [1]. Typically, equalization at the receiver is preferred to equalization at the emitter because it can be designed to take into account the varying characteristics of the channel in what is called adaptive equalization [2].

Continuous-time adaptive equalizers base their operation on the fact that the spectrum of the incoming data is known prior to its reception, so the degradation caused by the channel can be evaluated and subsequently corrected. For example, the power spectrum of an ideal NRZ random binary data stream is a squared sinc function [3], so a comparison of the power at different frequency ranges allows to determine whether the incoming signal is under- or overcompensated to act on it accordingly.

Three different architectures have been proposed to carry out the power spectrum comparison of the incoming data signal: the combination of two band-pass filters, one high-pass and one low-pass filter, and one low-pass filter and one all-pass filter.

This work studies analytically the differences between these techniques, pointing out their influence on the performance of continuous-time adaptive equalizers and establishing measurable criteria as to which one achieves better results. Besides, the theoretical results have been tested experimentally by means of measurements carried out on adaptive equalizers fabricated in CMOS technology.

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8764-18, Session 5

Architectural evaluation of dynamic and partial reconfigurable systems designed with DREAMS tool

Andrés Otero, Ángel Gallego, Eduardo de la Torre-Arnanz, Teresa Riesgo, Univ. Politécnica de Madrid (Spain)

Reconfigurable systems are considered a halfway solution between software and hardware, since they provide an unrivalled flexibility, without compromising performance. Among the benefits of this technique, stands out the reduction of the static power consumption and the possibility of using smaller devices by silicon sharing. However, in spite of the reconfiguration features enabled at hardware level by the last generations of SRAM-based devices, its application is mainly limited to the academia, without having significant impact on the industry. This situation is attributable to the lack of flexibility revealed by commercial design tools provided by FPGA manufacturers. This is noticeable both regarding the high overhead of the communications among modules and the limited module relocation features, which lead to constrained architectures with penalized efficiency.

To overcome those limitations, authors have proposed in a previous work a design tool called DREAMS, aiming the design of Dynamically Reconfigurable and Modular Systems. This tool has been envisaged as a post processing stage, which starting from independent netlists corresponding both to the static and reconfigurable system modules, carries outs the necessary steps to integrate them in a reconfigurable system. Among those steps are the generation of the communication among modules, solved without requiring extra logic resources; the solution of routing conflicts, appearing due to the impossibility of setting area constraint in commercial routers, and the management of clock resources. Module netlists can be designed with conventional tools, and integrated in the system after deployment, increasing its upgrading possibilities. Strategies selected to carry out those steps are compatible with module relocation, enabling this way the design of highly flexible architectures

The goal of this work is to design and evaluate the range of possible architectures which can be designed with DREAMS tool, in order to assert its flexibility. To do so, several variants are compared, including (i) mesh-type architectures, (ii) slot-based architectures and (iii) fine-grain unrestricted architectures. Evaluation is carried out in terms of the internal and external fragmentation, the reconfiguration time, the capability of relocating modules and the maximum communication bandwidth, having also in mind the impact of the architecture granularity. Design time required by the tool is also provided. In addition, the tool is exploited to deal with the heterogeneity of the reconfigurable architecture, as well as to design specific-purpose communication infrastructures, compatible with the envisaged system architectures. Moreover, specific features of DREAMS to design scalable modules, which are able to occupy a variable number of resources on the device offering a run-time variable performance, is also evaluated.

Among the results, design guide lines are to be provided, in order to select a suitable virtual architecture, as well as to define its granularity and the associated communications infrastructure, depending on different system parameters.

8764-19, Session 5

Virtual platform for power and security analysis of wireless sensor network

Alvaro Diaz Suarez, Javier Gonzalez Bayon, Pablo Sanchez Espeso, Univ. de Cantabria (Spain)

Wireless Sensor Networks (WSN) include low-power and low-cost devices (nodes) with strong power requirements (long autonomous lifetime). The nodes have to use the available battery carefully and avoid expensive computations or radio transmissions. Therefore, effective simulation mechanisms that allow the developer to obtain estimations at the early stages of the WSN design, prior to deployment, are necessary. Not only power consumption is an important concern in this design but security is becoming a real problem, since some WSN process sensitive data. Thus, it is needed to secure the processed data tamper-proof. This paper proposes a framework for network simulation and embedded SW performance analysis that focuses not only in time and power estimation but also in providing simulations of the most common and dangerous attacks that a WSN can suffer nowadays and also a novel “entropy security-oriented measure”. This measure provides information about how good is the security encryption used in WSN transmissions. All this information will help to solve the whole WSN deployment design with useful measures about power and security.

8764-20, Session 5

A hierarchical scheduling and management solution for dynamic reconfiguration in FPGA-based embedded systems

Teresa G. Cervero García, Sebastian Lopez Suarez, Roberto Sarmiento Rodríguez, Univ. de Las Palmas de Gran Canaria (Spain); Julio Daniel Dondo, Fernando Rincón, Juan Carlos López, Univ. de Castilla-La Mancha (Spain); A. Gómez, Univ. de Las Palmas de Gran Canaria (Spain)

Under static scenarios, it is relatively easy to schedule and manage the reconfiguration process since all the variations corresponding to predetermined and well-known tasks. However, the difficulty increases when the adaptation needs of the overall system change semi-randomly according to the environmental fluctuations.

One of the limiting factors that have prevented a widely dissemination of the reconfigurable technology is the absence of an appropriate model for certain target applications capable of offering a reliable control. Moreover, the lack of flexible and easy-to-use scheduling and management systems are also relevant drawbacks to be considered. In this context, this work proposes a change in the paradigm of dynamically reconfigurable systems, by attending to the dynamically reconfigurable control problematic as a whole, in which the scheduling and the reconfiguration management are packed together as a hierarchical structure, interacting together as one entity from the system point of view, but performing their tasks with certain degree of independence each other. In this sense, the top hierarchical level corresponds with a dynamic scheduler in charge of planning and adjusting all the reconfigurable modules according to the variations of the external stimulus. The lower level interacts with the physical layer of the device by means of instantiating, relocating, removing a reconfigurable module following the scheduler’s instructions.

In regards to how fast is the proposed solution, the total partial reconfiguration time achieved with this proposal has been measured and compared with other two approaches: 1) using traditional Xilinx’s tools; 2) using an optimized version of the Xilinx’s drivers. The collected numbers demonstrate that our solution reaches a gain up to 10 times faster than the other approaches.

8764-21, Session 5

Efficient and decentralized data transfer architecture for component based embedded systems

Jesus Barba, Univ. de Castilla-La Mancha (Spain)

Multimedia embedded systems usually expose a chain-based architecture where each functional stage of the media algorithm is encapsulated in a media core in charge of processing the stream of data. Therefore, in this kind of systems, the interconnection mechanisms are key to cope with the enormous bandwidth demands.

In this paper, we present a decentralized data transfer architecture for bus based embedded systems. The communication infrastructure introduced here is parameterizable, dynamically configurable and optimized for hardware media component processing platforms.

Unlike conventional approaches, where a software control routine has to oversee all the steps of the data exchanging process (e.g. DMA configuration, trapping interruptions, ...), our approach moves such responsibility to the hardware components which are highly autonomous. This has a positive impact in performance since the processor is not mediating in every single data transfer that takes place in the system.

8764-8, Poster Session Thursday

Processor core for real time background identification of HD video based on OpenCV Gaussian mixture model algorithm

Mariangela Genovese, Ettore Napoli, Univ. degli Studi di Napoli Federico II (Italy)

The identification of moving objects is a fundamental step in computer vision processing chains. The development of low cost and lightweight smart cameras steadily increases the request of efficient and high performance circuits able to process high definition video in real time.

The paper proposes two processor cores aimed to perform the real time background identification on High Definition (HD, 1920x1080 pixel) video streams.

The implemented algorithm is the OpenCV version of the Gaussian Mixture Model (GMM), an high performance probabilistic algorithm for the segmentation of the background that is however computational intensive and impossible to implement on general purpose CPU with the target of real time processing.

In the proposed paper, the equations of the OpenCV GMM algorithm are optimized in such a way that a lightweight and low power implementation of the algorithm is obtained. The reported performances are also the result of the use of state of the art truncated binary multipliers and ROM compression techniques for the implementation of the non linear functions.

The first circuit has commercial FPGA devices as a target and provides speed and logic resource occupation that overcome previously proposed implementations.

The second circuit is oriented to an ASIC (UMC-90nm) standard cell implementation.

Both implementations are able to process more than 60 frames per second in 1080p format, a frame rate compatible with future HD television. The proposed designs, while providing a processing capability of more that 120Mps feature reduced logic occupation (2% of a Virtex5 FPGA and 0.03mm2 of silicon area in CMOS 90nm technology) and low power (about 1nJ per pixel for the FPGA designs and about 0.5nJ per pixel for the ASIC implementation).

Several video sequences have been processed demonstrating that the proposed circuits provide a good quality of the processed video sequences.

8764-16, Poster Session Thursday

An FFT-based coprocessor for real time scale-space video filtering on FPGAs

Giorgio Lopez, Ettore Napoli, Univ. degli Studi di Napoli Federico II (Italy)

In today's electronics applications computer vision algorithms have become highly pervasive: common examples are process control and object recognition. The need to compute images and video streams in real time immediately arises from all of these scenarios. The paper presents a dedicated coprocessor for frequency domain scale-space-oriented filtering of block-partitioned images/frames. In particular, the filters implemented in the proposed architecture realize SIFT's Difference of Gaussians algorithm. Bandpass filters are realized by subtracting pairs of sigma-related Gaussian LPFs. By choosing an appropriate block partitioning size we reduce the amount of operations required to perform the block-based filtering while keeping flexibility regarding the image/frame size. The coprocessor consists in an iteratively used datapath of which the central part is a 1D FFT unit which operates on 128 samples sequences. The datapath performs the required operations of FFT/iFFT and filtering iteratively, using the FFT unit and a set of ancillary memories. The operations are repeated for each filter in the bank and for each block of the image/frame. The proposed architecture is flexible and allows the implementation of many other filtering operations without any effect on the performances of the circuit.

The architecture has been implemented on a Xilinx Virtex 5 VLX110 FPGA leading to these results: running at a clock frequency of 100MHz, since the complete elaboration of a single block takes approximately 82K clock cycles and a VGA frame decomposes in the DoG pyramid into 44 128-by-128 blocks, the processor elaborates a frame in 34ms. This leads to a maximum frame rate of 30fps, making the architecture suitable for real time processing.

8764-30, Poster Session Thursday

Transmission line pulse system for avalanche characterization of high power semiconductor devices

Michele Riccio, Giovanni Ascione, Giuseppe De Falco, Luca Maresca, Martina De Laurentis, Andrea Irace, Giovanni Breglio, Univ. degli Studi di Napoli Federico II (Italy)

Understanding the avalanche behavior of a power semiconductor devices has become of paramount importance in these last years due to the increasing of power density in the electronic devices and growing demand for high reliability in power applications.

Since the isothermal I-V blocking characteristics represent a footprint of the avalanche behavior for every semiconductor device, a specific test-circuit is needed in order to obtain experimentally such characteristic.

In this contribution we present an optimized Transmission Line Pulse (TLP) circuit suitable for the electrical characterization of high power semiconductor devices operating in avalanche condition. The proposed solution is based on a simple and low cost circuit, which is capable to produce very short current pulses (duration of about 100ns) with amplitude in the range of some tens of amps even on high breakdown voltage DUT (up to 1600V). This testing circuit exhibits high flexibility in its application since it uses a micro-controller based logic to generate all the timing signals (needed to drive power switches present in the circuit) and to implement the control functionality.

To prove the effectiveness of the proposed circuit, a prototype has been made and used to test different power devices (diodes, MOSFETs, IGBTs) at different operating temperature. In the final paper, all the details on the circuit design will be discussed. A broad set of SPICE simulations will be presented to show the effect of different power switches (i.e. CoolMOS / IGBT), transmission line and external components used to boost the current pulse capability of the system. Finally, experimental results will be provided.

8764-31, Poster Session Thursday

State of the art direct digital frequency synthesis methodologies and their performance on FPGA

Ettore Napoli, Mariangela Genovese, Univ. degli Studi di Napoli Federico II (Italy)

The Direct Digital Frequency Synthesizer (DDFS) is a critical component routinely implemented in many electronic systems. Modulation, filtering, arithmetic computation are only some of the applications that require a DDFS and whose performance heavily depend on DDFS behaviour.

Straightforward implementations are usually considered onerous in terms of logic resources and power dissipation while providing far from optimal working frequency. As a consequence the scientific literature, with a noticeable effort in recent times, proposes various DDFS design techniques that implemented by using state of the art ASIC (Application Specific Integrated Circuits) technologies provide greatly improved performances in terms of speed, power dissipation and logic occupation.

The performance trend provided by the advanced and optimized designs that target ASIC technologies is not guaranteed to remain the same when the target technology is, as often happens, a family of commercially available Field Programmable Gate Array (FPGA) devices.

Due to the ever increasing use of FPGA devices for both prototyping and fast time to market release of electronic systems, the study of the

performance of DDFS design techniques when implemented on FPGA devices, is of great interest.

This paper presents the FPGA implementation of the best DDFS architectures proposed to date.

DDFS performance trends are compared with the ASIC implementations. Further, the DDFS circuits are optimized in order to better suit the FPGA technology and compared against the DDFS implementations provided by the Intellectual Property (IP) that are included in the design suites of the FPGA manufactures.

The comparison is conducted considering as implementation target both low end and high end FPGA devices produced by different vendors.

Implementation results show that advanced design techniques are preferable when power dissipation is the primary issue while the RAM based implementations are preferable when logic resource occupation is not an issue and maximum working frequency is required.

8764-32, Poster Session Thursday

Analysis of phase transitions using multi-phase model

Vladimir V. Shchennikov, Institute of Metal Physics (Russian Federation); Sergey V. Ovsyannikov, Univ. Bayreuth (Germany); Igor V. Korobeynikov, Grigory V. Vorontsov, Natalia V. Morozova, Institute of Metal Physics (Russian Federation); Vsevolod V. Shchennikov Jr., Institute of Engineering Science (Russian Federation)

Phase transition of overall “metal”-“insulator” type where the “metal” and “insulator” correspond respectively to the states with high and low “effective conductivity” (that may mean both electrical or thermal conductivity, elastic modulus, etc.) is considered in the model for anisotropic multi-phase material [1]. The examples are discussed of application of approach for consideration of various kinds of properties (the thermoelectric, elastic, etc.) in real systems near the threshold of “metal”-“insulator” transitions under either pressure or temperature or any other impacts. The threshold of “metal”-“insulator” phase transition was found to depend on the kind of property measured. The approach allows both to obtain the true properties of each phase in the multi-phase system as well as to estimate the configuration of phase inclusions in the system. The applications of the approach are discussed for analyzing of phase transitions in a set of semiconductor compounds AX (A – Zn, Hg, Pb, Sm, and X – Te, Se, S) [2], as well as for evaluation of the inclusions configuration in iron ores, etc. [3].

The model seems to be perspective for using in micro-device technology e.g. for optimization of properties, for design of micro devices with improved characteristics or for analyzing of signals.

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8764-34, Poster Session Thursday

MPPM system for indoor wireless optical communications with angle-diversity detection

Alberto García-Viera Fernández, Silvestre Rodríguez Pérez, Beatriz Rodríguez Mendoza, Oswaldo B. González Hernández, Alejandro J. Ayala Alfonso, Univ. de La Laguna (Spain)

Recently, there has been a growing interest in the use of wireless optical communications in some well-defined indoor environments. Wireless optical communications present certain advantages over RF transmission that make them suitable in certain specific scenarios. Optical systems do not interfere with RF systems, thus avoiding EM compatibility restrictions. Moreover, there are no current legal restrictions involving bandwidth allocation and, since radiation is confined by walls, these systems produce intrinsically cellular networks, which are more secure against deliberate attempts to gain unauthorized access than those involving radio transmissions. There are two major limitations for establishing a wideband IR communications link: the power requirements and the intersymbol interference caused by multipath dispersion. In general, the use of angle-diversity receivers makes it possible to reduce the impact of ambient light noise, path loss and multipath distortion.

In this paper, an IR wireless communication system based on Multiple Pulse Position Modulation (MPPM) employing angle-diversity detection is studied via simulation. Although the system is designed to operate at infrared wavelengths, it can also be easily adapted for Visible Light Communications. MPPM is proposed as a modulation method to improve bandwidth efficiency in PPM since the use of MPPM allows for higher bit rates than PPM. The system designed allows for comparing the performance based on the computation of the bit error rate (BER) as a function of the SNR for different MPPM and PPM modulation schemes employing angle-diversity detection. In this paper, two of the three ways of achieving angle-diversity detection are studied: conventional and sectored receivers. The results show a significant enhancement when angle-diversity receivers are used as compared to employing receivers using a single-element detector, with the sectored receiver offering the highest performance, regardless of the modulation scheme applied. Furthermore, the results show that PPM offers good performance for lower bit rates, though the BER increases rapidly when the bit rate is increased, even when angle-diversity receivers are used. MPPM proves to be more bandwidth efficient than PPM, since it allows for the use of a wider pulse for transmitting the same number of information bits per symbol.

8764-22, Session 6

Hardening digital systems with distributed functionality: robust networks

Anna Vaskova, Celia López-Ongil, Marta Portela-García, Mario Garcia Valderas, Univ. Carlos III de Madrid (Spain)

Digital systems have spread their applicability to a huge number of different fields. Continuous monitoring and controlling applications demand cheap solutions with several nodes, task distribution and low power consumption. These distributed systems are being used in advanced solutions for spacecrafts, avionics, but also in consumer electronics, such as automotive, smart buildings, civil engineering, etc.

Current electronic technologies are very sensitive to natural radiation. Very deep submicron devices are suffering Single Event Effects even at sea level. Hardening modern electronic devices is mandatory for every safety critical application and very recommendable for many other applications.

Hardening digital systems is a well known problem, but when dealing with distributed functionality and low cost solutions, new questions arise. Not only single faults (SEUs) are important, but also multiple faults (MBUs) remaining uncorrected for large periods of time become a concern in the design of dependable distributed networks. New fault mitigation techniques together with re-defined sensitivity

evaluation methods are required.

In this sense, distributed functionality will benefit the hardening process when designers include collaborative hardening among the different nodes in the system/network. Common and critical tasks can be replicated in order to introduce redundancy in the system with a very low extra cost. Non-common and non-critical tasks can be also replicated thanks to extra cheap nodes. Finally, non-common and critical tasks can be hardened with appropriate mitigation techniques which impose extra cost only when essential.

Sensitivity analysis for systems with distributed functionality implies single and multiple fault injection capability together with a deep analysis of system behaviour along its operation. Fault effects are not always immediate and not always catastrophic.

In this work a method for hardening and evaluating digital systems with distributed functionality is presented. The applicability of the method is analysed when dealing with different systems, especially multi-redundant sensor networks.

8764-23, Session 6

Fault tolerant architectures by partial reconfiguration

Luis Andrés Cardona, Univ. Autònoma de Barcelona (Spain); Guo Yi, Ctr. Nacional de Microelectrónica (Spain); Carles Ferrer Ramis, Ctr. Nacional de Microelectrónica (Spain) and Univ. Autònoma de Barcelona (Spain)

The utilization of SRAM-based FPGAs in the implementation of embedded systems is in continuous growth. The flexibility that these devices offer in terms of hardware re-programming is also a critical point to take into account when designing fault tolerant systems. As the configuration values are stored in volatile memory, any source that affects this configuration memory can lead to change the circuit and therefore to produce erroneous results.

This essential requirement of fault tolerance becomes mandatory when the operation field is aerospace. In such an environment the configurable device is exposed to charged particles that can generate changes in the transistor states which could be reflected as changes in memory values (bit-flip, SEUs).

In this work we have to deal with these limitations as our application is related with data compression in aerospace systems.

This paper presents an initial approach to add fault tolerance in an aerospace application implemented in a commercial-off-the shelf FPGA (Virtex-5). The exploration of creating dependable systems using non-qualified devices is a challenging topic. By using the mentioned FPGA, we can take advantage of the partial reconfiguration facility. This feature allows us to get more flexibility in hardware management at run-time also as a mean to correct specific parts of the system when faults are detected. Preliminary results regarding influence in area by using different approaches are presented.

8764-24, Session 6

Introduction on performance analysis and profiling methodologies for KVM on ARM virtualization

Antonios Motakis, Alexander Spyridakis, Daniel Raho, Virtual Open Systems (France)

With embedded systems getting everyday increasingly more capable, virtualization technologies as well have started entering the embedded space. These include different types of virtualization implementations, such as operating system virtualization, paravirtualization, but also full hardware virtualization is today possible, thanks to hardware virtualization extensions being now implemented in embedded processors. The ARM Cortex-A15 family of processors, is one of those processors implementing hardware virtualization capabilities, and software utilizing them has also started appearing, including a port of the Linux Kernel Virtual Machine.

This new ecosystem that has emerged around virtualization on the Cortex-A15 technologies, has created a need for solutions to help understand the performance of these implementations. This is made more complicated by the fact that hardware implementations of the Cortex-A15 are still very young, with consumer products having just started appearing in the market. With the KVM port on the ARM Cortex-A15 getting more stable every day, there is now interest in profiling its performance in order to discover bottlenecks and improve upon its performance.

Motivated by this trend, in this work we look into the existing research on the x86 platform, related to performance profiling of Virtual Machines. We identify some of the most interesting approaches, and perform a tentative analysis on how these apply to the KVM on ARM port. These take into account hardware an software based counters for profiling, and issues related to the limitations of the simulators which are often used, such as the ARM Fast Models platform, are pointed out.

8764-25, Session 6

OPC mask simplification using over-designed timing slack of standard cells

Yifan Qu, Chun Huat Heng, Arthur Tay, Tong Heng Lee, National Univ. of Singapore (Singapore)

It is well known that VLSI circuits must be designed to sustain the variations in process, voltage, temperature, etc. As a result, standard cell libraries (collections of the basic circuit components) are usually designed with large margin (also known as ``timing slack"). However, in circuit manufacturing, only part of the margin will be utilized. The knowledge of the rest of the margin (over-designed timing slack), armed with models that link between timing domain and shape domain, can help to reduce the complexity of mask patterns and manufacturing cost.

This paper proposed a novel methodology to simplify mask patterns in optical proximity correction (OPC) by using extra margin in timing (over-designed timing slack). This methodology can be applied after a conventional OPC, and is compatible with the current application-specific integrated circuit (ASIC) design flow. This iterative method is applied to each occurrence of over-designed timing slack. The actual value of timing slack can be estimated from post-OPC simulation. A timing cost function is developed in this work to map timing slack in timing domain to mask patterns in shape domain. This enables us to adjust mask patterns selectively based on the outcome of the cost function. All related mask patterns with over-designed timing slack will be annotated and simplified using our proposed mask simplification algorithm, which is in fact to merge the nearby edge fragments on the mask patterns. Simulations are conducted on a standard cell library and a full chip design to validate this proposed approach. When compared to existing OPC methods without mask simplification in the literature, our approach achieved a 51% reduction in mask fragment count and 13-20% reduction in MEBES file size, and this directly leads to a large saving in lithography manufacturing cost. The result also shows that timing closure is ensured, though part of the timing slack has been sacrificed.

8764-26, Session 7

A micropower supervisor for wireless nodes with a digital pulse frequency modulator battery monitor

Mirko Carloni, Rocco D'Aparo, Pierpaolo Scorrano, Univ. Politecnica delle Marche (Italy); Berardo Naticchia, Smart Space Solutions S.r.l (Italy); Massimo Conti, Univ. Politecnica delle Marche (Italy)

In the last few years the increased development of wireless technologies and its applications (like WSN - Wireless Sensor Network) has led to the development of micropower devices with power management and real time power control, aimed to maximize the battery life time.

The main and simplest method to estimate residual battery life time is by voltage measurement. This kind of measurement is too simple

and commonly is useless in many cases, especially when long term lithium thionyl chloride batteries are used. In this case, since its voltage is flat for more than 90 % of the battery discharge, a current control should be used.

However, these kinds of devices, have various problems as a limited range of measurement and not negligible quiescent current that may distort the measurements.

In this work we have developed a micropower supervisor for wireless sensor nodes with a charge battery monitor, whose features are aimed at solving the problems just described.

The current measured by a sense resistor, is filtered by a super-capacitor, amplified by a current sense amplifier and then fed to a voltage to pulse frequency modulator. In this way, also if wireless node consumes time limited high current spike like during transmission, the charge consumption can be estimated without the saturation of the current sense amplifier.

First, supervisor's features were characterized using known current consumptions profiles and afterward it's performance has been verified with different applications in various working conditions. As result, this device that consumes only about 10 uA, can measure a basal consumption less than 50uA, and can measure high power consumption without saturation, if current spikes are time limited, as usually it happens in wireless mesh network nodes, always maintaining a satisfying matching between expected results with results obtained.

8764-27, Session 7

Wireless sensor network for wide-area high-mobility applications

Ignacio Del Castillo, Félix B. Tobajas Guerrero, Roberto Esper-Chaín, Valentín De Armas, Univ. de Las Palmas de Gran Canaria (Spain)

In recent years, IEEE 802.15.4 based Wireless Sensor Networks (WSN) have experienced significant growth, mainly motivated by the standard features, such as small size oriented devices, low power consumption nodes, wireless communication links, and sensing and data processing capabilities. In this paper, a WSN architecture intended for its deployment in applications operating over extended geographic regions with high node mobility support is proposed. Following an analysis of typical performance and structural features of WSN Network layer protocols, this paper describes and proposes different approaches for wide-area WSN with node mobility support, presenting the development, implementation, deployment, and experimental validation and characterization of a fully compatible IEEE 802.15.4 based solution. Among the significant improvements of the proposed WSN architecture, it supports the coexistence of multiple PAN coordinator nodes operating simultaneously on the same network, with sensor nodes belonging to it being able to establish a connection with any of them in order to exchange data frames. This feature is possible thanks to the proposed field segmentation of the Extended Address assigned to each node, allowing the sensor nodes that want to connect to a PAN coordinator node, to select those nodes that belong to the same network, and proceed to validate the association process using a proposed frame exchange based validation protocol. The resulting WSN provides a great flexibility and geographically redundant coverage of sensor nodes operating in the range of any of the available PAN coordinator nodes. Finally, the deployment of an experimental WSN based on the proposed solution for monitoring the temperature in a cooled vehicle fleet over a wide geographic area is presented. The proposed solution eases the development of devices used for wide-area high-mobility applications, such as wearable electronics, environmental sensing, identification, or authentication, by supporting spontaneous self-configuration.

8764-28, Session 7

Intelligent microchip networks: an agent-on-chip synthesis framework for the design of smart and robust sensor networks

Stefan Bosse, Univ. Bremen (Germany)

Sensorial materials consisting of high-density, miniaturized, and embedded sensor networks require new robust and reliable data processing and communication approaches. Structural health monitoring is one major field of application for sensorial materials. Each sensor node provides some kind of sensor, electronics, data processing, and communication with a strong focus on microchip-level implementation to meet the goals of miniaturization and low-power energy environments, a prerequisite for autonomous behaviour and operation. Reliability requires robustness of the entire system in the presence of node, link, data processing, and communication failures. Interaction between nodes is required to manage and distribute information. One common interaction model is the mobile agent. An agent approach provides stronger autonomy than a traditional object or remote-procedure-call based approach. Agents can decide for themselves, which actions are performed, and they are capable of flexible behaviour, reacting on the environment and other agents, providing some degree of robustness. Traditionally multi-agent systems are implemented in software and executed on program controlled computer architectures. This approach does not well scale to micro-chip level and requires full equipped computers and communication structures, and the hardware architecture does not consider and reflect the requirements for agent processing and interaction. We propose and demonstrate a design and synthesis methodology and framework for multi-agent systems implementable entirely on microchip-level with resource and power optimized digital logic supporting Agent-On-Chip architectures. The agent behaviour and mobility is fully integrated on the micro-chip using finite-state machines and register-transfer logic. The agent behaviour, interaction, and mobility features are modelled and specified on a machine-independent abstract programming level using a state-based agent behaviour language (APL). With this APL an agent compiler is able to synthesize a hardware model (VHDL), a software model (C, ML, for test purposes), or a simulation model (XML) suitable to simulate a multi-agent system using the SeSAm simulator framework.

8764-29, Session 7

STAR: FPGA-based software defined satellite transponder

Daniele Davalle, Riccardo Cassettari, Sergio Saponara, Luca Fanucci, Univ. di Pisa (Italy); Luca Cucchi, Intecs S.p.A (Italy); Franco Bigongiari, Sitael S.p.A. (Italy); Walter Errico, Sitael (Italy)

Nowadays, small satellites are one of the most interesting concepts for Earth Observation (EO) missions. Their lower mass allows for a lower mission cost budget vs. a large multi-payload satellite. Moreover, new space mission scenarios based on the co-operation of satellites can be explored: the multiple functionalities of a single large satellite can be distributed on a formation or constellation of small satellites, offering several advantages in terms of daily coverage, time resolution and reliability.

This paper presents a flexible Telemetry, Tracking & Command (TT&C) transponder for EO small satellites, developed within the STAR project, in collaboration with INTECS and SITAEL companies. With respect to state-of-the-art EO transponders, STAR includes the possibility of scientific data transfer thanks to the high data-rate downlink transmission capabilities (up to 40 Mbps). This feature represents an important optimization in terms of hardware mass, which is important for EO small satellites. Furthermore, in-flight re-configurability of communication parameters via telecommand is important for in-orbit link optimization, which is especially useful for low orbit satellites where visibility can be as short as few hundreds of seconds.

STAR exploits the principles of digital radio to minimize the analog section of the transceiver, working at the common intermediate frequency (IF) of 70 MHz, which constitutes the interface with the

S/X band radiofrequency front-end. The system is composed of a dedicated configurable high-speed digital signal processing part (SP) described in technology-independent VHDL working with a clock frequency of 184.32 MHz and a low speed control part (CP) based on the 32-bit Gaisler LEON3 soft processor clocked at 32 MHz, with SpaceWire and CAN I/O interfaces.

The algorithms in SP allow TT&C functionalities in compliance with CCSDS/ECSS standards and include filtering, pulse-shaping, frequency conversion, encoding/decoding, (de)randomization, carrier and symbol synchronization, SNR estimation, etc. Several SP algorithmic parameters can be changed while in flight, e.g., data-rate, modulation and filtering. All the quantization parameters were fine-tailored to reach a good trade-off between hardware complexity and implementation loss which is less than 0.5 dB at BER = 10-5 for the RX chain. The IF I/O ports require 8-bit precision.

CP can access three memory areas in SP through the APB interface: the configuration/status registers and the two FIFOs used for transmission/reception data interchange.

The system prototype is fitted on the Xilinx Virtex 6 VLX75T-FF484 FPGA for which a space-qualified version is available. The total device occupation is 82 %.

8765-1, Session 1

WIMAGINE: an implantable electronic platform for wireless 64-channel ECoG recording

Michael Foerster, Jean Porcherot, Stéphanie Robinet, Raffaele D'Errico, Vincent Josselin, Corinne Mestais, Guillaume Charvet, CEA-LETI (France)

The WIMAGINE® platform was developed as a first long term implantable prototype for recording and transmitting ECoG signals to a PC.

The targeted neurosignals have amplitudes ranging from 5µV to 3mV and the frequencies of interest lie in the 0.5Hz to 300Hz range. The ASIC CINESIC32 has been specifically designed for the amplification and digitization of these signals, includes the constraints for patient safety and the integration constraints of being low power and low noise. A user interface on the PC allows the configuration of any combination of recording electrodes at sampling frequencies of 390Hz, 585Hz, 976Hz or 2900Hz and analog gains of x1, x5, x290, x990 or x1370. The CINESIC32 also includes a 12bit ADC, a digital low pass filter and an SPI interface. The input referred noise has been measured to 0.7µVRMS within the WIMAGINE platform for a power consumption of 12mW during the acquisition of 32 channels at 976Hz with a gain of 1370.

The link with the PC is ensured through a ZL70102 transceiver using the MICS band in the 400 MHz range. Transmission rates of 450 kbps with a BER of less than 2x10-10 could be achieved at distances of up to 2m using a custom made platinum antenna and a custom designed base station. The remote power supply is ensured through an inductive link at 13.56MHz able to provide up to 100mW over 2cm through a biocompatible platinum antenna. The two ASICs, the UHF transceiver and various sensors (temperature, accelerometer and current sensor) are interfaced with an MSP430F2618 that is handling the high and low level communication protocols, configuring the ASICs and streaming the data from the ASICs and the sensors back to the PC application. The firmware of this microcontroller has been low power optimized and is upgradable remotely.

The WIMAGINE platform has been extensively tested, including with recordings on primates implanted with ECoG recording grids (ethical approval was obtained from ComEth). Visual evoked potentials could be obtained, consistent with the VEP obtained with a commercial recording system and with data found in the literature. The power consumption of the whole device during a 1kHz recording on 32 electrodes with a gain of 1370 was measured at 72mW.

The next step is the packaging of the designed electronics into a biocompatible housing that has already been designed and the use of this implant as a BCI neuroprosthesis for chronic implantation in clinical trials.

8765-2, Session 1

A battery-free 64-channel neural spike wireless sensor array

Alberto Rodríguez-Pérez, Jesús Ruiz-Amaya, Jens Masuch, José Antonio Rodríguez-Rodríguez, Manuel Delgado-Restituto, Ángel B. Rodríguez-Vázquez, Ctr. Nacional de Microelectrónica (Spain)

This work presents a 64-channel wireless sensor for neural spike recording. The system is completely battery-free: it gets the energy from an inductive link with an external unit, which is also used for data communication.

The sensor was designed to be implanted at the cortex level of the brain and acquire the neurocortical signals by means of the well-known MultiElectrode Arrays (MEAs). In a preferential configuration, the interconnection between the sensor array and the MEA is done by means of flip-chip.

Each of the channels occupies an area of 400um x 400um. They embed all the necessary circuitry to filter, amplify and digitize the input neural signals. Additionally, they perform some digital signal processing to compress the acquired information. The LNA was design following a specific optimization flow to get a triple trade-off between area, input-referred noise and power consumption. In the other hand, a novel architecture was used to implement a PGA-ADC with reduced power consumption an area occupation. Experimental results showed that the LNA has a mid-band gain of about 47.5dB for a nominal bandpass of 217Hz – 7.16kHz, the integrated input referred noise is 3.4uVrms. The ADC shows a SNDR of 47dB along the whole Nyquist band for the different configuration modes, which corresponds to an ENOB of almost 8-bits.

Three different operation modes can be programmed in the system: calibration, signal tracking and feature extraction. During the calibration operation, the system performs a mechanism to auto-calibrate the BP-filter bandwidth and the PGA of each of the channels. During the signal tracking mode, the signal captured by each of the neural electrodes are sampled at 30kHz and sent to the output without any kind of compression. Under the feature extraction mode, the system drastically reduces the data output bitrate by detecting the presence of spikes using an adaptive neural threshold detection algorithm and only transmitting their more important features by means of a Piece-Wise-Linear (PWL) approximation. During this mode, the ADC sampling frequency is set at 30kS/s while any spike is detected, and is changed to 90kS/s during the spike characterization period. Data streams coming from the channels are serialized by an embedded digital processor and transferred to the outside by means of the same inductive link used for powering the system.

The inductive link uses the ISM band of 40.68MHz. Both the input and output data are transferred with an OOK modulation. The system embeds both the energy harvesting and power management circuits to supply the complete array, as well as the RF front-end circuitry for the wireless communication.

The prototype was implemented using a CMOS 0.13um standard process. The total power consumption of the system was 377uW, in average 5.9uW per channel, one of the lowest power consumptions compared to the state-of-the-art.

8765-3, Session 1

Low-power techniques in multi-channel cortical recording implants *(Invited Paper)*

Alexandre Schmid, Ecole Polytechnique Fédérale de Lausanne (Switzerland)

Cortical recordings have recently gained in interest, following the demonstration of the possibility to deduce some voluntary behavior from the real-time electrical activity recorded from multichannel motor cortex implants. These recent developments benefit from an integrated research approach where microelectronics, microelectrodes as well as signal processing developments are considered from a system-level perspective to mitigate their respective trade-offs. The advent of this domain with its own specifications opens the door to the development of new therapeutic and research tools, and also presents distinctive technical challenges to overcome. Specific circuit and system-level techniques aiming at reducing power consumption, circuit area, and data throuput of cortical implants are discussed, which target recording the electrical activity of the motor and epileptogenic cortical areas using multichannel systems.

8765-4, Session 2

Design of cell microgripper and actuation strategy

Aurelio Soma, Sonia Iamoni, Politecnico di Torino (Italy)

The analysis of the mechanical properties of cells is a field of great interest both in medicine and biology because it becomes fundamental each time it is necessary to recognize and prevent some diseases causing alterations in cellular behaviour and resistance. Biological Micro Electro-Mechanical Systems (Bio-MEMS) allow the application of extremely small and precise forces increasing, as a consequence, the number of results possible per experiment and the number of experiments that can be performed simultaneously. The aim of our work is to present a microgripper for cell manipulation and to detect the best structure design for keeping the call and the integrated strategy for its actuation. Specifications and targets impose several limitations and difficulties in micro manipulators design and these obstacles are even more important when the target of microgripping are biological particles (e.g. living cells). The main parameters that have to be taken into account while designing a cell micromanipulator are, aside from its actuation principle, its kinematics, its fingertips shape, its releasing strategy and its biocompatibility. Our device can be used for the manipulation of a single-cell having a diameter up to 40 µm and it is made of SU-8, a biocompatible polymer; it has a compliant structure that creates, in closed configuration, a room defined by the cylindrical carved gripper tips to keep the cell, reducing the contact stress during gripping.

The proposed layout also reduces the micro-fabrication steps, time and costs as no dopants and no more than one mask layer need to be used for its realization.

Both thermal and piezoelectric actuation strategies are investigated in order to understand their main advantages and limitations related, for example, to motion range, hysteresis, low biocompatibility of materials, thermal stability and insulation, high temperature and high voltage; all these parameters have to be considered to ensure the cell's integrity during its micromanipulation.

8765-5, Session 2

Thermal actuated micropump for biological and medical application

David Rabaud, Rémy Lefevre, Arnaud Salette, Loïc Dargent, Hakim Marko, Quentin Le Masne, Christophe Dehan, Panagiota Morfouli, Laurent Montès, IMEP-LAHC (France)

MEMS micropumps are developed for medical injection devices and biological microfluidics (lab-on-chip). While most actual micropumps use piezoelectric based actuators, we present an original approach based on bimetallic effect used for large deflection of a flexible silicon membrane. The main interest of such an original technology relies on a very simple and fully integrated IC compatible process. We have simulated, fabricated and characterized fully integrated thermally actuated membranes. Analytical and numerical models have been used to simulate and optimize the performance of the actuated diaphragm. It predicts the deflection behavior under definite power actuation and pressure. In particular, heat transfer analysis is conducted to evaluate temperature field distribution within the device. We will present the technological process and specific test bench for wafer level characterization. Our characterization results show large membrane displacements (~80µm) obtained under low driving power and leading to flow rates well suited for bio and medical applications. While standard analytical models give over-estimated values, our results show a very good fit between experiments under pressure and theoretical predictions, with less than 4% difference when taking into account large displacement and thermal. Dicing, wiring and a specific packaging is studied. We also present original method for rapid prototyping, especially for making plug-and-flow microfluidic channels.

8765-6, Session 2

Optimization of dielectrophoretic separation and concentration of pathogens in biological samples

Emilie Bisceglia, Commissariat à l'Énergie Atomique (France); Myriam Cubizolles, CEA-LETI (France); Frédéric Mallard, bioMérieux SA (France); Florian Pineda, CEA (France); Olivier Francais, Bruno Le Pioufle, Ecole Normale Supérieure de Cachan (France)

Nowadays, finding new methods for the direct and fast separation of pathogens from a complex biological sample is being a major challenge in biomedical diagnostics. Indeed the improvement of sample preparation prior to pathogen detection and analysis could dramatically improve the global performance of diagnostic of infectious diseases.

In this present study, we investigate the dielectrophoresis (DEP) force as a means to extract micro-organisms from a complex biological sample under a highly non-uniform electric field. To perform capture of the micro-organisms, we designed a devoted micro-system based on an interdigitated electrodes array.

Different parameters were investigated, such as the width of the electrodes and the gap between the electrodes. These parameters are directly driving the distribution of the electric field inside the separation chamber. To optimize these relevant parameters, we perform numerical simulations using COMSOL Mulitphysics and correlate them with experimental results. To assess the genericity and the robustness of the DEP trap, we perform capture experiments on different species of bacteria (E. coli and S. epidermidis) and yeasts (C. albicans).

Both simulations and experiments ended up with the same results: an array with 10µm gaps and 100µm electrodes provide the best conditions to carry out a generic DEP capture.

Other parameters such as viability of micro-organisms under non-uniform electric field will be discussed, as it is a great concern for further analysis after the capture. This parameter strongly depends on the structure of the micro-organism, and we observed great variations between the different species.

The optimization of the capture efficiency of the device has first been tested on micro-organisms in pure solutions. On E coli and C albicans cells, capture yields can reach 75%. As the DEP force strongly depends on the size of the micro-organisms, we obtain lower yields with S epidermidis.

The device efficiency was also investigated using these micro-organisms spiked in human blood, thereby mimicking real biological samples.

We strongly assume that this micro-system based on dielectrophoretic capture may fill in the critical gap of sample preparation when dealing with biological samples, and may provide advantages of genericity and simplicity.

8765-7, Session 2

Modeling of an implantable device for remote arterial pressure measurement

Jose A. Miguel, Yolanda Lechuga, Mar Martinez, Univ. de Cantabria (Spain)

Vascular diseases are responsible for nearly 35% of all annual deaths in Europe. Nowadays, the use of stents, defined as bio-compatible flexible tubes implanted in a blood vessel during an angioplasty procedure to reopen an obstruction, has become the most frequently used method for the treatment of common vascular illnesses. However, the mayor drawback in its implantation is the appearance of the so-called In-Stent Restenosis (ISR), or reclosure of the vessel due to tissue growth inside the implanted stent.

Regular procedures for ISR monitorization usually require patient hospitalization, involving a high impact on national healthcare costs. An intelligent stent (e-stent), capable of obtaining and transmitting real-time measurements of physiological parameters, can be a useful tool for ISR monitorization without hospital admission.

An e-stent requires an implantable sensor to acquire physiological measurements, a signal conditioning integrated circuit and a radio frequency transmission link. Particularly, this work focuses on blood pressure and flow measurement, using MEMS capacitive pressure sensors as physical transducers. A behavioural model of the e-stent, implemented in Matlab, is presented and tested under different grades of ISR to validate its response under real disease conditions.

Any implantable device must achive reduced size, low power consumption and cost, minimal invasiveness, and long-time reliability.

These conditions make testing and realistic fault modeling, critical issues for its validation. As a crucial part of the e-stent, special attention has been given to the MEMS pressure sensor model. Using finite element analyisis (FEA) tools, usual analytical models proved to be precise under fault-free scenarios, although showing serious lack of accuracy for sensors with fabrication faults. Hence, the creation of new mathematical models for those faulty cases, based on FEA simulation results, seems to be a neccesary design step; especially for those cases in which the geometry and/or material properties of the sensor are altered.

8765-22, Poster Session Thursday

Lab-on-a disc platform for particle focusing induced by inertial forces

Maria Kitsara, Gerson R. Aguirre, Dublin City Univ. (Ireland); Vitaly Efremov, Dublin City University (Ireland) and Biomedical Diagnostics Institute (Ireland); Jens Ducree, Dublin City Univ. (Ireland)

Dean forces have been consistently used in microfluidic mixing units and recently also have been used to separate particles in inertial force driven systems by secondary flows. Di Carlo et al. have established a microfluidic separation unit which uses inertial force created by curved asymmetric channels [1].Theory stipulates that there is a particle density effect that the system influences separation to a greater extent due to non-buoyancy between fluid and particle.

In the present work, we propose a centrifugal lab-on-a-disc platform, which can provide a higher inertial force (centrifugal) leading to shorter and faster focusing of particles, due to the innately induced pressure gradient. This comprises the primary advantage of the proposed platform compared to a pump system. The asymmetric channels dimensions used in the current work are based in work published elsewhere [2]. The rotatable disc shaped microfluidic device was fabricated using standard soft lithography by casting poly(dimethylsiloxane) (PDMS) polymer on a SU-8 photoresist master. Afterwards, the PDMS mold was bonded using O2 plasma to a PMMA disc 1.5mm-thick on top of which a thin film of PDMS was previously spin-coated. The height of the channels is ~70µm and the number of the separation turns is almost 4 times less than in the literature. With this continuous separation system, polystyrene beads of 21um diameter size can be manipulated on demand by simply modifying the frequency of rotation in the range 4 – 12 Hz.

A mixing section driven by Dean forces has also been added to the microfluidic system for the binding of ligand-functionalized beads to HL60 cancer cells. Thus the system makes use of secondary flows in curved channels entirely driven by Dean flows only differentiated by symmetry and orthogonality to centrifugal force. Further work will focus in the separation of red blood cells from HL60 cancer cells spiked into blood samples.

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8765-23, Poster Session Thursday

Physical and chemical gels of lipid nanoparticles for controlled delivery of lipophilic drugs and proteins

Anne-Claude Couffin, Thomas Delmas, Jean-Sébastien Thomann, Ismail Cheibani, Emilie Heinrich, Thomas Courant, Antoine Hoang, Commissariat à l'Énergie Atomique (France); Rachel Auzély, Eric Bayma, Ctr. de Recherches sur les Macromolécules Végétales (France); Isabelle Texier-Nogues, Commissariat à l'Énergie Atomique (France)

The controlled delivery of drugs and biologicals (proteins, antibodies, DNA and derivatives) is a growing need to take the full benefit of the development of new therapeutic strategies. However these new molecules or biomolecules display solubility issues, or high degradation rates once injected. Therefore, both suitable delivery materials for their encapsulation and protection from the surrounding environment, and smart delivery devices (such as micro-needles or implanted pumps) are necessary to achieve controlled delivery of these precious therapeutic agents.

We have developped new bio-inspired gel materials, based on lipid nanoparticles which act as reservoirs for lipophilic drugs. The lipid nanoparticles, termed lipidots™, are synthetic analogs of lipoproteins: they are biocompatible, colloidally stable, non-immunogenic, and obtained from a cheap and simple solvent-free process. The particles can be assembled to form physical or chemical gels, with tunable rheological properties. Physico-chemical studies have been carried out to determine the limits of the stability domains for colloidal and gel formulations (choice of surfactants for nanoparticle surface, and composition ratios of lipids, surfactants and co-surfactants). In particular, it is demonstrated that lipid nanoparticles keep their integrity in the gel.

Gels of lipidots™ constitute two-compartment materials, with an oily phase for lipophilic drug loading, and an aqueous phase suitable for the encapsulation of biomolecules, such as therapeutic proteins. Drug and protein release kinetics can be tuned according to gel composition. Moreover, the polymeric surfactants ensuring particle stability and gel cohesion can be engineered to design smart gels, whose drug release is triggered by an external stimulus, such as redox potential or light. Preliminary results obtained with different smart gels will be presented. Ultimately, these materials will be integrated in devices for dermal delivery.

8765-24, Poster Session Thursday

Effect of terahertz radiation on cell

Liliya Dvoretskaya, National Research Univ. of Information Technologies, Mechanics and Optics (Russian Federation)

Electromagnetic radiation has an effect on all levels of living matter. Particularly significant effect of this radiation on the molecular and cellular levels of various tissues of the human body, mainly in the cells providing updated body. Questions relating to the study of physical mechanisms by which electromagnetic radiation on biological objects in particular the effect of THz radiation on animal cell and a theory which precisely describe this process is the actual problem.

Cell is an independent functional unit and the processes occurring in body are made up of a coordinated set of functions of all cells.

Animal cells is our model is represented as a spherical cavity (diameter 17mkm) with a shell (membrane) of thickness 10 nm, in which is located inside the core (diameter 1 mkm). The kernel is the main part of the cell, it is responsible for the storage, sale and transfer of genetic information, and controls all the processes of cell activity. Outside the core is covered with a double membrane with pores inside is karyenchima chromatin (untwisted strands of DNA) and nucleoli are composed of RNA.

Interaction of spherical fluctuations within the cell nucleus and leads to a change in the (destruction) of the state media the excitation waves that disrupt vital processes of that they encode and affect the accuracy of the transmission genetic information from cell to cell i.e. lead to mutations.

In this paper the following results:

1. a model of an animal cell

2. the simulation cell with the relative permittivity of the cytoplasm and karyoplasm have your own resonant frequencies of terahertz radiation 0.05-2 THz.

In this paper checked the accuracy of the data about abuse of the process of ion transport across the cell membrane and changes in the vital processes of the cell.

8765-25, Poster Session Thursday

Tri-axial tactile sensing element

Julian Castellanos-Ramos, Rafael Navas-González, Fernando Vidal-Verdú, Univ. de Málaga (Spain)

Tactile sensors have been successfully employed in many medical applications [1]. Miniature tri-axial taxels or tactile sensor elements

able to detect normal as well as tangential forces are required for some of them like minimally invasive surgery and implemented commonly with MEMS on silicon or polymers [2] Other medical applications do not require such high spatial resolution, for instance those related to assistive robotics and human-robot interaction that involves contact with the whole robot body [3], or others related to advance prosthetics [4]. A 13 x 13 square millimeters tri-axial taxel is presented in this work that is suitable for such applications. A common approach to detect tangential forces is based on a kind of four leg (or joint) structure. Forces exerted on this structure produce mechanical deformations and change resistance or capacitance values of sensing units somewhat linked to each leg or joint. In our taxel, the structure is placed atop of four piezoresistive sensing areas made with screen-printing technology. The sensing principle is not based on mechanical deformation in this case, but on the variation of the contact area at micro or even nano scale. Therefore, a uniform pressure on each sensing unit should improve the sensor performance. Finite Element Analysis with COMSOL is carried out in this work to determine what structure is the best to get a uniform pressure distribution on the bottom sensing areas. Simulations show the influence of every parameter of the structure in this final goal. An example of this structure has been fabricated in plastic with a 3D printer and a commercial tactile sensor has been used in this work to test it. This sensor (5800N from Tekscan) has large spatial resolution (1.3 mm), therefore each sensing area is composed of 5 x 5 taxels. This allows us to see the pressure distribution on each sensing area that is caused by a force upon the top structure. A multiple linear regression approach was used to obtain each triaxial component of force based on the reading of the sensing areas of the commercial tactile sensor. A three axis linear motorized translation stage with a tri-axial precision force sensor (nano17 from ATI Industrial Automation) is used to find the parameters of the linear regression model and characterize the proposed tri-axial taxel.

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8765-26, Poster Session Thursday

Monitoring the effects of fibrinogen concentration on blood coagulation using quartz crystal microbalance (QCM) and its comparison with thromboelastography

Ramji S. Lakshmanan, Vitaly Efremov, Sinéad Cullen, Barry Byrne, Anthony J. Killard, Dublin City Univ. (Ireland)

Increased fibrinogen levels have been identified as a major risk factor in cardiovascular disorders. Fibrinogen (M.W. =340kDa), a soluble dimeric glycoprotein found in plasma, is a major component of the coagulation cascade. At the final stage of this process, fibrinogen is converted to insoluble fibrin due to the enzymatic action of thrombin. The time taken for this process is typically used as an “end-point” in most clot-based assays. However this ‘end-point’ does not provide any information relating to the dynamic changes in physical properties or kinetics of a forming clot. However, a global coagulation profile as measured by Thromboelastography (TEG) provides information on both the time and kinetics of changes in physical properties during clot formation. TEG has a freely-suspended pin in a rotating cup, in which the blood sample is placed with suitable coagulation activators. As the clot forms between the cup and the pin, the fluid resistance transfers rotation of the cup to the pin and the deflection of the pin is indicative of the occurring physical property changes. In this work, Quartz Crystal Microbalance (QCM), which is a piezoelectric resonator, is used to study a global coagulation profile of plasma and compared with TEG. QCM has a characteristic resonant frequency and was measured using a lorentzian fit of the conductance spectrum. In addition to frequency, the half-width at half maximum (HWHM or DG) was also obtained. Changes in resonant frequency (Df) are indicative of mass adsorption/coupling to the QCM surface and changes inDG are indicative of viscoelastic property changes. These parameters were used to evaluate the effect of fibrinogen concentration on formation of a fibrin clot by activation of the intrinsic pathway of coagulation. Both Df and DG changes increased as a function of fibrinogen concentration. Furthermore, it was observed that TEG is less sensitive to low concentrations of fibrinogen and haemodilution, while QCM is able to monitor clot formation in both circumstances. QCM being a surface-sensitive technique is capable of reliably detecting the earliest stages of the coagulation cascade. Using a two parameter system (Df and DG) traces, which are similar to TEG, can be obtained that provide both qualitative and quantitative information pertinent to the formation of a fibrin clot.

8765-8, Session 3

A novel microfluidic anti-factor Xa assay device for monitoring anticoagulant therapy at the point of care

Leanne F. Harris, Paul V. Rainey, Vanessa Castro-López, Dublin City Univ. (Ireland); James S. O’Donnell, Trinity College Dublin (Ireland); Anthony J. Killard, Univ. of the West of England (United Kingdom)

Millions of patients worldwide are receiving oral anticoagulant therapy to treat hypercoagulable diseases. While standard testing is still performed in the central laboratory, POC diagnostics are being developed due to the increasing number of patients requiring long-term anticoagulation and with a need for more personalized and targeted therapy. Many POC devices on the market focus on clot measurement, a technique which is limited in terms of variability, highlighting the need for more reliable assays of anticoagulant status. In addition, the emergence of new drugs that target specific factors in the clotting cascade cannot be monitored using traditional clot-based assays. The anti-Xa assay, a factor specific optical assay, was developed to measure the extent to which exogenous FXa is inhibited by heparin-antithrombin complexes.

We have developed a novel microfluidic device and assay for monitoring the effect of heparin anticoagulant therapy at the point of care. The assay which was also developed in our institute is based on the anti-Xa assay principle but uses fluorescence as the method of detection. Our device is a disposable laminate microfluidic strip, fabricated from cyclic polyolefin (COP), more commonly referred to as zeonor, which is extremely suitable for application to fluorescent device platforms. We present data on the execution of the anti-Xa assay in this microfluidic format, proving that the assay can be used to measure heparin in human plasma samples. We have established that the assay ranges from 0 to 0.8 U/ml for the anticoagulants tested, with assay reproducibility of <10% and a rapid result obtained within 60 seconds. Correlations were also performed with central laboratory assays to determine if our device correlates well with standard assays. Results indicate that with further development, the fluorogenic anti-FXa assay and device could become a successful method for monitoring anticoagulant therapy.

8765-9, Session 3

Probing the mechanism of material specific peptides for optical biosensors

Sathish Kumar Ramakrishnan, Marta Martin, Elias Estephan, Thierry Cloitre, Csilla Gergely, Univ. Montpellier 2 (France)

The possibility to engineer bio-nanomaterials with programmed synthesis and controlled immobilization of biomolecules through biomimetic molecular evolution approach has been demonstrated. Material specific peptides with exquisite molecular recognition function were used as a linker for the attachment of biomolecules. We have reported enhanced binding sensitivity of biomolecules without sacrificing its biological activity to porous silicon (Si)

microcavities and other semiconductor materials, including GaN, GaAs, and InP. Exploring the origin of peptide material specificity not only open up rational design approach with precise control over biomimetic bio-sensor design, but more importantly provides a new route of functionalizing of various material surfaces with enhanced sensitivity over classical grafting chemistry. To study the fine prints of experimentally obtained peptides, theoretical understanding of surface interactions may serve as important clues for further refinement. By taking advantage of classical molecular dynamics (MD) simulations and density functional theory (DFT), we investigated the origin of this smart recognition function by calculating the adsorption modes and the strength of interaction of experimentally selected 12mer peptides revealing high binding affinity towards silicon. Here, we attempt for the first time to model the interaction of the peptides (in buffer solution) with semiconductors and we calculate their binding energies at the atomic level, enabling thereby linking direct evidence to our experimental evidence. Several peptide conformations have been taken into account simultaneously upon the surface, and their conformation changes were identified. Our studies demonstrate that the peptides possess certain recognition function and their high interaction energy with the surface makes them unique among the populations. We hope to shed a light towards the understanding of the interactions between peptides and semiconductor surfaces that is a highly relevant challenge also towards the development of novel devices with a high degree of biocompatibility.

8765-10, Session 3

Cell array fabrication by plasma nanotexturing of PMMA

Dimitrios Kontziampasis, Athanasia Bourkoula, Panayiota Petrou, Angeliki Tserepi, Sotirios E. Kakabakos, Evangelos Gogolides, National Ctr. for Scientific Research Demokritos (Greece)

In our previous work we have shown that plasma etching can roughen a polymer surface (nanotexturing)[1], which can then be used to create a high intensity protein or DNA microarray. [2-4]

Cell behavior (i.e. attachment, proliferation e.t.c.) on nanotopography is currently a hot topic. However studies often have diverging results. This is due to the fact that each cell has a different behavior towards topography and local surface chemistry ant thus the fabrication method of the specific nanotopography. [5]

We use Oxygen plasma etching to both randomly nanotexture a PMMA surface and change its surface chemistry. We find that 3T3 cells behave quite differently an flat PMMA surfaces as compared to PMMA nanotextured surfaces, showing an on-off attachment behavior.

We exploit this effect to create nanotextured areas by using a stencil mask which allows selectively etching of the PMMA surface and furthermore use it to create cell arrays.

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8765-11, Session 3

Deflection of microcantilever beams subjected by a point force

Davut E. Sahin, Bozok Univ. (Turkey); Mohammad A. Changizi, Ion Stiharu, Concordia Univ. (Canada)

Position sensitive detectors (PSD) are used in many applications to measure displacement and vibration. One of these applications is determining the deflection of microcanlilever beams (MCLB). MCLB's are used as not only biosensors but also an element of electronic circuit. Reflection of the light using in PSD from the cantilever surface indicates the deflection of the point where the light is seen on the surface. The deflections of the cantilever versus the measured deflection on the PSD are not the same. The real deflection is related through the geometry of the system. In this study, real deflection of cantilever beam when a point force applied at the end of the beam is calculated basing on small and large deflection theories.

8765-12, Session 4

Wireless data and power transmission aiming intracranial epilepsy monitoring

Gurkan Yilmaz, Oguz Atasoy, Catherine Dehollain, Ecole Polytechnique Fédérale de Lausanne (Switzerland)

Epilepsy is regarded as one of the most common neurological disorders by World Health Organization. Although in most cases it can be treated with medication, certain patients have to undergo a two-step surgery. First surgery aims to place electrodes over the cortex to localize the focus of epilepsy, and then corresponding part is resected in the second surgery. However, currently, signals collected by the electrodes are transmitted to the external recording device via cables which passes through the skull and the skin. In this study, we present a system which enables wireless data and power transmission between the electrodes and the external recording device, therefore, reduces the risk of infection due to the additional holes opened to take the cables out.

Wireless power transfer link is implemented using inductive coupling and a power management unit in the implant. 4-coil resonant inductive link scheme is exploited since it exhibits a high efficiency and optimal load flexibility. Power management unit consists of an active rectifier, voltage reference and a low drop-out voltage regulator, all implemented as IC. Power link provides 10 mW under 1.8 V dc to the load, more specifically the electrodes.

Wireless data communication is realized using the same frequency, 8 MHz, as the power link. Load shift keying is performed for uplink (from implant to external) communication by switching an integrated modulator which, in fact, detunes the resonance. Modulated signal is recovered on the external device by means of an integrated self-referenced ASK demodulator. Data rate is adapted for a fast ripple (< 500 Hz) detection system with 2 kSample/s sampling rate, 8-bit resolution, and 16 recording channels, which requires 256 kbit/s. Assuming a 20% overhead for communication protocol, 300 kbit/s communication is realized with this system. Finally, in-vitro tests that emulate the real operation scenario are performed to compare the results with the results in air.

8765-13, Session 4

BIO instrument for parallel impedance spectroscopy of biological cell cultures

Thomas Frank, Ingo Tobehn, Alexander Rösner, CiS Forschungsinstitut für Mikrosensorik und Photovoltaik GmbH (Germany)

For the parallel impedance spectroscopy of biological cells bio-instrument was developed. This includes 16 sensors with corresponding wells and electronics for impedance spectroscopy. The measuring range is between 1 kHz and 100 kHz. It is based on the AD5933. The Bio-instrument can be operated wirelessly; it provides an interface for Labview. Mouse fibroblasts (L929) were used to evaluate the system.

The basis of this system is the adhesion of certain cells on the sensorial surface, thus giving information about the vitality of cell cultures according to the biocompatibility of active substances, materials and consumables.

The sensorial elements can be delivered in different realizations: for a galvanic coupling, the sensors may be ordered with different electrode materials in the absence of a passivation layer and in the case of a capacitive linkage, the interdigital structures will be furnished with a dielectric film.

A Graphical User Interface has been programmed with LabView to aid the user by creating, transforming and controlling the commands, that are presented to the system. Furthermore it is supporting the manipulation and evaluation of the gained data.

The interdigital structures got an active surface area of 1630 µm x 1950 µm. By picking TiN, Au or MoSi2 as the contact material, electrode distances between 1.1 µm and 75 µm are possible, The width of these electrodes is thereby always bigger than the distance by a factor of 1,3. This relation results due to optimization processes via FEM programs.

The big advantage of this system is that the data manipulation is done mainly by the hardware, which reduces the amount of noise that influences the data.

8765-14, Session 4

Polymer electronics for in vitro electrophysiology

Michele Sessolo, Dion Khodagholy, Adel Hama, Jonathan Rivnay, Ecole Nationale Supérieure des Mines de Saint-Étienne (France); Esther Steidl, Bruno Buisson, Neuroservice (France); George G. Malliaras, Ecole Nationale Supérieure des Mines de Saint-Étienne (France)

In the last decade, microelectrode arrays (MEAs) have become an indispensable tool in the study of different properties of neural networks such as network formation, network dynamics and signal processing. The traditional technology is based on micro-sized metallic electrodes produced through photolithographic etching of physically deposited noble metal coatings. As the size of the electrodes decrease, however, both signal quality and stimulation ability drop due to the high impedance of the metal-tissue interface. Moreover, the fabrication of such devices relies on traditional silicon patterning technology, making commercially available MEAs expensive and restricted to rigid substrates. Conducting polymers such as poly(3,4-ethylenedioxythiophene) doped with poly(styrenesulfonate) (PEDOT:PSS), show lower impedance and higher capacitance compared to metals, as well as an augmented biocompatibility. Thanks to their soft mechanical properties and processability, conducting polymers can be solution-processed by simple printing techniques on flexible substrates, leading to a new generation of prosthetic devices with unique conformability and form-factors. Here, we present a novel approach to photolithographically define polymer MEAs, patterning at the same time the polymer active sites and the insulating layer. We use the MEAs for in vitro recording of electrophysiological signals from mouse hippocampus slices, demonstrating that our platform is capable of monitoring spontaneous unit activities as well as evoked responses induced by drug perfusion into the nervous tissue. The fabrication process is extremely versatile and can be used to pattern onto a large variety of substrates (both hard and flexible), with virtually any functional material. We further demonstrate the potential of this approach by patterning multilayer structures composed of PEDOT:PSS and proteins or polypeptides, including collagen and poly-L-lysine. In this way, the proliferation of neuronal cells can be controlled with micron-scale resolution and directed towards the electrically active area of the device, allowing for a better transduction of electrophysiological signals.

8765-15, Session 4

Zinc oxide nanostructures as low-cost templates for neuronal circuits

Anna Kritharidou, Zafeiroula Georgoussi, Christos Tsamis, Eleni Makarona, National Ctr. for Scientific Research Demokritos (Greece)

It has been long established that cells respond differently to smooth surfaces compared to materials with micro- or nanoscale roughness, while cell behaviors are exquisitely sensitive to the nanoscale topography of the substrate [1]. With this objective in mind nanostructured substrates of ZnO were explored as templates for the development of topography-mediated neuronal cultures.

The nanostructured surfaces were produced with varying nanotopographical features via a rapid, low-cost and facile technique that allows the systematic investigation of nanotopographically-mediated formation of cell cultures. The proposed technique was on based the hydrothermal growth of ZnO nanostructures on spin-coated ZnO nanoparticle seeding layers (via inexpensive sol-gels) over standard 4” silicon substrates [2]. Patterning of the substrates was achieved with standard lithographic and lift-off techniques.

Neuro-2A mouse neuroblastoma cells were cultured on the ZnO-nanostructured templates and studied over the course of 4 days every 24 hours in order to assess their viability. Standard glass slides were used as controls, while poly-lysine coated templates and controls were used for comparison. Our results demonstrated that the templates can support cellular growth and proliferation, even in the absence of any adhesive agent maintaining their normal growth, rendering the poly-lysine coating step obsolete and unnecessary. The effect of the nanotopography on the neurite outgrowth was also investigated. Initial results indicate that the proposed methodology is suitable for neuronal cell growth with a great potential to become an alternative cost-efficient and easy-to-mass-produce technique for the realization of engineered neuronal networks in ZnO nanostructures.

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8765-16, Session 5

All-silicon monolithic optoelectronic platform for multi-analyte biochemical sensing *(Invited Paper)*

Konstantinos Misiakos, National Ctr. for Scientific Research Demokritos (Greece)

Despite the advances in optical biosensors, the existing technological approaches still face two major challenges: the inherent inability of most sensors to integrate the optical source in the transducer chip, and the need to specifically design the optical transducer per application. In this work, the development of a radical optoelectronic platform is demonstrated based on a monolithic optocoupler array fabricated by standard Si-technology and suitable for multi-analyte detection in a real time label- free format. In the all-silicon array of transducers, each optocoupler has its own excitation source and share a common detector so that multianalyte testing can be performed by multiplexing the input light source. The light emitting devices (LEDs) are silicon avalanche diodes biased beyond their breakdown voltage and emit in the VIS-NIR part of the spectrum. The LEDs are coupled to individually functionalized interferometers consisting of single mode planar waveguides. The integrated nature of the basic biosensor scheme and the ability to functionalize each transducer independently allows for the development of miniaturized optical transducers tailored towards point of care multi-analyte detection at a good enough speed and sensitivity.

8765-17, Session 5

Real-time polarimetric biosensing using macroporous alumina membranes

Jesús Alvarez, Univ. de València (Spain); Laura Sola, Consiglio Nazionale delle Ricerche (Italy); Geoff Platt, Farfield Group Ltd. (United Kingdom); Marina Cretich, Consiglio Nazionale delle Ricerche (Italy); Marcus Swann, Farfield Group Ltd. (United Kingdom); Marcella Chiari, Consiglio Nazionale delle Ricerche (Italy); Daniel Hill, Juan P. Martínez-Pastor, Univ. de València (Spain)

Recently nanostructured materials like porous silicon or porous alumina have gained special attention for the development of biosensors as they have higher surface areas than planar biosensors for capturing analytes permitting lower limits of detection. The usual approach employed for quantifying the amount of analyte that binds to the bioreceptors immobilized on the pore surfaces is based on reflective interference spectroscopy (RifS). The main limitation of the interferometric approach lies in the need of having a porous film

with pores diameters below 100 nm in order to avoid light scattering and so obtaining well resolved interference fringes. In that sensing structure, the adsorption of the analytes in the pores is mainly governed by the stationary flux which results in a slow response time of the biosensor.

In this work, we report on the first demonstration of real-time biosensing in free standing macroporous alumina membranes. The 200 nm pore diameters of these membranes permit flow-through allowing targeted delivery of the analytes to the bioreceptors immobilized to the functionalized surface of the porous alumina for a rapid response time. The interrogation mechanism is based on measuring the anisotropy of the macroporous alumina membrane by a polarimetric setup resulting in real-time sensing at one data point per second. Biosensing experiments were carried out on macroporous alumina membranes whose surfaces were chemically functionalized with an epoxy-functional silane and then spotted with b-Lactoglobulin protein. Prior to the bioassay, the volumetric sensitivity of the whole system was tested using different solutions of NaCl in DI water, obtaining a limit of detection below 2.7x10-6 refractive index units. Thereafter the sensitivity, selectivity and stability of the biosensor were determined by flowing through the membrane solutions of rabbit anti-b-Lactoglobulin and goat anti-rabbit Immunoglobulin G as primary and secondary antibodies.

8765-18, Session 5

Nanobionsensor for HPV vaccine monitoring

Jose A. Saez, Elisabeth Fernandez, Jordi Suarez, Socorro Vazquez, LEITAT Technological Ctr. (Spain); Marina Cazorla, Maria J. Lopez-Bosque, Alvaro Mata, Parc Científic de Barcelona (Spain); Marc Massa, Francesc Mitjans, Laurent Aubouy, LEITAT Technological Ctr. (Spain)

Nanobiosensors developed in the present work are based on hybrids biomolecule-nanoparticle, and designed to enable the identification of antibodies generated on individuals who present a pre-existing immunity against human papilomavirus (HPV), the cause of nearly all cases of cervical cancer. Therefore, this biosensor will allow determining vaccination requirements for each individual to reduce its costs maintaining its effectiveness and safety.

The main objective of this work is the development of a portable and easy-to-use device capable of providing real-time individualized profile of the immune response from a small blood sample. To accomplish this objective it was essential to obtain a system as sensitive as possible. Therefore, an impedimetric biosensor has been designed consisting of interdigitated microelectrodes functionalized with gold nanoparticles covalently attached to L1 protein fragments (the most immunogenic forming the HPV capside), capable to recognize specific antibodies against HPV-L1 proteins (types 6, 11, 16 and 18, the most incident and aggressive) from non-treated blood samples.

Electrochemical measurements were performed in order to validate the sensitivity of the system, optimize the protein concentration on the electrode surface, and obtain the highest sensitivity using the lowest amount of patient blood sample. Our device is able to quantify changes in the electrical impedance caused by the presence of IgG antibodies against up to four HPV-L1 types, with sensitivity in the nanomolar range.

A portable electronic platform device, based on system-on-chip MD8710, has been developed to enable fast and easy real-time measurements. This platform is able to perform and display impedimetric measurements based on pre-defined parameters, allowing easy reconfiguration and reutilization with other different biomolecule-nanoparticle hybrids.

The two-step functionalization process and the possibility to use directly non-treated blood samples, converts this biosensor platform into a versatile system able to quantify the immune response for other vaccines.

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8765-19, Session 6

Design and fabrication of high-throughput application-specific microfluidic devices for studying single-cell responses to extracellular perturbations

Amin Abbaszadeh Banaeiyan, Göteborg Univ. (Sweden); Doryaneh Ahmadpour, Univ. of Gothenburg (Sweden); Caroline Beck Adiels, Mattias Goksör, Göteborg Univ. (Sweden)

Single cell analysis techniques provide the unique opportunity of determining the intercellular heterogeneity, which due to the genotype variations and different physiological states of the cells i.e. size, shape and age, cannot be retrieved from averaged cell population values. In order to obtain high-value quantitative data from single-cell experiments it is important to have platforms enabling high-throughput studies. Here, we present a microfluidic chip, which is capable of capturing cells in suspension inside individual traps. The device consists of three adjacent micro-channels with separate inlets and outlets, laterally connected through the V-shaped isolated traps. V-shaped traps, with openings smaller than the size of a single cell, are fabricated in the middle (main) channel perpendicular to the flow direction. Cells are guided into the wells with precise control of the flow rate and are kept still by flow-induced Stokes drag forces at the bottom of the traps. The cells can then be exposed to extracellular environmental changes by introduction of specific stimuli either in the main channel or in the side channels. The most powerful aspect of this high-throughput device is the flexibility of application-specific design and low-cost fabrication. Micro-channels and traps of different sizes can be fabricated in polydimethylsiloxane (PDMS), offering the possibility of independent studies on cellular responses with different cell types and different extracellular environmental changes. Proof-of-concept applications of the device have been verified both numerically and experimentally for Saccharomyces cerevisiae (yeast cells) and mammalian cells (Mouse embryonic fibroblast). We believe that this versatile high-throughput cell trapping approach will, to a great extent, contribute to further development of the current knowledge and information acquired from single-cell studies and provide high quality experimental data required for systems biology.

8765-20, Session 6

Integrated biochip for PCR-based DNA amplification and detection on capacitive biosensors

Nikolaos Vourdas, Despina Moschou, National Ctr. for Scientific Research Demokritos (Greece); George Tsekenis, Biomedical Research Foundation, Academy of Athens (Greece); Ioanna Zergioti, National Technical Univ. of Athens (Greece); Stavros Chatzandroulis, Angeliki Tserepi, National Ctr. for Scientific Research Demokritos (Greece)

Fabrication and development of Lab-on-chip (LoC) devices are imperative for Point-of-Care (PoC) solutions, towards fast and inexpensive disease diagnostics. Bioanalytical protocols for this reason usually include an amplification step, which is performed by means of the Polymerase Chain Reaction (PCR) process and followed by analysis of the PCR products utilizing a detection device. There is an increasing demand for LoC devices (replacing time-consuming procedures in bulky bench-top instruments) to perform this analysis, attaining small footprint, high throughput, small energy consumption, low reagent demands, ease of fabrication and advanced integration characteristics. Several attempts have been made to integrate miniaturized PCR (uPCR) devices with microheaters, but to our knowledge there are only few such devices on polymeric substrates and even less LoC systems, integrating the uPCR module, the heaters and the detection device (sensor).

In this work, we present the fabrication and evaluation of an integrated LoC device consisting of a μPCR module with resistive microheaters and a biosensor array, for disease diagnostics. The LoC is built on a Printed Circuit Board (PCB) platform, implementing

both the amplification of the DNA and the detection on-chip. The fabrication of the resistive electrical part of the LoC, namely the resistive microheaters for uPCR and the wirings for the sensor read-out are fabricated by means of conventional lithography and copper etching (standard PCB technology). The microfluidic network is continuous-flow and is built onto the PCB utilizing commercial photopatternable polyimide layers. The chip performs 30-cycle PCR on the uPCR module, after which the product is led for detection in a well, where a Si-based biosensor array is placed, forming a 300 um deep chamber. The sample flow is driven by an external micropump, while the microheaters are temperature-controlled. Tests are planned for the on-chip amplification and detection of mutations of the KRAS gene, responsible for colon cancer.

8765-21, Session 6

A passive microfluidic fragmentation system for continuous fluid-particles separation

Antoine Viana, Julien Marchalot, Yves Fouillet, Lucas Digianantonio, Myriam Cubizolles, CEA-LETI (France); Jean-Luc Achard, Lab. des Ecoulements Géophysiques et Industriels (France)

We present herein a microfluidic system based on passive effects for continuously separate a diphasic fluid-particles flow.

In a previous work, a design based on the red cells lateral migration effect [1] and the resulting cell-free layer locally expanded by geometric singularities was developed, and led to an autonomous technology for blood fragmentation [2]. The system could advantageously replace the standard blood centrifugation process which can only be performed into dedicated laboratories. First implemented into a 2 cm x 4 cm sized PDMS chip, the design was later optimized, leading to blood fragmentation with plasma extraction yields of 24 % for a 1:20 blood injected up to 400µL/min [3].

We are now extending the scope of the device to a more general separation tool, providing a new method for concentrating – or removing - analytes from an input solution. Validation and measurements were performed with various objects, such as fluorescent beads, yeasts, spores or bacteria. Our measurements show that our continuous separation technics give excellent yields for any particle greater than 5 µm.

This technology can be implemented as a SamplePrep system, first step of an on-site analysis protocol. Its concentrating feature can be used to isolate rare analytes prior to further analysis, possibly into a lab-on-chip device. Its ability to operate passively, on several kinds of objects – organic or inorganic – opens the way to environmental applications, such as water cleaning or analysis. In addition, its low-cost and reliable manufacturing, compact size, low weight and ease of use design make this technology a possible support for the deployment of health policies in developing countries.

8766-1, Session 1

Nanotechnology for advanced photonic materials and structures *(Invited Paper)*

Robert W. Boyd, Univ. of Ottawa (Canada)

In this talk, we review the use of fabrication and diagnostic methods created within the context of nanotechnology for the development of new structure and devices of importance to the field of photonics. We find that these nanotechnology methods are useful at a wide variety of circumstances. For instance, nanotechnology methods can be used to create materials that show enhanced nonlinear optical response. Such enhanced response can occur in metamaterials, in nanocomposite materials, and in materials possessing a structuring of the surface morphology. Under many circumstances, this enhancement can be understood as resulting from a consequence of local field effects. Special capabilities are enabled by the use of metal-dielectric composite materials. In this case, the nonlinear optical response can be further increased by means of surface plasmon resonances that occur at the interface between the metallic and dielectric component. Especially interesting is the case of a semicontinuous metal film, which show enhanced nonlinear optical response and in addition properties that are in some ways intermediate between those of metal and of dielectics. Another photonic system of considerable interest are those based on the fabrication of photonics crystals. We will review especially the properties of cavities and line defect waveguides in a two-dimensional photonic crystal. Line-defect waveguides possess strong ability to create large dispersion in the refractive index, leading to significant modification of the group velocity or light with important implications for photonic technology. Lastly, we will describe how structured surfaces can lead to large nonlinear effects and large modification of the polarization of light for applications such as environmental sensing.

8766-2, Session 1

Plasmonic nanorod metamaterials *(Invited Paper)*

Wayne Dickson, Gregory A. Wurtz, Anatoly V. Zayats, King's College London (United Kingdom)

Guiding and manipulating light on length scales below the diffraction limit requires structural elements with dimensions much smaller than the wavelength. Recently, novel plasmonic metamaterial has been developed based on arrays of aligned gold nanorods grown in self-assembled anodic aluminium oxide templates. This metamaterial provides a flexible platform with tuneable resonant optical properties across the visible and telecom spectral range, that can be specifically designed by changing the length, diameter and separation between the nanorods. Such metamaterials, with a controllable and engineered plasmonic response, can be used instead of conventional plasmonic metals for designing plasmonic waveguides, plasmonic crystals, label-free bio- and chemo-sensors and for development nonlinear plasmonic structures with the enhanced nonlinearities. In this talk we will overview fundamentals and applications of plasmonic nanorod metamaterial for designing new types of nanoscale waveguides, biosensing platforms and nonlinear optical devices.

8766-3, Session 2

Photocathodes using surface plasmon resonance

Hidenori Mimura, Chung-Han Chen, Yoichiro Neo, Takahiro Matsumoto, Shizuoka Univ. (Japan)

Electron sources generating ultra fast pulsed electron beam are strongly desired for vacuum tube amplifiers or generators in tera-hertz (THz) frequency. A metal photocathode excited by laser is a promising candidate for generating ultra fast pulsed electron beam. However, the quantum efficiency is extremely low, the orders of 10-4. This is because reflectance at the metal surface is relatively high and electrons excited inside the metal by laser light suffers electron-electron scattering before escaping into vacuum. To overcome such problems, we have fabricated a photocathode using surface plasmon resonance. The photocathode consists of a quartz right triangular prism and an Al thin film. Incident laser generates an evanescent wave on the surface of the Al film deposited on the prism and the evanescent wave excites surface plasmon resonance in the metal film. The surface plasmon resonance reduces light reflection to zero because all incident photons are absorbed by surface plasmon at the resonance angle. Consequently, all the incident photon energy is transferred to surface plasmon. The electrons excited in surface plasmon do not need to travel inside the metal before escaping into vacuum, because the evanescent wave couples with surface plasmon just at the interface between vacuum and the metal film. The dependence of the reflectance on the incident angle of laser is well explained by considering Al2O3 layer on the Al thin film. Maximum photoemission is not observed at the angle of plasmon resonance, but observed at the angle where maximum field enhancement occurs. In the presentation, I will show emission characteristics of the photocathode using plasmon resonance and the photoemission mechanism.

8766-4, Session 2

Analysis of resolution limit in plasmonic lithography and high-density line patterning for practical applications beyond 2x nm half pitch

Jae W. Hahn, Yonsei Univ. (Korea, Republic of)

Plasmonic lithography is based on the surface plasmon polariton which greatly enhances the transmission of light through a metallic bowtie aperture to create a bright nano-size light spot. We have studied a theoretical model to analyze the ultimate resolution of plasmonic lithography using a bowtie ridge aperture in a metal film. The theoretical analysis predicts that the resolution of plasmonic lithography strongly depends on the ridge gap, achieving values under 1x nm with a ridge gap smaller than 10 nm. A micrometer-scale circular contact probe is fabricated for high speed patterning with high positioning accuracy, which can be extended to a high-density probe array. The positioning accuracy of the circular probe was less than 3 nm, which is reasonably small for the stitching and overlay of patterns in plasmonic lithography. To record the high density line array patterns, we reduce the grain size and the LER to ≈ 17 nm from 29 nm using a well-controlled developing process with a smaller molecular weight KOH-based developer at a temperature below 10°C. Finally, we recorded high-density line patterns with a half pitch up to 22 nm using a plasmonic direct writing system that use the contact probe and it was found that the theoretical model fits well with the experimental results of the maximum pattern depth for various half pitches. By recording high density line array patterns with the circular contact probe, we demonstrated remarkable progress toward the practical realization of plasmonic lithography using a high density array of contact optical probes for high throughput. Further work for parallel patterning with plasmonic lithography using the array probe should progress in the near future.

8766-5, Session 3

Dense chains of stacked quantum dots in Ge/Si heterostructures *(Invited Paper)*

Vladimir A. Yuryev, Larisa V. Arapkina, Mikhail S. Storozhevikh, Oleg V. Uvarov, Victor P. Kalinushkin, A. M. Prokhorov General Physics Institute (Russian Federation)

Growth and characterization of multilayer Ge/Si(001) heterostructures with dense arrays of Ge QDs and chains of stacked Ge clusters is reported. Ge hut nucleation and growth at low temperatures on Ge/Si(001) WL is discussed on the basis of explorations by high resolution STM and in-situ RHEED. RHEED pattern evolution during

Ge deposition is investigated at low and high process temperatures. Different RHEED pattern dynamics for different growth modes is observed, which reflects the difference in Ge adatom condensation from 2D gas and surface migration, which control hut densities and nucleation rates. Atomic-level models of growing huts (pyramids and wedges) are proposed. Extension of growing huts along <110> axes is non-uniform regardless of the shape. Growing pyramids form asymmetrical and symmetrical shapes, symmetrical ones appearing after addition of every fourth monolayer. Only symmetrical configurations of pyramids composed by 2, 6, 10, etc. monolayers are supposed to be stable. This explains less stability of pyramids compared to wedges in low-temperature arrays. Nucleation of pyramids and wedges on WL patches from identical embryos composed by 8 dimers through formation of 1 monolayer high 16-dimer nuclei different in symmetry is discussed. HRTEM studies of multilayer Ge/Si heterostructures are presented with the focus on low-temperature formation of QD dense arrays with long chains of stacked Ge clusters. Driving forces of self ordering of Ge QDs in the molecule-like quantum chains are discussed. Si p–i–n-diodes with stacked Ge/Si(001) QD dense arrays in i-domains exhibit photo-emf in the spectral range from 0.8 to 5 μm. A significant increase in photo-emf is observed in the fundamental absorption range under the wide-band IR irradiation. This phenomenon is explained in terms of positive and neutral charge states of the QD layers and the Coulomb potential of the ensemble. A new photovoltaic QDIP is proposed.

8766-6, Session 3

Exciton lifetime measurements on single silicon quantum dots

Fatemeh Sangghaleh, Royal Institute of Technology (Sweden); Benjamin Bruhn, Torsten Schmidt, Electrum Lab. (Sweden); Jan Linnros, Royal Institute of Technology (Sweden)

Time-resolved measurements are performed on single silicon quantum dots, using an unconventional PL set up consisting of an image intensifier and charged-coupled CCD camera, which enables simultaneous data acquisition for a large number of individual quantum dots. The excitation source was a pulsed laser (405 nm) with the repetition rate of 5kHz and equal ON/OFF time duration of 100 μs.

The samples were fabricated by electron beam lithography (EBL) and reactive ion etching (RIE), as the initial steps to create matrices of undulating silicon nano-walls. Finally self-limiting oxidation led to the formation of individual nano-sized crystals on the upper part of the walls. The well-defined position of silicon quantum dots fabricated using this method enables single dot spectroscopy measurements.

Photoluminescence spectra of the same quantum dots are also measured at room temperature resulting in the expected emission peak position in the range of 1.55- 1.8 eV and FWHM at ~130 meV.

The photoluminescence intensity of individual nanocrystals decays mono-exponentially. The extracted lifetime values can differ significantly from dot to dot in the range between 5- 45 μs, even for the dots with the same emission energies. This reveals the influence of other parameters than only the dot size on the exciton recombination mechanism.

We demonstrate that the ensemble that can be built from our single quantum dots exhibits similar properties as other ensembles in the literature and that the stretched exponential shape of the ensemble lifetime simply results from a distribution of different individual lifetimes.

8766-7, Session 3

Semiconductor nanowire based devices for energy and sensor applications

Laurent Montès, Ronan Hinchet, Gustavo A. Ardila Rodriguez, Xin Xu, IMEP-LAHC (France); Alexis Potié, IMEP-LAHC (France) and LTM CNRS (France); Thierry Baron, LTM CNRS (France); Mireille Mouis, IMEP-LAHC (France)

We present new concepts, characterization techniques and prototypes of piezoresistive and piezoelectric devices based on semiconductor nanowires and heterostructured nanowires, with the objectives to be integrated in future IC devices for sensing and/or mechanical energy harvesting. We propose a specific method to investigate the electromechanical properties of nanodevices, based on an integrated ultrathin flexible membrane approach. This technique is used to apply very large strain in the devices (up to a few hundreds of GPa), and can also be used for dynamic studies. While in transistors and nanowires the change in mobility or resistance is very limited (a few %), the applied stress can drastically change the electrical properties of tunnel junction nanowires or heterostructured nanowires so that the current change could be in the order of a few decades, leading to ultra-sensitive strain or pressure sensors with large gauge factor, larger than 600. In a second approach, we have studied the electromechanical properties of different kinds of individual wurtzite semiconducting piezoelectric nanowires, such as ZnO and GaN, and GaN/AlN/GaN heterostructured nanowires. We present two original techniques based on an AFM set-up to study the electromechanical properties of such piezoelectric nanowires. In particular we show a large enhancement of the piezoelectric potential when using nanowires (mV) and even more drastically improved when considering heterostructured nanowires (hundreds of mV). First prototypes generating piezoelectric potential larger than 1V are also presented. Based on our results, analytical and numeric models, optimization of the nanowire based devices is also investigated and detailed, showing that piezoNEMS could be used as efficient sensing or energy harvesting devices.

8766-8, Session 3

Properties of individual GaP/ZnO core-shell nanowires with radial PN junction

Jozef Novak, Agata Laurencikova, Peter Elias, Stanislav Hasenohrl, Roman Stoklas, Institute of Electrical Engineering (Slovakia); Jaroslav Kovac, Ivan Novotny, Slovak Univ. of Technology (Slovakia)

Nanowires (NW) exhibit unique electrical and optical properties due to lowered dimensions and related confinement effects. An integration of these tiny objects necessitates better understanding of their individual intrinsic properties. Precise electrical characterization of NWs requests preparation of electrical nanocontacts with high stability, low contact resistance and ohmic behaviour. We applied a conventional field-effect transistor configuration that allows to estimate a type of conductivity and carrier mobility also. Structural properties of individual NWs were studied by means of SEM and TEM techniques.

The GaP nanowires under study were grown on the p-type GaP (111) B substrate by a VLS technique using 30 nm colloidal gold particles as seeds. A part of NWs was covered by a thin ZnO layer (10 – 140 nm) deposited by RF sputtering, To evaluate the electrical properties (type of conductivity and resistance) of the GaP NWs, they were cutted off from the substrate and deposited on the Si/SiO2 structure. Ohmic contacts to each separated nanowire were prepared by electron beam lithography (EBL) and lift off technique. We used four terminal contact morphology on the NW and Al gate contact on the backside of the Si substrate. This characterisation proved that GaP single NWs are p-type of conductivity and their resistance may be related to the Zn molar fraction in the gas phase. For characterisation of radial PN junction a part of ZnO shell was chemically removed and core and shell were contacted by EBL separately. This process consists of two steps: (i) the ZnO shell layer was removed from one NW end and an Au/Zn alloy was used to contact the GaP core, (ii) an Au/Al alloy was then used to make contact to the ZnO shell layer. The devices show a typical diode I-V characteristics and currents up to a few microamps in the forward direction.

8766-9, Session 3

Photoconductivity of catalyst-free grown aluminum nitride nanowires

Kasif Teker, Istanbul Sehir Univ. (Turkey) and Frostburg State Univ. (United States); Andrew Siemann, Frostburg State Univ. (United States)

One-dimensional aluminum nitride (AlN) nanowires are important not only for understanding fundamental concepts underlying the observed electronic, optical, and mechanical properties of materials, but also for the superior potential applications in many fields including power transistors, heat sinks, surface acoustic wave filters, resonators, sensors, piezoelectric nanogenerators, UV photodetectors, and light-emitting devices. Free-standing catalyst-free nanowire films provide great opportunities due to easy transfer of these high density nanostructures into any substrate for the development of new devices for many technological applications in flexible optoelectronics and piezoelectric electricity generators.

This paper presents a systematic investigation of catalyst-free AlN nanowire synthesis by chemical vapor deposition using Al and NH3, as source materials; and photoconductivity of the AlN nanowires. The growth runs have been carried out at 1100oC under H2 as carrier gas for about two hours. The growth runs have resulted in very high quality and dense AlN nanostructures. In addition, nanowire FET devices have been fabricated. A unique annealing scheme has been implemented to improve contacts between nanowires and gold electrodes, which resulted in very consistent electrical measurements. Photoconductivity studies of the AlN nanowires have been conducted at various light sources with wavelengths of 254 nm, 365 nm, 532 nm and 633 nm using a semiconductor parameter analyzer. Significant positive photocurrent responses have been measured under different photon energy excitations. Furthermore, photocurrent decay has been very rapid after the illumination ended. These studies will provide crucial information and insights for the development of UV optoelectronic devices and light sensors. The grown nanowires and devices have been characterized by SEM, XRD, TEM, FTIR, and semiconductor parameter analyzer.

8766-10, Session 4

Graphene nanoelectronics for high frequency applications

Mircea Dragoman, National Institute for Research and Development in Microtechnologies-IMT Bucharest (Romania)

The graphene is an interesting material for high frequency applications. Graphene high mobility is exceeding 10000 cm2/Vs and ballistic transport over 400 nm at room temperature are the basic ingredients for high frequency devices with cutoff frequencies exceeding 50-100 GHz. The paper will focus on metallic coplanar waveguides (CPW) on graphene and its applications as a matching circuit working up to 110 GHz , a graphene radio and a Schottky diode acting as a phase shifter. Graphene transistors are the key devices researched now. We will show that the cutoff frequency of these transistors are overestimated and a more realistic model must be taken into account due to the fact that in metals the electrons obey Schrodinger equation while in graphene we have chiral charged carriers. This distinction between different carriers in graphene and metals is also reflected in the relative high contact resistance of graphene transistor irrespective of the metal.

Other route to alleviate the graphene device limitations is to use other single and few-layer atomic thick materials. Although the progress done in silicene, MoSe2 the performances of the devices based on them are well below of similar devices based on graphene. We will show in our paper that we can have a graphene-like transistor considering a 1-2 nm metallic film deposited on graphene. We will report the fabrication at the wafer level of a FETs consisting of an ultrathin Ni layer, with a thickness of only 2 nm, deposited on a p-Si(111). The surface states of the Ni film localize charge carriers, and thus is acting as a dielectric gate and induce the creation of a quantum well in the Si inversion layer with a drastically reduced effective mass of charge carriers in Si comparable to graphene. The dependence of the drain current on the drain voltage has no saturation region being similar to a field effect transistor based on graphene. The drain current is 2 mA at a drain voltage of 3 V and a gate voltage of 1.07 V, while the transconductance is 0.6 mS for a drain voltage of 6 V and a gate voltage of 1 V. This FET is a graphene-like transistor with unipolar transport of carriers.

8766-11, Session 4

Aerographite: mechanical, electrical and optical properties of a cellular carbon nanomaterial with densities below 0.2 mg/ccm

Arnim Schuchardt, Christian-Albrechts-Univ. zu Kiel (Germany); Matthias Mecklenburg, Technische Univ. Hamburg-Harburg (Germany); Yogendra Kumar Mishra, Sören Kaps, Rainer Adelung, Christian-Albrechts-Univ. zu Kiel (Germany); Karl Schulte, Technische Univ. Hamburg-Harburg (Germany)

The recent progress in the synthesis of cellular carbon materials indicates its importance for functional applications like electrodes in batteries or supercapacitors. Aerographite is a cellular carbon nanomaterial which consists out of hollow tubes (diameter 2 to 5 µm) from graphitic carbon. This novel structure possesses a super low densities down to 0.2 mg/ccm. The synthesis of this material is based on a three dimensional sacrificial ZnO template which shape is adopted during a modified CVD synthesis. Since its development and the first characterisation of this new carbon material, it has been elaborated in more detail. Based on various SEM and TEM results of semi converted samples the growth model of Aerographite was further developed and will be discussed. In addition to this, more experiments with one and two dimensional templates where performed and the results will be presented. Cyclic mechanical measurements and insitu electrical characterisation will be shown and discussed. It will be reported about optical properties and related functional applications like optical coatings made from Aerographite. Due to the high surface to volume ratio, the potential of gas sensing and the integration in MEMS devices will be sketched. The potential application of Aerographite as battery or supercapacitor electrode materials will be elaborated in more detail. Related to this, first experiments of a Lithium test battery, equipped with Aerographite electrodes will be presented.

8766-12, Session 4

Humidity sensing of an epoxy/MWCNT composite by electrical conductivity measurements

Heinz C. Neitzert, Univ. degli Studi di Salerno (Italy); Andrea Sorrentino, Consiglio Nazionale delle Ricerche (Italy); Luigi Vertuccio, Univ. degli Studi di Salerno (Italy)

An epoxy/CNT composite material with a low concentration of multiwall carbon nanotubes in a diglycidil-ether bisphenol-A based epoxy matrix has been shown to be applicable, when maintained at a constant temperature, as humidity sensing element. An almost linear decrease of the electrical conductivity with increase of the sample humidity has been measured. Evaporated gold contacts exhibited a perfect ohmic behaviour and an excellent long-term stability, even after more than one year immersion of the sample into distilled water.

The maximum percentage weight gain for specimens hold at 68 and 100% of relative humidity for 200day is 2.5 and 4%, respectively. The water uptake process for all specimens is linear in the beginning, then slows and approaches saturation after prolonged time, following a Fickian diffusion process.

8766-13, Session 4

Amorphous silicon-graphene anodes for lithium ion batteries

Filippos Farmakis, Demokritos Univ. of Thrace (Greece); Kostas Alexandrou, Columbia Univ. (United States); Costas Elmasides, Systems Sunlight S.A. (Greece); Ioannis Kymissis, Columbia Univ. (United States); Nikolaos Georgoulas, Demokritos Univ. of Thrace (Greece)

It is well known that for applications such as Electric Vehicles (EV), new batteries with high capacity and extended lifetime at elevated temperatures and high charging rates are needed. Towards this direction, silicon is probably the most promising material for the next generation of Li-ion batteries due to its low discharge potential and to its extremely high capacity in Lithium. However, the intercalation of the lithium atoms within the silicon material provokes a high increase of its volume (up to 300%), that progressively leads to the pulverization of the layer resulting in poor cycling and high irreversible capacity loss. To improve the number of cycles, several routes have been proposed that allow the silicon to be able to expand in all direction (nanostructures) and/or to enhance its adhesion with the substrate (usually copper foil).

In this work, DC sputtered amorphous silicon thin films were grown on top of single layer graphene. The graphene was deposited by Chemical Vapor Deposition (CVD) on 25-μm thick copper foil. The resulted graphene-coated copper foil was introduced in the DC sputtering chamber, where amorphous hydrogenated silicon a-Si:H thin film was grown at various temperatures (from room temperature to 100 °C). A Swagelok cell with electrode area of 1.13 cm2, with lithium as counter and reference electrodes, was assembled to test the capacity of the electrode. LP30 electrolyte from Merck was used.

Cyclic electrical measurements at half cell level were conducted at various charging and discharging rates at room temperature. From those measurements, the addition of the single layer graphene as well as the parameters of the a-Si:H layer were investigated and correlated with the capacity, the number of cycles and the Coulombic efficiency of the lithium ion half cell.

8766-14, Session 5

A new application of bionanoparticles as drug delivery in breast cancer

Neda Esfandiari, Technical Univ. of Denmark (Denmark) and Univ. of Tehran (Iran, Islamic Republic of); Mohsen Karimi, Karolinska Univ. (Sweden); Mina Kohi Habibi, Univ. of Tehran (Iran, Islamic Republic of); Masoud Solimani, Tarbiat Modares Univ. (Iran, Islamic Republic of); Winnie E. Svendsen, Technical Univ. of Denmark (Denmark)

Breast cancer is the most common cancer in women worldwide. Every year 1.5 million new cases of breast cancer are diagnosed. Recently, targeted therapy by Herceptin monoclonal antibody (Tratuzumab) has been approved to treat Human Epidermal growth factor Receptor 2 positive (HER2+) tumors. Based on worldwide reports around 25% of breast cancer tumors are HER2+ and should be treated with Herceptin. The main obstacle in Herceptin treatment is high cost of the treatment.

In this study the main object is the conjugation of Herceptin to potato X virus particles through Carbodiimides chemical cross-linkers, resulting to Herceptin coated viral nano particles(VNP). It is expected that Herceptin coated nano-particles would have enhanced efficiency and stability in comparison to commercial Herceptin.

PVX virus particles were purified from infected nicotian test plans using standard protocols. Herceptin was conjugated to PVX particles using chemical linker, EDC and NHS. Conjugation of Herceptin and PVX was confirmed by TEM, DLS, ELISA and western blotting with PVX antibody(DSMZ, PV-0027) and goat anti human antibody (abcam), In the next step the efficiency and stability of Herceptin nano-particles will be evaluated in breast cancer cell culture and compared to commercial Herceptin.

The results of this study reduce the dose of Herceptin and cost of treatment in breast cancer patients.

8766-16, Session 5

Laser irradiation of biofunctional magnetic nanoparticles in aqueous solution

Alexander I. Omelchenko, Emil N. Sobol, Institute on Laser and Information Technologies (Russian Federation); Svetlana S. Pavlova, Ugric State Univ. (Russian Federation)

In spite of a tremendous progress of nanoparticles applications for drug delivery in human body the problem of stability of nanoparticals stays unsolved. Solution of this problem for nanoparticles transport in low permeable cartilaginous tissues, thin capillary network and cell plasma membranes is vary important for nanomedicine. Essence of the problem consist in the nanoparticles, to be infused in the body, begin interact with each others and with interstitial water and matrix, as well. It's often resulted in coagulation of the particles and its agglomeration. The reason of large scale agglomeration of nanoparticles relates to the nature of particles interaction, which takes place at the low distance (1-100 nm) between the particles.

Aim of this study is to enhance stability of aqueous dispersion of biofunctional nanoparticles of iron oxide used for laser engineering of cartilaginous tissue. Laser irradiation of iron oxides nanoparticles in starch aqueous solution is performed to obtain stable biofunctional nanoparticles. Optical properties of aqueous solution of these nanoparticles are investigated by static light scattering technique. Total absorption spectra of water solution of Fe3O4 –nanoparticles (magnetite) have been measured. It's revealed agglomeration of nanoparticles of magnetite in the intact solution. By means of magnetic trap with axis-symmetric field, the nanoparticles with the size of 5-10 nm have been separated from their large scale agglomerates. It was shown that ultrasound fragmentation and demagnetizing of the solution in the damped magnetic field do not allow obtaining stabile colloid without agglomeration. Laser treatment of nanoparticles of magnetite in starch aqueous solution makes stability of this colloid without agglomeration and sedimentation. Different mechanisms of this stabilization of colloid after laser irradiation of magnetite in starch are discussed.

8766-17, Session 5

Complexation of porphyrins with silver nanoparticles

Anna Gyulkhandanyan, Institute of Biochemistry (Armenia); Robert K. Ghazaryan, Yerevan State Medical Univ. (Armenia); Vardan Gasparyan, Marina Paronyan, Grigor V. Gyulkhandanyan, Institute of Biochemistry (Armenia)

It is known that nanoparticles of colloidal silver due to the porosity have an extremely large specific surface, which is an order of magnitude increases their sorption capacity. Previously we synthesized a set of water-soluble cationic porphyrins (PSs) that had high level of photodynamic inactivation of microorganisms: 2-3 ug/ml. The aim of this work was to study of processes sorption/ desorption of porphyrins on nanoparticles of silver, as well as the prospects of binary action of such nanocomposites (photothermal and photodynamic). This effect occurs when illuminated with light of nanocomposites: a) due to the plasmonic resonance and the strong heating of nanoparticles in the places of their location and lethal damage of structures of microorganisms, and b) due to a photodynamic effect of porphyrins, leading to the formation in organisms of destructive reactive oxygen species and in the first of singlet oxygen.

The interaction of cationic porphyrins with silver nanoparticles of 20 nm diameter was studied in the visible spectrum, in the range 350-800 nm. Investigation of sorption dynamics of porphyrins in the silver nanoparticles using two porphyrins: a) meso-tetra (4-N-butyl pyridyl) porphyrin (TBut4PyP), b) Ag-TBut4PyP, as well as of photosensitizer Al-phthalocyanine was carried out. Analysis of the dynamics of change in the absorption spectra for porphyrins TBut4PyP and Ag-TBut4PyP by adding nanoparticles leads to the conclusion that the binding of porphyrins occurs very quickly - less than 3 minutes (the percentage of adsorption on nanoparticles is 60,7 ± 3,0% and 55,6 ± 2,1%, respectively). The stable state of absorption intensity remained at 12 and 24 hours of observations of the spectra of porphyrins.

It was shown that the bimodal approach of destruction of microorganisms greatly enhances photodynamic inactivation of microorganisms and is the most promising method for the destruction of both Gram (+), and Gram (-) microorganisms.

8766-25, Session 5

Effects of morphology on the emission of photons from GaN membranes fabricated by using surface charge lithography

Marion A. Stevens-Kalceff, The Univ. of New South Wales (Australia); Ion M. Tiginyanu, Institute of Electronic Engineering and Nanotechnologies (Moldova) and Academy of Sciences of Moldova (Moldova); Veaceslav Popa, Technical Univ. of Moldova (Moldova); Patrice Brenner, Fachhochschule Karlsruhe Technik und Wirtschaft (Germany); Dagmar Gerthsen, Karlsruher Univ. (Germany)

Cathodoluminescence (CL) microanalysis has been used to investigate ultra-thin suspended GaN membranes fabricated by focused ion beam (FIB) pre-treatment of GaN epilayer surfaces with subsequent photoelectrochemical (PEC) etching. CL enables high sensitivity detection and identification of microstructural defects including trace levels of impurities and native defects (e.g. dislocations, vacancies, self-interstitials, etc), at nanoscale spatial resolution. The analysis of the spectral and spatial distribution of the emitted photons from GaN nanomembranes gives insight into the technologically important physical properties which are strongly influenced by microstructural defects associated with dopants and native defects. CL emission is associated with key features of the GaN nano-membranes including the suspended nano-membranes, the etch-resistant ion beam implantation support structures, etch-resistant dislocation-related whiskers and the underlying regions of etched GaN. Monochromatic CL images show that suspended nano-membranes emit 3.4 eV photons which at 295 K are associated with free exciton transitions, and 2.25 eV photons which are possibly associated defects related to implantation induced deep acceptor states. In contrast, CL is quenched from the etch-resistant ion beam implantation support structures. Dislocation-related whiskers emit mainly a broad yellow luminescence (YL) at ~2.25 eV. The CL emission from underlying etched GaN is dominated by the ~3.4 eV GaN near band edge emission. CL spectroscopy enables the optical quality of the suspended GaN nano-membranes to be assessed. Blue shift of the CL near band edge emission at ~3.4 eV indicates that the suspended GaN nanomembranes may exhibit the combined effects of quantum confinement and compressive strain. Knowledge of the defect microstructure of nanoscale GaN nanomembranes is essential to optimize device design and performance, and facilitate the development of MEMS/NEMS and optoelectronic applications related to the piezoelectric and optical properties of nanoscale GaN.

8766-23, Poster Session Thursday

Creation of entangled photons by two level atom trapped in one-dimensional nanocavity with weakly decaying resonance mode

Vladislav Cheltsov, Moscow State Mining Univ. (Russian Federation)

The fundamentals of the entangled photons' emission by model system- "two level motionless atom trapped in high-finesse one-dimensional nanocavity with a single linearly polarized weakly decaying resonance mode" are outlined. Photon's leakage out of the empty cavity through partially transparent mirror was accepted take place by exponential law at the rate Γ =0.2g, where g is coupling constant. The pictures of process have been obtained computationally, using Maple 7"-program and set of quantum amplitudes of interacting system for Γ << g. We have found that source of entangled photons at the outlet of nanocavity is disintegration of interference emission, ejected out of the cavity on resonance frequency ωa. In our earlier publications we predicted in this case existence of three quantum states, one of them being central interference component. The fact is that fields of atomic dipole and mode produce a pair of cooperative eigenstates with (ωa ± g)-eigenvalies,where the eigenstate with energy (ωa+g) is given by sum of unperturbed atomic states, the second one by their difference. For $\Gamma\approx$ 0 radiative transitions from those states go only to upper atomic state, with simultaneous emission of two antiphrasis photons. The latter interfere with the atomic amplitude, forming running carring wave on resonance frequency ωa, with its amplitude modulated by sin(g t). When maximums of beatings pass with relative probability Γ/4g through the partly transparent mirror, the field construction falls to two antiphrasis (ωa ± g)-photons, each of them taking its own spectral place outside the cavity. The profiles of (ωa ± g)-components have identical form exp(- t Γ)t Γ, with average lifetime in the cavity being estimated as 4ln Γ/Γ.

8766-26, Poster Session Thursday

Calculation of nanoparticle surface shape instability development

Tamara Pogosyan, Sergey A. Chivilikhin, National Research Univ. of Information Technologies, Mechanics and Optics (Russian Federation)

The aim of this work is the theoretical investigation of instability development of the nanoparticle surface shape during diffuse growth. The unperturbed surface is considered as an ideal sphere. The mass diffusive stream promotes increase of the sphere volume and development of free surface perturbations.

The relaxation of these perturbations due to action of capillary forces is also considered along with development of small perturbations of a free surface at the expense of perturbation of a mass diffusive stream. We use the effective coefficient of viscosity μ and surface tension coefficient σ of nanoparticle to describe a surface shape relaxation.

For the description of a mass stream to a free surface we solved the quasi steady-state diffusion equation where concentration is a solution of the Laplace's equation in spherical coordinates. We take into consideration only axisymmetric perturbations.

Action of capillary forces is taken from [1]. Perturbation of surface is expanded in series of Legendre polynomials. The coefficients of expansion change over time under the law:

bn = bn(0)*exp(γ(n)*t),

γ(n) = (1/R)*[V*(n+1) – (σ*n*(n+2)*(2n+1))/(2μ*(2*(n^2)+4n+3))] ,

where V is the unperturbed velocity of sphere radius increasing, n is index, R is radius of sphere.

There is an area of indexes n at certain ratios between parameters of system where γ(n) > 0, this means that loss of stability of a nanoparticle surface happens. For large values of indexes n, γ(n) = (V – σ/2μ). If V > σ/2μ, coefficients correspond to unstable harmonics and speed of instability development increases with index growth. That corresponds to formation of fractal structure of a surface.

We revealed various modes at which the surface of nanoparticle loses the stability and investigated dynamics of instability development of surface.

Reference

[1] Hrma, P. and Carter, C.E., "Capillarity-induced spheroidization of nearly spherical amorphous bodies by viscous flow", Journal of Non-Crystalline Solids 63, 391-412 (1984).

8766-27, Poster Session Thursday

Power generation in microbial fuel cell with simultaneous metal sulfide nanoparticles formation by sulfur-reducing bacteria

Oresta M. Vasyliv, Oleksandr I. Bilyi, Yaroslav P. Ferensovych, Svitlana O. Hnatush, Ivan Franko National Univ. of L'viv (Ukraine)

Microbial fuel cells (MFCs) are devices that use bacteria as the catalysts to oxidize organic and inorganic matter and generate electric energy. Desulfuromonas acetoxidans are colorless strictly anaerobic sulfurbacteria that support reductive stage of sulfur cycle in the nature. D. acetoxidans are proposed to be used as a biocatalyst for MFC because of high electron recovery (>80%) to the electric current as a result of electron transfer during the processes of organic matter oxidation, such as acetate, and S0, Fe3+- or

Mn4+-reduction with respectively H2S, Fe2O3, FeCO3, or MnCO3 production. Interaction between bioproduced hydrogen sulfide as a final product of bacterial dissimilative sulfur-reduction and various metals, which are used as exogenous electron mediators in MFC, can serve as a new inexpensive, simple and highly efficient method of metal sulfide nanoparticles bioformation with simultaneous electricity generation. Bioproduced nano-sulfides possess a potential of their further application as catalysts for coal liquefaction, solid lubricants, rechargeable batteries, solar cell devices, coatings for microwave shields etc. Electricity generation and ferrous sulfide nanoparticles formation were observed under D. acetoxidans bacteria cultivation during eight days in constructed microbial fuel cell with separate addition of such Carbon sources, as acetate, lactate and fumarate (3 g/l), 0.45 mM of FeCl3, and 10 g/l of Sulfur into their growth medium. The maximal obtained power in MFC equaled respectively 18 μW with application of acetate, 36 μW under addition of fumarate and 56 μW with usage of lactate as the sole Carbon source by investigated bacteria. FeS nanoparticles formation was observed in the anode chamber of constructed microbial fuel cell during the whole investigated period of D. acetoxidans growth under these cultivation conditions. It was determined that lactate is the most preferable Carbon source for investigated bacteria in terms of electricity generation in constructed MFC in the presence of ferric ions.

8766-28, Poster Session Thursday

Optical properties of silver nanoparticles coated by cyanine dyes molecular overlayers

Nikita A. Toropov, Anton A. Starovoytov, Viktor V. Zakharov, Nikita B. Leonov, Elena N. Kaliteevskaya, Tigran A. Vartanyan, National Research Univ. of Information Technologies, Mechanics and Optics (Russian Federation)

Optical properties of supported silver nanoparticles coated by cyanine dyes molecular overlayers were investigated. Silver nanoparticles were prepared by vacuum evaporation on a sapphire substrate. Cyanine dye molecules were spread over the silver nanoparticle arrays by spin-coating technique. The samples were characterized by scanning electron microscopy and optical spectroscopy. Significant enhancements of the dye absorption, fluorescence and photoinduced transformation as well as the shifts of the resonance positions of plasmon resonances were observed.

The extinction spectrum of the hybrid material was rationalized as a result of mutual interactions between the plasmon oscillations localized in the metal nanoparticles and resonance absorption and refraction of dye molecules. Plasmon resonances are shifted due to the anomalous refraction of dye molecules. Depending on the spectral position of the dye absorption band relative to the inhomogeneously broadened plasmon band this shift may lead to considerable clarification of the sample at particular wavelengths that was observed experimentally.

On the other hand, the absorption of dye molecules is enhanced due to the incident field amplification in the near field of metal nanoparticles. Even when the dye absorption band overlaps with the tail of the plasmon band of silver nanoparticles, 3 to 5 times enhancement of the dye absorption was obtained.

Besides that a nearly 4-fold increase of cyanine dyes fluorescence intensity in the presence of metal nanoparticles was observed.

Finally, the photoinduced transformations of the dye molecules situated in the near field of the metal nanoparticles were studied. The rate of the transformations was found to increase.

8766-30, Poster Session Thursday

Simulation of size distribution function's evolution in colloidal solutions of zinc oxide nanoparticles

Anton V. Alfimov, Elizabeth M. Aryslanova, Sergey A. Chivilikhin, National Research Univ. of Information Technologies, Mechanics and Optics (Russian Federation)

There are a large number of studies on the physical and chemical properties, methods of synthesis of nanoparticles to the date. However, the description of the transport processes, coagulation, and relaxation of nanoparticles in liquids and gases is an urgent task of modern science.

The presented work is a theoretical study of the coagulation process of spherical zinc oxide nanoparticles suspended in water, synthesized using the hydrothermal method. The typical particle size is 40-100 nm.

A mathematical model is created using the modified DLVO theory to describe the interaction forces between nanoparticles and method of the fluctuation-dissipation Langevin dynamics to simulate the coagulation process. The effects of system parameters' variation (initial concentration and particle size) on the character of particle size distribution's evolution are studied.

For systems under consideration it was possible to find an analytical expression for the interaction force between nanoparticles in a carrier environment, taking into account the following effects: the long-range repulsive force due to the overlap of nanoparticles' shells forming in the water – weak electrolyte; the short-range forces of attraction and repulsion due to Van der Waals interaction.

The resulting expression for the interaction force was used in the numerical simulations of the nanoparticle coagulation by means of the fluctuation-dissipation Langevin dynamics.

The described model was used to perform a number of numerical experiments. The character of the dependences obtained in the limits of applicability of the model corresponds well to the experimentally determined curves for similar systems.

8766-31, Poster Session Thursday

Bacterial reduction of silver nitrate as the potential mechanism for silver nanoparticles forming

Olga D. Maslovska, Oleksandr I. Bilyi, Vasyl B. Getman, Svitlana Hnatysh, Ivan Franko National Univ. of L'viv (Ukraine)

The antibacterial activity of silver has been known for centuries. Numerous approaches for silver nanoparticles forming are developed. Desulfuromonas acetoxidans are uncoloured sulfur bacteria that inhabit sulfur-containing aquatic environments. These are gram-negative obligative anaerobes that are able to conserve energy to support growth by coupling the complete oxidation of organic compounds to the reduction of Fe(III). D. acetoxidans can probably also reduce Ag(I) to Ag(0). Dissimilatory reduction of Ag(I) to Ag(0) is a potential mechanism of metal nanoparticles forming. The aim of this work was the investigation of influence of different concentrations of silver nitrate and silver nanoparticles on growth of D. acetoxidans and principles of forming Ag nanoparticles by D. acetoxidans in process of their growth under different concentrations of silver nitrate. For investigation of influence of silver nitrate and silver nanoparticles on growth of D. acetoxidans, bacterial cells were growth on modified Postgait C medium with fumarate addition as carbon source, without sulfur and on modified Postgait C medium with sodium lactate as carbon source with addition sulfur at 28 0C under anaerobic conditions during 4 days cultivation. The first step of investigation was to select concentration ranges of AgNO3 and Ag nanoparticles for investigations. The dose-dependent decrease of biomass was observed under the influence of silver nitrate in the medium. Under the influence of AgNO3 the highest biomass was obtained with addition of 2 μM metal salt in the growth medium. Addition of 10 μM of AgNO3 caused the decrease of biomass accumulation by 35% in comparison with samples without addition metal salt. Concentration range of AgNO3 from 2 to 10 μM was used for investigation of Ag nanoparticles forming during D. acetoxidans growth. Measurement of D. acetoxidans growth and Ag nanoparticles forming by investigated bacteria was based on cells and silver nanoparticles light scattering particularities changes.

8766-32, Poster Session Thursday

Modelling the initial stage of porous alumina growth during anodization

Elizabeth M. Aryslanova, Anton V. Alfimov, Sergey A. Chivilikhin, National Research Univ. of Information Technologies, Mechanics and Optics (Russian Federation)

Aluminum has a great tendency to oxidation. Artificially on the surface may build a thick layer of Al2O3, which has a porous structure. Electrochemical oxidation is a process of formation of oxide film on the metal surface, placed as an anode in an electrolyte. The benefits of anodizing include shortness of process, high firmness and heat-resistant material, good adhesion to the surface of aluminum, electrical insulation, etc. Anodizing aluminum in hydrogen sulfate can occur using direct and alternating current. When an alternating current the film grows slower and is more friable.

In the anodizing process, aqueous solutions of acids (oxalic acid, phosphoric acid, chromium, etc.) moderately dissolve oxide Al2O3. The process is carried out in a vessel with the electrolyte, which houses the anode (aluminum) and a cathode (inert conductive material), which are respectively connected to the positive and negative power supply output. Thus on the metal film is formed, the top layer of which is a microporous partially hydrated metal oxide, under which is the lower layer - anhydrous microscopically thin glassy oxide film has considerable hardness.

Currently, there are various models of the growth of a porous film of aluminum oxide, but not the models that take into account the effect of the electrolyte layers of aluminum and the growth rate of aluminum oxide, as well as in the models described not influence the effect of surface diffusion. This paper presents a model that accounts for these effects.

As a result of the created model equations were found for changes in the disturbance of alumina for the initial stage of anodizing aluminum oxide porous border aluminum-alumina and alumina-electrolyte, with the influence of surface diffusion of aluminum oxide.

8766-33, Poster Session Thursday

Implementation of all-optical logic gate by adiabatic population transfer

Emil A. Gazazyan, Gayane Grigoryan, Vigen O. Chaltykyan, Olesya Tikhova, Institute for Physical Research (Armenia)

A universal reversible Toffoli logic gate was first introduced in 1980. It was shown that any reversible processor can be constructed using only circuits of this gate. Due to its universality the Toffoli gate is important not only in the classical Boolean functions, but also in a quantum computer.

In this paper we demonstrate a simple realization of all optical four-bit Toffoli gate in a resonant medium consisting of five-level atoms. The proposed scheme is based on the cyclic adiabatic population transfer resembling the techniques of STIRAP and b- STIRAP in Λ-type atoms. The latter are rather well studied both theoretically and experimentally not only for individual atoms, but also in media and have already successfully been used for designing a three-bit optical adder in the experiment. In the present work we also examine in detail the generalization of these population-transfer methods for five-level diagrams in order to construct a four-bit universal logic operator. The main advantage of such an operator as compared with the three-bit one is that the number of inputs and outputs is a multiple of two. We show that under certain conditions and sequence of turning on and off the laser pulses a five-level system may be reduced to an effective Λ-diagram.

8766-34, Poster Session Thursday

Gold nanoparticles embedded in organic/inorganic hybrid matrix: electrical and electrochemical behavior

Sandra Moreira, Carlos Silva, Maria de Jesus Gomes de Matos Gomes, Manuel Filipe Costa, Univ. do Minho (Portugal)

Gold nanoparticles (AuNPs) with different diameters, from 3 to 32 nm, were immobilized in amine-alcohol-silicate matrix by mixing a preformed nanoparticle colloid with the precursors of amine-alcohol-silicate (AAs) prior to the sol-gel transition. These nanocomposites show high optical quality and optical features dictated by the size of the nanoparticle dopants but also present a high degree of flexibility which can largely enhance the range of practical applications.

The current–voltage, impedance and capacitance–voltage characteristics of these materials have been measured.

The electrochemical and impedimetric results reveal that AuNPs with different sizes give different signals, thus providing useful information that allows the employment of AuNPs in electrochemical biosensors.

Capacitance–voltage measurements showed that these composites embedded AuNPs exhibited a large hysteresis window of 2.4V which indicates the possibility of charge storage in the Au nanoparticles embedded AAs hybrids.

8766-19, Session 6

Line width roughness reduction strategies for low energy multibeam lithography

Julien Jussot, Univ. Joseph Fourier (France); Béatrice Icard, CEA-LETI (France); Erwine Pargon, LTM CNRS (France); Claire Sourd, CEA-LETI (France); Jessy Bustos, STMicroelectronics (France); Isabelle Servin, Laurent Pain, CEA-LETI (France)

With the increase of the semiconductor manufacturing costs linked to the introduction of multi-patterning and the delay of EUV take-off, massively parallel electron beams lithography (ML2) appears to be a credible alternative to the industrial realization of integrated circuits of the future for sub-20nm nodes. This mask-less technique offers cost cut opportunities and production flexibility. This work is carried out within the frame of the collaborative program IMAGINE, to push and to speed up the Mapper technology, working at low energy (5keV). From a process point of view, different topics need to be addressed to fit the ITRS specifications and the industry requirements. With the downscale of dimensions, roughness is getting more and more predominant, thus it is important to determine accurately to what extent roughness can be mitigated. This paper is focused on the evaluation of different roughness mitigation techniques. The following various techniques are discussed: use of bias writing strategy, in-track surfactant rinse after wet development and various post-litho treatments such as thermal treatment, HBr plasma and UV light. All Line Width Roughness (LWR) measurements were carried out with a CD-SEM and LWR is obtained from a Power Spectral Density (PSD) fitting method. For each technique, a specific smoothing of the LWR in the different frequency domains is observed and commented. Finally, a combination of all the different LWR reduction treatments listed above is evaluated to reach the minimum value of LWR using an Ebeam resist exposed at low energy.

8766-20, Session 6

Role of shape: ZnO tetrapods in fabrication of smart composites

Xin Jin, Univ. of Kiel (Germany); Yogendra Kumar Mishra, Rainer Adelung, Christian-Albrechts-Univ. zu Kiel (Germany)

ZnO exhibits interesting functional properties and various micro- and nanostructures have been successfully synthesized using different techniques. Here we examine the function of tetrapodal shaped ZnO microparticles which are synthesized by a new method, flame transport synthesis, that allows fast large scale production. The

shape and size of various desired structures can be synthesized in a controlled manner. Due to high aspect ratio in 4 different directions, tetrapod can be used as the basic unit of 3D interconnected network structures. Here we demonstrate the importance of the shape of tetrapodal ZnO in fabricating smart and multifunctional composites for different applications. We show two aspects: firstly, polymer composite were fabricated with tetrapodal ZnO as reinforcement and luminescent filler in elastomer matrix. Simultaneous tensile test and photoluminescence (PL) measurement were performed on the composite. An interesting correlation between the tensile modulus and PL signal from the composite was observed. It is shown that the interlocking of tetrapods is essential to this correlation which introduced a novel concept for self-reporting materials. Furthermore, the interlocked tetrapods 3D network can be infiltrated with more than one polymer matrix. In the case where the tetrapods network is present at the interface of two polymers, they can act as an anchor to join two polymers together. We demonstrate this concept by an extreme example: two polymers with very low adhesive properties. Teflon and silicone elastomer were joined by this method which achieved a peeling strength in the order of 200 N.m-1 [1]. [2].

[1] X. Jin et al. Advanced Materials 24: 5676–5680 (2012).

[2] X. Jin et al. Advanced Materials (2012) (In press).

8766-21, Session 6

Diffractive microstructures based on metallic nanowires: a low cost devices for optical focusing

Soraya Zaiba, Univ. des Sciences et de la Technologie Houari Boumediene (Algeria); Timothée Kouriba, Univ. Joseph Fourier (France); Omar Ziane, Univ. des Sciences et de la Technologie Houari Boumediene (Algeria); Guy Vitrant, IMEP-LAHC (France); Patrice L. Baldeck, Univ. Joseph Fourier (France)

In the present paper, we will show how diffractive microstructures can lead to efficient lenses which present several advantages with respect to other proposed solutions. For instance, based on micro patterned planar metallic structures, they do not require 3D fabrication tools as is the case for refractive micro lenses. Also, they only require wavelength-scale resolution and not very small nanostructuring as used in recently proposed lenses based on plasmon propagation in metallic nanoholes. Nevertheless we obtain comparable performances and we show that the diffraction phenomenon which is at the origin of the observed effects can indeed lead to efficient focusing in the Fresnel region. The structures we proposed in this paper consist of pairs of parallel metallic nanowires fabricated by direct laser writing technique. The fabrication set-up is based on a metallic photoreduction initiated by two photon absorption using a nanosecond Q-Switched Nd-YAG laser. We show for instance experimentally that a pair of metallic nanowires separated by 2 µm when irradiated with an unpolarized light (at λ=546 nm) lead to a focusing at 2 µm with a diffraction limited resolution and an intensity enhancement at the focusing point of about 2.2 times the incoming intensity. Two different theoretical models were used to corroborate our experimental measurement. The first one is the diffraction theory based on the Rayleigh-Sommerfeld integral and the second one is the well kwon FDTD simulation. These two models are in a very good agreement with experiments and confirm the origin of the focusing process. In addition they show that, in the case of our microstructures, plasmonic effects do not contribute to the focusing process. Finally, we propose a 2D array of microlenses based on a grid of metallic nanowires separated by a distance D. This device has slightly the same lens characteristics as a pair of metallic nanowires but with an intensity enhancement higher than 6, and thus may present practical interest in view of applications.

8766-22, Session 6

Influence of irregular growth of monoatomic steps during Si/Si(001) epitaxy on generation of surface defects

Larisa V. Arapkina, Vladimir A. Yuryev, A. M. Prokhorov General Physics Institute (Russian Federation)

This report covers investigation of the structural properties of surfaces of Si epitaxial layers deposited on different Si(001) vicinal substrates. Structural properties of the surface epitaxial layers, especially their defects, could affect the growth of nanostructures. We have studied structural properties of the Si epitaxial layers deposited by MBE. Experiments were performed in UHV using GPI-300 high resolution STM coupled with Riber EVA 32 MBE chamber. We have investigated the Si/Si(001) epitaxial layers deposited on the Si(001) wafers tilted ~ 0.2° to the [110] or [100] direction. We used the standard methods of surface cleaning before MBE. Growth of the epitaxial layers was performed at the temperatures from 360 to 700°C and at different Si deposition rates. A study of the growth temperature effect on the surface morphology has shown that the step-flow growth is observed at the temperature above 600°C. The structure of the surface depends on its tilt direction and the Si deposition rate. For samples tilted to [100], decrease in the Si deposition rate results in appearance of the structure formed by the monatomic steps running along [110] and formation of shapeless pits on the surface instead of the structure formed by the bent monatomic steps running along [100]. We suppose these defects to be connected with a process of transition from the mixed SA + SB monoatomic step to two individual SA and SB steps instead of formation of the DB step. Change of the tilt direction from [100] to [110] results in appearance of the structure formed by SA and SB steps and faceted pits with the rectangular bases. We suppose a source of the pits forming to be connected with repulsion of the SA steps which form long sides of pit bases. Reduction of the growth temperature below 600°C causes formation of rough surfaces.

8766-35, Session 6

Reversible nano-lithography of soft and hard materials

Jae Hong Park, National Nanofab Ctr. (Korea, Republic of); Hyun Ik Jang, National Nanofab Ctr. (Korea, Republic of) and KAIST (Korea, Republic of); Jun Yong Park, KAIST (Korea, Republic of); Dong Eon Lee, Seoul National Univ. (Korea, Republic of); Seok Woo Jeon, Chi Won Ahn, KAIST (Korea, Republic of); Kwang Soo Yoo, Univ. of Seoul (Korea, Republic of)

The methodology suggested in this research provides the great possibility of creating nanostructures composed of various materials, such as soft polymer, hard polymer, and metal, as well as Si. Such nanostructures are required for a vast range of optical and display devices, photonic components, physical devices, energy devices including electrodes of secondary batteries, fuel cells, solar cells, and energy harvesters, biological devices including biochips, biomimetic or biosimilar structured devices, and mechanical devices including micro- or nano-scale sensors and actuators.

8767-1, Session 1

Monolithic integration of high-Q wedge resonators with vertically coupled waveguides

Fernando Ramiro Manzano, Univ. degli Studi di Trento (Italy)

Whispering gallery mode microresonators with ultra-high quality factors (UHQ's) have attracted great attention because of their importance for fundamental science and potential applications. However, typical UHQ resonators, microspheres and microtoroids, lack the possibility of integration into lightwave circuits due to their planarity constrains. For this reason, the improvement of the quality factors of planar resonators fabricated using conventional semiconductor processing has provoked significant interest. In this context, CMOS-compatible alternatives in the form of wedge resonators have been proposed. In such a cavity geometry, the fundamental modes are pulled away from the resonator's periphery reducing significantly the surface-induced scattering losses. In fact, a new benchmark of UHQ on a chip has been set by using silica wedge resonators (1). However, the mode retraction from the cavity inhibits the possibility to side couple with integrated waveguides and therefore, halts the full integration within a planar lightwave circuit. In this work, we propose and demonstrate experimentally the complete integration of wedge resonators with vertically coupled dielectric bus waveguides (2). In this approach the resonator and the waveguide lay in different planes which permits to realize the optical components in independent and isolated technological steps. As a result, the waveguide remains intact when the wedge geometry of the cavity is formed. Owing to the fact that the vertical coupling gap is accurately controlled through a deposition procedure, the lithographic techniques employed are conventional and inexpensive. Advantageously, the vertical coupling scheme permits to select different materials for the resonator and the waveguide. Moreover, the gap material can be selectively removed in order to form freestanding wedge resonators extending the material and application ranges. These features are highly valuable for a number of applications such as cavity optomechanics, non-linear optics, label-free sensing and integrated photonics. In conclusion, this work shows the feasibility of a full integration of wedge resonators on a chip featuring arbitrary gaps, geometries and materials, enabling simplified and precise control of the light injection into the cavity and opening the door to an industrial mass-fabrication of UHQ resonators.

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8767-2, Session 1

Fano lineshapes of 'Peak-tracking chip' spatial profiles analyzed with correlation analysis for bioarray imaging and refractive index sensing

Kristelle Bougot-Robin, Shunbo Li, Hong Kong Univ. of Science and Technology (Hong Kong, China); Weisheng Yue, Longqing Chen, Xixiang Zhang, King Abdullah Univ. of Science and Technology (Saudi Arabia); Weijia Wen, Hong Kong Univ. of Science and Technology (Hong Kong, China); Henri Benisity, Institut d'Optique Graduate School (France)

The asymmetric Fano resonance lineshape, resulting from interference between background and a resonant scattering, is archetypal in resonant waveguide grating (RWG) reflectivity. Resonant profile shift resulting from a change of refractive index (from fluid medium or biomolecules at the chip surface) is classically used to perform label-free sensing. Lineshapes are sometimes sampled at discretized "detuning" values to relax instrumental demands, the highest reflectivity element giving a coarse resonance estimate. A finer extraction, needed to increase sensor sensitivity, is obtained either by fitting data to known models or, as presented here, using a correlation approach, correlating the sensed signal to a zero-shifted reference signal. We demonstrate experimentally and theoretically the superior merits of correlation against Gaussian and Lorentzian shape fitting. Sampling and sensitivity are discussed. Our findings are illustrated with resonance profiles from silicon nitride RWGs operated at visible wavelengths. We recently demonstrated that direct imaging multi-assay RWGs sensing may be rendered more reliable using "chirped" RWG chips. The scheme circumvents the classical but demanding spectral or angular scans: instead of varying angle or wavelength through fragile moving parts or special optics, a RWG structure parameter is varied. Then, the spatial reflectivity profiles of tracks composed of RWGs units with slowly varying filling factor (thus slowly varying resonance condition) are measured under monochromatic conditions. Extracting the resonance location using plain images of these "pixelated" Fano profiles allows multiplex refractive index based sensing. Together with good fluidic stabilization for sensitive optical measurements, an improvement over the "best-pixel" maximum position tracking by more than 2 orders of magnitude is obtained and provides down to 2x10-5 RIU sensitivity. Together with highly accurate fitting demonstration through correlation analysis, this scheme based on a "Peak-tracking chip" demonstrates a new technique for bioarray imaging using a simpler set-up that maintains high performance with cheap lenses.

8767-3, Session 1

Systematic optimization of the storage capacity of photonic crystal slab waveguides

Panagiotis Kanakis, National and Kapodistrian Univ. of Athens (Greece); Thomas Kamalakis, Harokopio Univ. of Athens (Greece); Thomas Sphicopoulos, Univ. of Athens (Greece)

The realization of integrated all-optical delay lines is considered to be one of the major milestones towards the development of future all-optical networks. Slow light nanophotonic structures such as photonic crystal slab waveguides are attracting increasing attention on the field due to the large slow down factors obtained, the enhancement of nonlinear phenomena and the ability to confine light at a sub-wavelength scale. Optical losses and dispersion induced broadening are two major impairments, which limit the performance of slow light photonic crystal slab waveguides. Up until now, many authors demonstrated an improvement in the performance of these waveguides by means of exhaustive search, altering only a few design parameters of the waveguide. In this work, we propose and numerically demonstrate a systematic optimization procedure in order to maximize the storage capacity of photonic crystal slab waveguides. Unlike exhaustive search, our procedure allows the simultaneous altering of several design parameters in an attempt to maximize the storage capacity of the waveguide. The optical losses and dispersion-induced broadening are incorporated into the optimization procedure in a rigorous manner. A step-by-step optimization procedure for data rates of 40Gb/s and 100Gb/s is presented, starting from a standard W1 photonic crystal slab waveguide. The results clearly indicate an almost threefold improvement on the storage capacity compared to the starting waveguide.

8767-5, Session 1

Talbot effect from periodic and quasi-periodic structures: application to 3D quasi-crystalline photonic lattices formation

Rafael Drampyan, Anahit Badalyan, Paytsar A. Mantashyan, Vahram Mekhitaryan, Institute for Physical Research (Armenia); Varsenik Nersesyan, Russian-Armenian (Slavonic) State Univ. (Armenia)

We report the first experimental investigation of image self-replication - Talbot effect with the use of 1- and 6 - fold rotational symmetry (FRS) micrometric scale masks to create 3D intensity modulated light. Computer generated different rotational symmetry negative amplitude masks of reduced size (0.6 cm in diameter) represent itself ~10 000 - 35 000 holes on opaque disk, periodically disposed along hypothetic equidistantly positioned concentric circles with 10-50 μm distances between 10 μm holes. These masks while having strong periodicity in azimuthal direction are examples of multi-periodical and nearly periodical structures, respectively, along transverse X-Y directions. Since the Talbot image self-replication period in axial direction depends on light wavelength and the square of structure periods which are different along transverse X and Y directions, this give a possibility of creating the complex 3D light intensity distributions with different Talbot axial periods across the beam transverse plane (complex lattice beams).

A cw single mode 532 nm, 100 mW laser beam was used in the experiment for formation complex lattice beams. The observed high contrast of the far field diffraction patterns from the masks by probe beam at 532 nm beam showed their high quality.

For the analysis of three-dimensional intensity distributions a CCD camera mounted on a translation stage was used. After observation of the transverse intensity patterns at multiple equidistant longitudinal positions, all these two-dimensional replicated images were stacked to get a full 3D intensity distribution of the lattice beam. The results showed pronounced multi-periodicity and nearly-periodicity of 3D intensity distribution in the axial direction for 1-, and 6- FRS masks, respectively.

3D intensity modulated light beams are promising for formation of crystalline and quasi-crystalline refractive index micro- and nano-structures in photorefractive materials, which in turn are perspective for numerous applications.

8767-6, Session 2

Hydrogenated amorphous silicon nanowires with high nonlinear figure of merit and stable nonlinear optical response

Luca Carletti, Institut des Nanotechnologies de Lyon (France); Christelle Monat, Christian Grillet, Ecole Centrale de Lyon (France); Philippe Grosse, CEA-LETI-Minatec (France); Badhise B. Bakir, Sylvie Menezo, Jean-Marc Fédéli, CEA-LETI (France); David J. Moss, The Univ. of Sydney (Australia)

Optical nonlinear phenomena such as four-wave mixing, third harmonic generation and self-phase modulation are essential to realize all-optical signal processing onto compact on-chip systems able to comply with the increasing bandwidth demand of telecommunication networks. From recent investigations, hydrogenated amorphous silicon (a-Si:H) has emerged as a possible key material in this field. The associated fabrication process on this platform can be fully CMOS compatible. Furthermore a-Si:H can exhibit both a high nonlinear Kerr index (n2) and low two-photon absorption (βTPA) at telecom wavelengths, i.e. a high nonlinear figure of merit (FOM=n2/(βTPA*λ)), which is critical for creating efficient nonlinear photonic devices. Although crystalline silicon (c-Si) already benefits from a very mature technology and possesses a high Kerr coefficient, its poor FOM (~0.3-0.5) prevents it from being used in some applications requiring, for instance, positive net gain parametric amplification since a FOM of at least 2 is needed. At the 1.55μm telecom wavelength, nonlinear two-photon absorption tends to be reduced in a-Si:H because of its larger bandgap energy (~1.7eV) as compared to c-Si (~1.12eV). In order to test the nonlinear properties of this material, tightly confining a-Si:H based nanowires with a top SiO2 cladding and relatively low propagation loss (4.5dB/cm) were fabricated onto SiO2/Si wafers using a 200mm CMOS pilot line at CEA-LETI. From our self-phase modulation measurements conducted using picosecond pulses at a wavelength of 1.55μm and fitted to standard theory, we estimate a FOM for our material platform of about 5. Furthermore, unlike some of the previous work performed on a-Si:H, we found no deterioration of the material nonlinear response over hours of operation under several Watts of peak pump power. The high nonlinear FOM found and the material nonlinear response stability demonstrate the great potential of the a-Si:H optical nonlinear chip-based platform for creating compact all-optical signal processing architectures.

8767-7, Session 2

Travelling wave resonators fabricated with low-loss hydrogenated amorphous silicon

Timo Lipka, Julia Amthor, Jörg Müller, Technische Univ. Hamburg-Harburg (Germany)

Hydrogenated amorphous silicon offers a unique photonic platform to merge electrical integrated circuits with optical communication links and is a potential candidate for a three-dimensional integration of complex photonic-electronic integrated circuits (PEICs).

In addition to the low material absorption of amorphous silicon in the near infrared the main reasons for the high attraction of this material as photonic platform is primarily due to following reasons. The employment and compatibility of mature CMOS-fabrication technology reduces process development time and saves costs, and the strong refractive index contrast (n = 2) permits a high integration density and hence photonic systems with low footprint, low power consumption, and functional devices covering a wide variety of photonic applications. Due to the moderate deposition temperature <300 °C, this will allow merging the advantages of integrated electronic circuits in data processing and storage with high-speed parallel optical data transmission by interconnecting both application areas on the same substrate with plasma deposition of a-Si:H at the backend.

Travelling wave resonators are key components for the fabrication of complex photonic systems and cover a lot of essential functions like filtering, routing, switching, and modulation. In this paper, photonic wire based microring, racetrack and disk resonators of different dimensions (5-100μm in radius) have been fabricated with low-loss a-Si:H and were systematically investigated, thereby achieving extinction ratios of >20dB for both polarizations, large free spectral ranges up to 18nm for 5μm rings and high Q-factors of 500k for 100μm disks.

Based on these devices, broadband filters consisting of CROW and SCISSOR configured resonators were designed and fabricated. Furthermore four channel WDM-filters which are based on cascaded racetrack and ring resonators were studied. The design, the fabrication, and the optical characterization are presented.

8767-8, Session 2

High-resolution 3D structural and optical analyses of hybrid or composite materials by means of scanning probe microscopy combined with the ultramicrotome technique: an example of application to engineering of liquid crystals doped with fluorescent quantum dots

Konstantin E. Mochalov, Institute of Molecular Medicine (Ireland) and Moscow Engineering Physics Institute (Russian Federation); Anton E. Efimov, V.I. Shumakov Federal Research Ctr. of Transplantology and Artificial Organs (Russian Federation); Alexey Y. Bobrovsky, Lomonosov Moscow

State Univ. (Russian Federation); Anton A. Chistyakov, National Research Nuclear Univ. MEPhI (Russian Federation); Vladimir A. Oleinikov, National Research Nuclear Univ. MEPhI (Russian Federation) and Shemyakin-Ovchinnikov Institute of Bioorganic Chemistry of the Russian Academy of Sciences (Russian Federation); Valery P. Shibaev, Lomonosov Moscow State Univ. (Russian Federation); Igor R. Nabiev, Univ. de Reims Champagne-Ardenne (France) and Moscow Engineering Physics Institute (Russian Federation)

Combination of nanometer-scale 3D structural analysis with optical characterisation of the same material is a challenging task. Its results may be important for nanophotonics, materials science, and quality control. SNOM approaches permit only 2D-structural analysis of surfaces accompanied by optical investigation, whereas TEM of non-transparent samples cannot be combined with optical analysis. Information on the 3D distribution of optically active doping substances (e.g., photonic and liquid crystals) may lead to their breakthrough optimisations.

We have developed a new technique for complementary high-resolution structural and optical characterisation followed by optical microspectroscopic measurements accompanied by reconstruction of the 3D structure in the same area of the sample. The 3D structure is reconstructed by combination of ultramicrotomic and SPM techniques allowing the study of the 3D distribution of implanted nanoparticles and their effect on the matrix structure. The combination of probe nanotomography and optical microspectroscopy makes it possible to directly estimate how the 3D structural characteristics of materials affect their macroscopic optical properties.

The technique developed has been applied to the engineering of materials made from cholesteric liquid crystals and fluorescent quantum dots (QDs). These materials permit photochemical patterning and image recording through the changes in the dissymmetry factor of circular polarization of QD emission. The differences in the polarisation images and morphological characteristics of the liquid crystal matrix have proved to be correlated with the arrangement of the areas of homogeneous distribution and non-homogeneous clustering of QDs. The reconstruction of the 3D structure of the liquid crystal matrix in the areas of homogeneous QD distribution has shown that QDs embedded into cholesteric liquid crystal matrices do not perturb their periodic planar texture.

The combined optical/SPM/ultramicrotome technique will be indispensable for evaluating the effects of inorganic nanoparticles on the organisation of organic and liquid crystal matrices, biomedical materials (including drugs), cells, and tissues.

8767-9, Session 2

Submicron scale germanium selective epitaxial growth at different growth temperatures

Yasutaka Mizuno, The Univ. of Tokyo (Japan); Naoyuki J. Kawai, Univ. of Tokyo (Japan); Kazumi Wada, The Univ. of Tokyo (Japan)

Ge selective epitaxial growth (SEG) is an important technique for Ge device on Si because Ge can be grown only on device areas with small density of threading dislocation. Kim, et al.[1] and Park, et al.[2] reported comparisons of Ge-SEGs at different growth temperatures from the view points of the migration from masks[1] and the facet formation[2]. The width of the SEG stripes are over ten microns, whereas the Ge optical device size is one micrometer or less. Thus we have to understand the shape of Ge-SEG in submicron scale width to use the SEGs for Ge device fabrication. In this research we performed Ge-SEGs at different growth temperatures, and discussed the growth mechanism.

(100) surface Si covered with 150nm thick SiO2 was used as substrate. SiO2 stripes were removed for SEG, and then Ge was grown by UHV-CVD at 500, 600, 700 and 750˚C.

The cross section of the Ge stripes were measured by SEM. Ge heights in wide stripes are constant regardless of growth temperature. This means that Ge growth is transportation-limited. However, Ge height in submicron stripes varied with temperature. This growth rate enhancement (GRE) in narrow trenches is explained by a precursors migration model, where Ge precursors migrate from the mask into trenches. According to this model, GRE of 500˚C:600˚C:700˚C:750˚C is 1:2:6:10. This suggests that we should shorten the growth time in submicron stripes Ge-SEG at higher growth temperature.

In Ge-SEG, (311), (111) and (911) facets appeared. When the growth temperature is higher, facet length of (311) decreases, while facet length of (111) and (911) increase. This suggests that stability of Ge facets is (111)>(911)>(311). At first stage of growth, energetically favorable rebonded double-layer steps lead to (311) facet formation, but at last stable (111) and (911) facets are formed to minimize total surface free energy.

8767-10, Session 3

Ge on Si waveguide-integrated photodiodes for high speed and low power receivers

Léopold Virot, STMicroelectronics (France) and Institut d'Electronique Fondamentale (France); Laurent Vivien, Institut d'Electronique Fondamentale (France); Jean-Michel Hartmann, Jean-Marc Fédéli, CEA-LETI (France); Delphine Marris-Morini, Eric Cassan, Institut d'Électronique Fondamentale (France); Charles Baudot, Frédéric Boeuf, ST Microelectronics (France)

Development of fast silicon photonics integrated circuit is mainly driven by the reduction of the power consumption. As a result, photodetectors with high efficiency, high speed and low dark current are needed to reduce the global link consumption. Germanium is now considered as the ideal candidate for fully integrated receivers based on SOI substrate and CMOS-like processes. We report on low power and high speed waveguide-integrated Ge photodetectors. Butt coupled and lateral PIN structure photodiodes have been fabricated by Germanium selective growth and ion implantation at the end of silicon waveguide. Three types of photodiodes are reported, with dark current as low as 6nA at 1V reverse bias, optical bandwidth over 40GHz at zero bias and responsivity up to 0.8A/W at a wavelength of 1550nm. Such devices are suitable for data rate over 40Gb/s and can be easily integrated with other photonic devices to fabricate wafer scale integrated circuits for datacom and telecom applications.

8767-11, Session 3

Electro-refractive effect in Ge/SiGe multiple quantum wells

Jacopo Frigerio, Politecnico di Milano (Italy); Papichaya Chaisakul, Delphine Marris-Morini, Institut d'Électronique Fondamentale (France); Stefano Carlo Cecchi, Politecnico di Milano (Italy); Mohamed-Saïd Rouifed, Laurent Vivien, Institut d'Électronique Fondamentale (France); Giovanni Isella, Politecnico di Milano (Italy)

Ge/SiGe multiple quantum wells (MQW) has received a great attention in the context of silicon photonics for the realization of efficient electro-absorption (EA) modulators based on the quantum confined stark effect (QCSE). QCSE causes strong variations in the absorption spectrum, which are associated to a change of the refractive index at a given wavelength, as stated by Kramers-Kronig relations. Large changes in the refractive index would make Ge/SiGe MQW attractive for the realization of electro-optic devices such as Mach-Zender phase modulators. The electro-refractive (ER) effect is operating at energies below the EA peak for a given configuration of the Ge/SiGe MQW, thus constituting a promising way to extend their operative wavelength. In order to characterize the electro refractive effect in germanium quantum wells , 20 MQW (10 nm Ge/15 nm Si0.15Ge0.85) were grown on a Si0.1Ge0.9 virtual substrate by low-energy-plasma-enhanced-chemical-vapor-deposition (LEPECVD) and characterized by high resolution x-ray diffraction. The sample was then processed in 64 μm long slab waveguides by standard optical lithography

and dry etching. The electro-refractive effect was experimentally characterized by the measurement of the shift of Fabry-Perot fringes in the transmission spectra of the device for different applied voltages. A refractive index variation up to 1.3 10-3 was measured with an applied electric field of 88 kV/cm at 0.84 eV, 50 meV below the excitonic resonance, with a VπLπ figure of merit of 0.46 Vcm. The device performances are promising for the realization of Mach Zender modulators in the Ge-Si material system, with several potential advantages over the EA modulators such as the improved thermal stability and the extended operative wavelengths.

8767-12, Session 3

Franz-Keldysh effect of Ge-on-Si pin diodes at common chip temperatures

Marc Schmid, Mathias R. Kaschel, Martin Gollhofer, Michael Oehme, Univ. Stuttgart (Germany); Jens Werner, Kai Ulbricht, Univ. of Stuttgart (Germany); Erich Kasper, Jörg Schulze, Univ. Stuttgart (Germany)

Integrated optical interconnects for complementary metal oxide semiconductor circuits have great potential to enable information communication at high data rates. To date, the heat dissipation of contemporary chips under load is considerable and limits their electrical performance. The chip temperature will certainly affect the characteristics of integrated passive and active optical devices.

This work concentrates on the device characteristics and performance of Ge-on-Si pin diodes for the use as absorption modulators. At first, the impact of temperature on electrical and on optical characteristics of these pin diodes is investigated. Secondly, the feasibility of optical modulation using the Franz-Keldysh effect is demonstrated for temperatures up to 359 K.

The Ge-on-Si pin diodes are grown using a molecular beam epitaxy system. The layer structure includes a double Si/Ge-heterojunction and an intrinsic zone with a thickness of 500 nm. During the growth process several annealing steps are performed to reduce the dislocation density and incorporate tensile strain in the intrinsic zone. The dark current is proportional to the diode area and amounts to 40 mA/cm2 at a reverse voltage of 1 V. An analysis of the temperature dependence of the dark current shows that it is dominated by generation/recombination of carriers probably at threading dislocations. The optical absorption spectra recorded show a shrinkage of the infrared cut off wavelength of about 0.6 nm/K. In addition the change of absorption at the direct bandedge with different applied biases, i.e. the Franz-Keldysh effect, is demonstrated for temperatures from 300 K to 359 K. With regard to modulation of an optical signal the on/off ratio is evaluated as function of the voltage swing. With a moderate voltage swing of 2 V the maximal absorption change is 300 cm-1 and the optimal working regime shifts from 1625 nm at 300 K to 1665 nm at 337 K.

8767-13, Session 3

Resistance-capacitance limitation of fast double heterojunction Ge p-i-n photodetectors

Mathias R. Kaschel, Marc Schmid, Martin Gollhofer, Michael Oehme, Erich Kasper, Jörg Schulze, Univ. Stuttgart (Germany)

The optical bandwidth of Ge p-i-n photodetectors for high-speed optical on-chip communication is limited by the transit time and the RC load. The transit time depends only on the carrier velocity and the thickness of the absorber region while diffusion can be neglected. The important parameters for the RC load are the detector area, series resistance, background doping and the thickness of the intrinsic region. Therefor the appropriate design and technology steps are important to optimize these parameters and to suppress the parasitic effects of the device capacitance load time.

The presented Ge on Si photodetectors are grown by molecular beam epitaxy on a p-- Si substrate. The n++ top as well as the p++ buried contact layer exhibit a Si/Ge heterojunction. In addition the buried contact layer serves as the virtual substrate for the intrinsic layer to adjust the different lattice constants of Si and Ge for a low defect density epitaxy. The photodetectors are structured in a double mesa process with microwave coplanar lines to contact the high doped contact layers.

This work presents the vector network analyzer (VNA) measurements up to 110 GHz and the analysis of the scattering parameters of photodetectors with different areas and design layouts. Different de-embedding procedures utilizing short and open test interconnects are compared to obtain the amplitude and phase of the device impedance and to evaluate the resulting equivalent circuit description. An in-depth analysis of the reflection parameter compared to the equivalent circuit explains the frequency characteristic and it is used to determine the RC bandwidth. The expansion of the depletion layer, which is dependent on the voltage, the doping profiles and the background doping of the absorber layer, controls the balance of diffusion and drift currents. A model is established to summarize these effects and optimize the photodetector layouts for fast zero-bias operation.

8767-14, Session 4

TriPleX waveguide platform: low loss technology over a large wavelength range *(Invited Paper)*

Marcel Hoekman, Arne Leinse, René G. Heideman, LioniX BV (Netherlands)

Integrated optics and Planar Light wave Circuits (PLC) play an increasingly important role in the development of a broad range of applications. In order to realize complex chip designs a stable proprietary waveguide platform is developed by LioniX. The waveguide structures in this platform form a new class of integrated-optical planar light wave circuits and are based on Low Pressure Chemical Vapor Deposition (LPCVD) processing of alternating layers of stoichiometric Si3N4 and SiO2. The technology is branded TriPleXTM technology and it allows for medium and high index-contrast waveguides that exhibit low channel attenuation. The waveguides can be tapered in thickness adiabatically over a device allowing spot size converters to be integrated on chip. In addition, TriPleXTM waveguides are suitable for low loss operation at wavelengths ranging from 405 nm through 2.35 µm. Record low losses down to 0.1 dB/m (0.001 dB/cm) have even been measured in the telecom wavelength range around 1550 nm. The high index-contrast and broad wavelength range make the TriPleX™ technology extremely suitable for a variety of applications. This presentation will give an overview of the newest developments in the waveguide platform, some examples of applications and the accessibility of it for users via Multi Project Wafer runs.

8767-15, Session 4

Generic process for low-cost InP integrated photonics in industrial foundries *(Invited Paper)*

Luc M. Augustin, Technische Univ Eindhoven (Netherlands); Huub P.M.M. Ambrosius, Technische Univ. Eindhoven (Netherlands); Peter J. A. Thijs, Technische Univ. Eindhoven (Netherlands) and SMARTPhotonics B. V. (Netherlands); Francisco M. Soares, Norbert Grote, Fraunhofer-Institut für Nachrichtentechnik Heinrich-Hertz-Institut (Germany); Dominik Szymanski, Wroclaw Univ. of Technology (Poland); Michael J. Wale, Oclaro, Inc. (United Kingdom) and Technische Univ. Eindhoven (Netherlands); Meint K. Smit, Technische Univ. Eindhoven (Netherlands)

In the coming years we expect a revolution in photonic integration technology through the introduction of generic foundry processes: highly standardized photonic integration processes that enable realization of a broad range of Application Specific Photonic ICs (ASPICs) from a small set of basic building blocks. This will lead to a dramatic reduction of the development costs of Photonic ICs which

will bring them within reach for SMEs, universities and research institutes. It is similar to the revolution that took place for ASICs in microelectronics more than three decades ago.

In 2007 the photonic foundry approach was adopted by the FP6 Network of Excellence ePIXnet and for InP-photonics the JePPIX platform was initiated. Within JePPIX, the COBRA Research Institute of the TU Eindhoven started pioneering small-scale access to MPW runs for research purposes. Since 2009 the EuroPIC and PARADIGM projects have been working on transfer of the foundry model from a university environment to an industrial environment: the platform technologies of Oclaro and the Fraunhofer HHI. The COBRA generic Integration process will be commercialized by SMARTPhotonics.

A significant number of designs have been realized since then for a variety of applications in telecoms, datacoms, medical and sensing, from parties all over the world.

8767-16, Session 5

A CMOS-compatible silicon photonic platform for classical and quantum integrated optics *(Invited Paper)*

Christophe Galland, Ran Ding, Yang Liu, Yi Zhang, Li He, Nicholas Harris, Tom W. Baehr-Jones, Michael Hochberg, Univ. of Delaware (United States)

We have developed a CMOS-compatible SOI photonic platform featuring active components such as PIN and photoconductive (MIM) Ge-on-Si detectors, PIN ring and Mach-Zehnder modulators, and traveling-wave modulators based on a PN junction driven by an RF transmission line. We have characterized the yield and uniformity of the performance through automated cross-wafer testing, demonstrating that our process is reliable and scalable. The entire platform is capable of up to 25 GB/s data rate. Fabricated at the IME/ASTAR foundry in Singapore, it is available to the worldwide community through OpSIS, a successful multi-project wafer service based at the University of Delaware.

After exposing the design, fabrication and performance of the most advanced platform components, we will present our newest, still unpublished results. These include: optimized Y-junctions (3dB coupler) for 50/50 beam splitting with ultralow loss (0.28 0.02) on a large optical bandwidth; waveguide crossings with very low loss (0.18±0.03 dB) and cross-talk (-41±2 dB), and non-uniform grating couplers (insertion loss -3.2±0.2 dB). All this components were tested across a full wafer and exhibited remarkable uniformity.

In the second part, we will focus on emerging applications for silicon photonics in the field of quantum optics and quantum technologies. In both approaches to quantum optics (discrete or continuous variables), Si photonics offers attractive improvements over bulk systems, such as high visibility quantum interference (thanks to phase stability and single-mode waveguides); ultrafast feed-forward and photon routing (using integrated detectors, electronics and modulators); enhanced non-linearities for heralded and entangled photon generation (using resonators and dispersion engineering); etc. We will review recent proposals and experiments performed in related systems (e.g. silica waveguide circuits), like quantum walks and quantum gates. Finally, we will present our on-going work in the area and our endeavored results in quantum cryptography, squeezed state generation and homodyne detection for quantum state tomography.

8767-17, Session 5

ePIXfab: the silicon photonics platform *(Invited Paper)*

Amit Khanna, IMEC at Ghent Univ. (Belgium); Peter A. O'Brien, Tyndall National Institute (Ireland); Jose M. Pozo, TNO (Netherlands); Maryse Fournier, Lab. d'Electronique de Technologie de l'Information (France); Lars Zimmermann, IHP GmbH (Germany); Timo Aalto, VTT Technical Research Ctr. of Finland (Finland); Pieter Dumon, IMEC (Belgium)

Silicon photonic devices offer opportunities for large and medium volume markets in devices and systems for communications, computing, spectrometry, biomedical applications and production. The ePIXfab service is used by academic and industrial R&D groups in Europe, Americas and Asia which submit designs that are fabricated on 200mm wafers with CMOS based technology. With funding from the European Union, the barriers for access to this high-end technology are now being addressed with easier design, training, and easy access to other technology providers.

ePIXfab's aim is to support the emergence of a fab-less silicon photonics ecosystem through a collaboration of various research centers across Europe (partners include imec (BE), CEA-LETI (FR), IHP (DE), TNO (NL), Tyndall National Institute (IR), VTT (FI) and CMC Microsystems (Canada)) providing under ePIXfab their diverse silicon photonics expertise. This is accomplished through services and products that cover the entire food chain of silicon photonics prototyping. (i) Cost-effective prototyping of silicon photonic ICs through multi-project wafer shuttles in imec, CEA-LETI and IHP's photonics technologies. Technologies include passive devices, advanced passive devices, modulators, detectors and heaters (ii) Cost shared and custom packaging through Tyndall National Institute. This offer comprises of fiber array packaging and active device packaging. (iii) Feasibility studies for SMEs and industry through different partner institutes. This study comprises evaluation of applying silicon photonics to products, offered free of charge for EU SMEs. (iv) Education and training through bi-annual one week trainings, annual workshop and multiple online webinars. While prototyping is directly supported by ePIXfab it also enables a route towards medium to large volume production of silicon photonic devices.

8767-4, Poster Session Thursday

Analysis of the Drever-Pound-Hall technique for the simultaneous detection of the detuning of more cavities on a single channel

Martina De Laurentis, Michele Riccio, Giuseppe De Falco, Luca Maresca, Andrea Irace, Giovanni Breglio, Univ. degli Studi di Napoli Federico II (Italy)

The Drever-Pound-Hall technique is a powerful tool to stabilize the laser frequency or to lock a cavity to a laser by controlling its length in the order of fraction of wavelength.

It had been widely applied as method to interrogate fiber optical cavity based sensors, as strain sensors or refractive index sensors, since it allows to reach very high sensitivity, especially in dynamic range, only theoretically limited by the laser shot noise.

In this paper we present a detailed analysis on the possibility to use the DPH technique for the simultaneous detection of detuning of two or more cavities each lying on a different output branch of a splitter, by interrogating them using only the single input channel of the splitter. To be more More precisely, starting from a reflection configuration of the present technique, where the error signal to control the cavity length is extracted by the signal reflected by the cavity, we analyze all the possible configurations to simultaneously interrogate and discriminate the different cavities using the same input channel to have not overlap and interference between the signals reflected by each of them.

The interest of this kind of analysis resides in the possibility to use the technique to design very compact and not much least invading sensors that requires bidirectional detection of the involved physical quantity or, the simultaneously and independent control of several parameters (like, for example, bidirectional strain sensors, that simultaneously detect the strain along two orthogonal directions, or magnetic field sensor able to determine the intensity of the field along perpendicular directions, or, refractive index sensor temperature calibrated). Using an single interrogation/detection channel the sensor can be placed far away from the interrogation/detection apparatus and connected to the latest only by means of a single optical fiber, instead to have more signal detection channels.

8767-34, Poster Session Thursday

Design fabrication and optimization of $LiNbO_3$ based titanium indiffused waveguide polarizers

Evren Oztekin, Mutlu Gökkavas, Yasemin F. Kanli, Seval Dönertas, Ekmel Ozbay, Bilkent Univ. (Turkey)

Lithium niobate (LiNbO3) has been widely employed in key industries such as telecommunications, fiber optic gyroscopes, and nonlinear optics owing to its high electrooptical coefficient allowing low modulator voltage, and mature fabrication technology facilitating reliable, high speed, and efficient modulator production. To date, two alternative waveguide fabrication processes have been widely studied and commercialized: Ti indiffusion and proton exchange. Proton exchange technique is the preferred method of choice for applications requiring polarizing capabilities, whereas Ti indiffusion has been regarded widely as a non-polarizing technique. It is desirable to fabricate polarizing waveguides with the Ti indiffusion method, since this process is relatively easier to control compared to the proton exchange technique requiring the employment of hot acidic melts and a post anneal process. In the literature, there exists one report [Dobrusin et al., OE Lett. 47, 120504 (2008)] describing the fabrication of polarizing waveguides (>33 dB) via Ti indiffusion. In this paper, we report our results on polarizing waveguides fabricated on x-cut y-propagating LiNbO3 by Ti indiffusion technique. The effect of several fabrication parameters, such as the diffusion temperature, diffusion time, diffusion atmosphere, pre-diffusion Ti-strip width, and Ti thickness are investigated with emphasis on the polarizing properties of the fabricated waveguides. By optimization of fabrication parameters, polarizing Ti indiffused waveguides with polarization extinction coefficient (PER) higher than 40 dB at their outputs, and fiber-to fiber insertion loss as low as 2 dB at 1550 nm wavelength were demonstrated. The polarizing capability of the Ti indiffused waveguides is attributed to refractive index anisotropy resulting in different respective propagation loss for the fundamental TE/TM modes.

8767-36, Poster Session Thursday

Narrow line-width microwave source based on bimodal Whispering Gallery Mode laser

Elodie Le Cren, Alphonse L. Rasoloniaina, Vincent Huet, Yannick Dumeige, Patrice Féron, Ecole Nationale Supérieure des Sciences Appliquées et de Technologie (France); Michel S. Mortier, Ecole Nationale Supérieure de Chimie de Paris (France)

The paper is dedicated to a potential application of the WGM micro resonators, a dual wavelength laser source. Our experiments are focused on the optical transition 4I13/2 -----> 4I15/2 in Er3+. We chose a pumping at 1480 nm in order to obtain a good overlap between the pump and laser whispering gallery mode volumes. The resonator is coupled with one or two half-tapered fibers. The matching of the effective refractive index of the mode guided in the taper and the sphere's best WGM depends on the wavelength. Consequently this kind of coupler permits the selection of the emitted wavelength and each taper can be considered as a wavelength tunable input/output coupler by varying the position and the gap between the sphere and the taper. With two tapers, we can obtain two different lasers sharing the same cavity without mode competition as it is the case for spatially separated eigenstates configuration. This property is important since it should insure that first order frequency fluctuations between the two lasers disappear. We study the resulting beat note signal in terms of central frequency, line-width versus laser output power, polarization and coupling.

8767-37, Poster Session Thursday

Multifunctional flexible displays based on intrinsically active polymers

Georgi Paschew, Rene Koerbitz, Andreas Richter, Technische Univ. Dresden (Germany)

Nowadays display-technology allows us to read information nearly everywhere and at all times. Depending on the kind of information or the place of action, different requirements have to be met by the displays. For example high resolution and short response time are necessary for high quality image and video capability e. g. on smartphone-screens. Other devices like e-book readers and electronic papers focus on the presentation of text and therefore need a high contrast. They use bistable, particle-filled micro-chambers to generate monochrome information. However, our displays are based on intrinsically active polymers, so called stimuli-responsive hydrogels. These three-dimensional polymer-networks have amazing characteristics, which make them suitable for a broad field of applications. Based on the change of environmental conditions, these gels can change their volume up to 90 % by absorption or release of water. At the same time, their optical properties switch from transparent to opaque. Using these effects we are able to manufacture displays with the unique property to generate palpable information for a tactile output and monochrome information for a visual display. Here we want to present a monochrome display consisting of just one layer poly(N-isopropylacrylamide). This polymer is a particularly temperature sensitive hydrogel which undergoes a phase-transition if a lower critical solution temperature (LCST) is exceeded. I. e. the gel becomes opaque within milliseconds by raising the temperature over the LCST. To initiate this effect, we use a special optoelectrothermic interface for selective heating of the gel-layer. In addition to low response times our flexible display features also a high resolution. Depending on the thickness of the polymer-layer, structures in the range of hundreds of microns can be visualized.

8767-38, Poster Session Thursday

Si-based light emitter in an integrated photonic circuit for smart biosensor applications

Susette Germer, Lars Rebohle, Wolfgang Skorupa, Manfred Helm, Helmholtz-Zentrum Dresden-Rossendorf e. V. (Germany)

Integrated optics concerns mainly the generation, guiding, and detection of light. Especially bio sensing needs systems that incorporate electronic and photonic devices for the detection of harmful substances, like synthetic estrogens or plasticizers. We present recent developments in the integration of Si-based light emitters into a photonic circuit for a planar optical waveguide-based bio detection system. The growing demand for sensitive biochemical sensors in the environmental control, medicine or process technology results in the development of integrated sensors, which should show a high resolution over a wide concentration regime. In our first approach we deal with the integration of a Si-based light emitting device (LED) into a photonic circuit for the detection of harmful biological substances. Light injection into a waveguide is commonly obtained by using an external source coupled to the waveguide, e.g. an optical fiber via total internal reflection. For simplifying this injection process, we built Si-based LEDs consisting of a metal-oxide-semiconductor (MOS) structure, in which the oxide film contains group-IV and/or rare earth elements, incorporated by ion-beam synthesis [1, 2]. The Si-based LED exhibits strong electroluminescence, tunable from the visible up to the UV region depending on the rare-earth element (e.g. Gd, Tb, Eu, Nd, Er). Currently, the Si-based LEDs are already available and best efficiencies were achieved by Tb or Er implantation with an external quantum and power efficiency of 16% and 0.3%. LOCOS (local oxidation of silicon) processing and an additional layer of SiON were applied to the device to improve the electrical stability and operation time. Our concept bases upon a Si-based photonic circuit which consists of the integrated LED, working as the light source, a newly fabricated dielectric strip-waveguide below a bioactive layer and a receiver. The dielectric strip-waveguide has a Si3N4 or SiON core, in which the light should be guided, and a cladding of SiO2. The receiver should be a photodiode (e.g. Ge, Si). In this work, we focus on the development and characterization of the dielectric waveguides. For theoretical pre-analysis we are using the finite element method by the FlexPDE software for calculating the mode profiles and resonance frequencies according to the cross sections of

the structures. The fabrication of the waveguides was done by plasma enhanced chemical vapor deposition (PECVD), photolithography and electron beam lithography. Obtained SEM results enabled an improvement of the fabrication recipe of the waveguides by using an additional Al-masking during the reactive ion etching (RIE). Furthermore, a new measurement setup is built up, which enables transmission measurements and the inspection of the beam profiles as well as the damping factors of the structures in dependence on their cross sections. In future, the theoretical calculations are going to be compared with the experimental results of transmission and beam profiling measurements. Moreover, the Si-based LED should be coupled with the waveguide e.g. by Bragg grating. Finally, this lab-on-a-chip system is showing a high potential to become an all-round applicable integrated sensor system, without using any external light sources or relay lenses, which is why it should be easily portable and customizable. [1] L. Rebohle, C. Cherkouk, S. Prucnal, M. Helm, W. Skorupa, Vacuum 83, 24 (2009) [2] L. Rebohle, T. Gebel, R.A. Yankov, T. Trautmann, W. Skorupa, J. Sun, G. Gauglitz, R. Frank, Optical Materials 27, 1055 (2005)

8767-39, Poster Session Thursday

Dot distribution type of grayscale photomask and colorscale photomask for fabrication diffractive and refractive microlens arrays

Qingle Tang, Huazhong Institute of Electro-Optics (China)

Recently, with the rapid development of the micro-fabrication technique of micro-optical devices and miniaturized optical systems with the feature size of micrometer or even small to nanometer, micro-optical structures, for instance, typical refractive and diffractive microlenses and micro-mirrors for main applications in optical communication, MOEMS, optical integration, military and biomedical imaging, wavefront detection, optical display, and optical data storage, etc., are finding increasingly widespread applications. So far, many methods to fabricate high quality microlenses with binary or continuous profiles, for example, photo-sensitive or thermal-sensitive shaping, hot- or UV-embossing, injection mounding, molding or casting, combination UV-photolithography with thermally reflowing, holographic exposure, sol-gel process, sputteringly etching or milling by ion beam, ion exchanging, X-ray or high energy beam lithography, micro-contact printing, directly writing by modulated lasers or e-beam, diamond turning, chemical or electrochemical process, and micro-structural formation by filling preshaped concave template with desired optical materials, etc., have already been extensively employed. Generally, the technique involving the conventional ultraviolet photolithography for prototyping photoresist microlenses leading to substrate microstructures needed, which defines the critical feature size and the layout of three-dimensional patterned structures, should be close to the demands of commercial mass production because of a longtime and relatively mature development of integrated microelectronic industry. However, for numerous applications of microlenses, the requirements including further simplifying technological flow, reducing production cost, shortening preparing and performing time, promoting fabricating precision, improving optical performance, forming feature microstructures over the curved surface of substrate treated, and having better compatibility with standard integrated circuit technology, etc., have continuously motivated investigators to explore more simple and reliable means.

Current researches show that the grayscale photomask techniques based on different working principles are inherent of very high resolution, and suitable to fabricate many kinds of micro-optics structures such as microlens, waveguide, and fine grating, etc[1-6]. So far many grayscale formation approaches including the micromirror projection display, the high energy beam sensitive glass photomask, the halftone photomask, the modulated scanning laser beam or e-beam method, the ion exchange processing, etc., have been developed. But mapping the layout of functional microstructures in photomask is usually a nonintuitive, complicated, time consuming, and expensive process.

The method based on microdrop distribution controlled by computer shows some attractive and competitive features compared to grayscale techniques mentioned above, such as low computational and fabricating cost, rapid arrangement of grayscale or colorscale microstructures, and allows for a more easily and rapidly understanding of designing requirements and parameter selection, because of the rapid advance of micro-jetting technology with precisely positioning function. The approach, which utilizes the grayscale or colorscale microstructures introduced in this paper, has a fine positioning and aligning accuracy in implementing pattern transferring, and then the pattern shaping errors can be remarkably decreased, and thus relatively complex micro-structures can be fabricated through common and inexpensive photolithographic facilities, so as to offer a potential of meeting the demands as above. In Sec. II, a grayscale model is established for describing the penetrating behaviors of UV-light in photolithography operation. In Sec. III, the colorscale technique for photomask is shown, which is similar to grayscale case. Finally, a brief summary is given.

By orderly distributing basic grayscale or colorscale microstructures introduced by us over polymer film for soft photomask utilized in single-mask photolithography, the pattern structures with multiple phase levels or smooth surface profile, which corresponds to the diffractive or refractive microlenses, respectively, can be obtained easily. According to the theoretical model and experimental relations between the transmitting power of UV-light and color with different brightness, the pattern structures with circle or non-circle (envelope) profile can be formed. It can be expect that the grayscale and colorscale technique based on microdrop jetting principle will play an important role in the mass production of many micro-optical structures.

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8767-40, Poster Session Thursday

Liquid-crystal tunable plasmonic stripe directional coupler switches

Dimitrios C. Zografopoulos, Romeo Beccherelli, Istituto per la Microelettronica e Microsistemi (Italy)

Plasmonic stripe waveguides have been proposed as a platform for inter-chip photonic interconnects, owing to their ease of fabrication, relatively low propagation losses, and the potential for dynamic tuning of the propagating signal via the direct application of a control current or voltage on the metal waveguide. Contrary to established approaches based on thermal tuning of the waveguide’s optical properties by current injection, in this work we design and theoretically study optical switches based on long-range plasmonic directional couplers, which are controlled via the electro-optic effect of nematic liquid crystal layers.

The switching dynamics of the nematic molecules are consistently solved, taking into account the coupling between the elastic and electrostatic underlying physical problems. Optical waveguiding properties are calculated by a fully-anisotropic finite-element-method,

and light propagation is modeled via the eigenmode-expansion method.

We systematically assess and compare the performance of both coplanar horizontal and stacked vertical configurations, providing a comparison in terms of performance characteristics, such as coupling length, switching voltage, insertion losses, crosstalk and bandwidth. These tunable plasmonic devices are envisaged as ultra-low power consumption switching elements in integrated platforms for optical inter-chip interconnects.

8767-18, Session 6

Electrically pumped Er-doped light emitting slot waveguides for on-chip optical routing at 1.54 µm

Joan Manel Ramirez, Yonder Berencén, Univ. de Barcelona (Spain); Oleksiy Anopchenko, Nikola Prtljaga, Univ. degli Studi di Trento (Italy); Pierrette Rivallin, CEA-LETI (France); Andrea Tengattini, Univ. degli Studi di Trento (Italy); Jean-Phillippe Colonna, Jean-Marc Fédéli, CEA-LETI (France); Lorenzo Pavesi, Univ. degli Studi di Trento (Italy); Blas Garrido Fernandez, Univ. de Barcelona (Spain)

We report here the development of a monolithically integrated electrically driven light source at 1.54 µm based on horizontal slot waveguides fabricated in a SOI platform. The slot waveguide layer stack is composed either of a SiO2 or a silicon-rich oxide doped with Er ions. Using horizontal slot waveguides allows injecting carriers in the slot where the active emitting species are located and at the same time provides light confinement and ensures good lateral propagation of light. Furthermore, we have been able to couple efficiently for the first time the light emitted by the active slot waveguide to a passive waveguide through an adiabatic slot taper. Finally, the photonic circuit is completed by coupling the light to the exterior through a grating coupler. Additionally, we have evaluated injected carrier losses finding that the light emitter can act as an optical modulator when a probe signal is injected. . To study this effect an electric pump & probe approach was conceived in order to determine parameters such as the modulation depth, on-chip propagation losses or d. c. operational power dissipation. A general device overview and future application perspectives will be given, providing a pathway for on-chip optical routing of Silicon-based photonic devices.

8767-19, Session 6

Light emission at telecom wavelengths from single-walled carbon nanotube

Adrien Noury, Nicolas Izard, Institut d'Électronique Fondamentale (France); Etienne Gaufrès, Univ. de Montréal (Canada); Xavier Le Roux, Laurent Vivien, Institut d'Électronique Fondamentale (France); Richard Martel, Univ. de Montréal (Canada); Masa Tange, Toshiya Okazaki, National Institute of Advanced Industrial Science and Technology (Japan)

Photonics has showed great potential for a lot of applications. Especially, using photons instead of electrons for data transmission may be a revolution. This new paradigm requires the development of efficient optical links including several building blocks: optical sources, modulators, detectors, multiplexers etc.

As silicon cannot be used as a light source mainly due to its indirect band-gap behavior, there is a need for finding a material able to emit light that would be compatible with silicon substrate and related technology. One promising candidate could be single-walled carbon nanotubes (SWNT). Indeed, optical properties of semiconducting SWNT (s-SWNT) have been intensively studied, but no significant progress was made in the extraction of only s-SWNT and their coupling in silicon photonic nanostructures.

In this paper, we studied semiconducting SWNT extraction method using ultra-centrifugation assisted by polymer. We demonstrated that emission intensity can be improved by about one order of magnitude and in some conditions a mono-emission from one nanotube chirality can be achieved. We optimized the material itself then we integrated it on several photonic structures. We first demonstrated the ability of nanotubes to emit light when drop-casted on top of a silicon waveguide and we investigated its thermal stability. We concluded over interesting integration ability on Silicon-On-Insulator (SOI) substrate, with coupling efficiency in the order of 10%.This is the first milestone to build a carbon nanotube based fully integrated LASER.

8767-20, Session 6

Efficient room temperature light emission from SiOCH thin films deposited by PECVD

Pierre Noe, Alexandre Mulot, CEA-LETI (France); Jean-Baptiste Jager, CEA-INAC (France); Vincent Calvo, Commissariat à l'Énergie Atomique (France); Vincent Jousseaume, CEA-LETI (France)

Silicon is known as a poor light emitter due to its indirect band gap. Various strategies have been developed to overcome its poor emission efficiency. The discovery of highly efficient silicon-based materials such as porous silicon or silicon nanocrystals opened the door to an all-silicon integrated optoelectronic circuit for photonic applications. The coupling of Er3+ ions with silicon nanocrystals embedded in silicon oxide or silicon nitride matrices has led to intensive studies in order to achieve a silicon-based light amplifier or laser emitting at the telecom wavelength of 1.5 µm. However, no evidence of optical gain of Er3+ at 1.5 µm has been achieve yet due to the low optical gain of Er and to the losses introduced by these silicon-based host matrices. The low invertible fraction of Er ions and the free carriers absorption of Si nanocrystals in competition with Er emission at 1,5 µm are the major limiting factors for net optical gain.

In this context, organosilicates SiOCH layers initially developed for "low-k" applications could be good candidates to succeed these challenges. In this work we show the emission properties of SiOCH thin films deposited by Plasma Enhanced Chemical Vapor Deposition (PECVD). The room temperature photoluminescence (PL) of the SiOCH films exhibits a broad emission band in the visible range. The PL correlated to C-related defects is tunable between 400 and 800 nm depending on the elaboration parameters such as the nature/ratio of precursors or post-deposition annealing treatments. PL external quantum efficiencies as high as 4% near 500 nm have been obtained and are near the state of the art of silicon-based luminescent materials. The films doped with Er show the typical 1.5 µm Er3+ emission. The behavior of the PL suggests that the excitation mechanism of Er3+ preferentially occurs by indirect excitation via the SiOCH matrix.

8767-21, Session 6

Warm white LED light by frequency down-conversion of mixed perylene-based dyes

Mauro Mosca, Fulvio Caruso, Leandro Zambito, Roberto Macaluso, Claudio Calì, Univ. degli Studi di Palermo (Italy); Eric Feltin, NOVAGAN (Switzerland)

The growing demand of the solid-state lighting market for the development of sources for illumination has led to the fabrication of the first white LED in 1997, which employed a blue LED coated by a Ce:YAG phosphor to mix the down-converted yellow light with the blue one. The white light appears cold due to the weakness of red components in the emission spectrum. In order to obtain a warmer white, one possible solution is to add a red phosphor to the yellow one to move the chromatic coordinates properly, though the luminous efficiency drastically decreases due to the increased light absorption of the coating layer. It is generally believed that the low efficacy of warm white LEDs is the main issue today.

Using photoluminescence of Lumogen® F Yellow 083 (BASF), a perylene-based polymer dye, we obtained a high efficiency cold white LED by generation of yellow down-conversion from a standard 450 nm GaN/InGaN blue LED with record values of 9.37 lm of luminous flux and 118.23 lm/W of luminous efficiency. The intense cold white light turned warmer, by adding a small quantity of another

perylene-based dye, Lumogen® F Red 305 (BASF). Different weight proportions of dyes were dissolved in solutions with equal amounts of poly-methyl-methacrylate (PMMA) in ethyl acetate. Finally, the LEDs were dip-coated in each solution and optically characterised.

Adding 2 mg of red dye to 10 mL of PMMA solution with 5 mg of yellow dye, the light turned into a purplish white with a dramatic decrease of the luminous efficiency (46.72 lm/W). Decreasing the amount of red dye to 0.5 mg, the white light appeared warm with a negligible decrease of the efficiency (116.11 lm/W) and a luminous flux of 8.03 lm.

8767-22, Session 7

Semi-insulating substrate based generic InP photonic integration platform

Norbert Grote, Francisco M. Soares, Klemens Janiak, Jochen Kreissl, Martin Möhrle, Fraunhofer-Institut für Nachrichtentechnik Heinrich-Hertz-Institut (Germany)

Monolithic photonic integration has been regaining a great deal of attraction during since the past decade. The dominant working method in photonics so far was to develop optimized fabrication processes for each application, starting from the specifications of the product. In contrast to this approach, in the frame work of the European projects EuroPIC and PARADIGM development of a generic photonic integration technology is being undertaken to be capable of realising complex InP based PICs from a small set of basic building blocks. In these R&D projects Fraunhofer HHI acts as one of the “foundry partners”.

A particular feature of HHI’s integration platform is the use of semi-insulating type substrate and waveguide layers which is regarded mandatory for implementing PICs with very high electrical bandwidth potential. Three well-characterized ridge waveguide variants differing in their guiding strength are currently offered on the platform as building blocks (BB), as are transition elements between these waveguides. Further waveguide-based passive (composite) BB available are: MMI couplers; Y-junction; waveguide crossings; circular arcs; and waveguide spot size converter (“10 µm” mode size). On top of the semi-insulating waveguides evanescent-coupled pin photodiodes of 40 GHz capability are integrated, forming a BB of its own. Relying on these elements a range of “receiver-type” PICs, including a Fiber-Bragg-Grating read-out chip and a WDM receiver with AWG demultiplexer, were designed and fabricated on multi-project wafers of 3” size. Very convincing performance was achieved on these early demonstrator PICs.

In the PARADIGM project extension of the platform is under development to additionally enable incorporation of laser-type BB’s. This is accomplished using MOVPE butt-joint growth of respective waveguide and detector layer stacks. In this way a highly complex PIC technology can be achieved, allowing for implementing both transmit and receive functionalities (Tx/Rx), besides passive-optical ones. DFB lasers integrated in this way showed already well-behaved characteristics (e.g. Ith <15 mA; SMSR > 40 dB). Various Tx/Rx test structures, for instance for on-chip stray light assessment, were fabricated, and a first Tx-type PIC including DFB lasers and electro-optic phase shifters was successfully demonstrated on this platform.

8767-23, Session 7

Heterogeneously integrated III-V/Si single mode laser based on a MMI-ring combination and triplet-ring reflectors

Shahram Keyvaninia, Steven Verstuyft, Univ. Gent (Belgium); Francois Lelarge, Guang-Hua Duan, Alcatel-Thales III-V Lab. (France); Sonia Messaoudene, Jean-Marc Fédéli, CEA-LETI (France); Tjibbe De Vries, Barry Smalbrugge, Jeroen Bolk, Meint K. Smit, Technische Univ. Eindhoven (Netherlands); Dries Van Thourhout, Gunther Roelkens, Univ. Gent (Belgium)

In this paper we show that using a DVS-BCB adhesive bonding process compact heterogeneously integrated III-V/silicon single mode lasers can be realized. Two new designs were implemented: in a first design a multimode interference coupler (MMI) – ring resonator combination is used to provide a comb-like reflection spectrum, while in a second design a triplet-ring reflector design is used to obtain the same. A broadband silicon Bragg grating reflector is implemented on the other side of the cavity. The III-V amplifier is heterogeneously integrated on the 400nm thick silicon waveguide layer, which is compatible with high-performance modulator designs and allows efficient coupling to a standard 220nm high index contrast silicon waveguide layer. In order to make the mode coupling efficient, both the III-V waveguide and silicon waveguide are tapered, with a tip width for the III-V waveguide of around 500 nm. The III-V thin film optical amplifier is implemented as a 3 µm wide mesa etched through to the n-type InP contact layer. In this particular device implementation the amplifier section was 500 µm long.

A waveguide-coupled output power up to 5 mW at 20°C and a side mode suppression ratio of more than 40dB is realized.

8767-24, Session 7

Ultra compact switching matrix on InP

Djamila Cherfi, Univ. des Sciences et Technologies de Lille (France)

The aim of the research is to design and fabricate a switching matrix permitting a microwave delay for the control of antennas array into embedded systems.

The matrix consists of two parts: first part is an “active region” with Digital Optical Switches (DOS) in InP allowing the operation of the device and the second one is a “passive region” in dielectric material guiding the light properly after switching. Thereby, the coupling has to be done between switches and dielectrics waveguides with a high optical confinement on same InP substrate to permit a monolithic integration.

DOS are a Y junction in InP integrated optics including a P-I-N junction in each output arms to allow carrier injection. In principle, the optical signal is equally separated into the two output branches without current injection, but when we inject current into one output arm, we obtain a lower refractive index and the optical signal is redirected into the other branch.

Simulations were executed to determine the geometry of dielectric waveguide with three dimensional beam propagation method (3D-BPM). A buried guide which constituted of a silicon nitride core and silicon oxide cladding materials with a nanotaper input which is an inverted taper (a tip) improving the fiber coupling (+50%) for these monolithic integration devices at 1.55µm wavelength.

Currently, the active structure used is an epitaxy grown using molecular beam epitaxy on n+ InP substrate. The device fabrication is in progress and the results aimed such as optical isolation (> 30dB), speed switching (nanoseconds), insertion losses (16dB), low consumption (45mW), no noise, polarization sensitive (10dB) and total length for the matrix (2.5mm).

To conclude, the coupling must be very good (with low losses) between each transition as Optical Fiber/Active structure (OF/AS) and Active structure/ Dielectric nanoguide (AS/DN). These tests realized provide results such as coupling losses of 1.8dB (OF/AS) and 0.5dB (AS/DN).

8767-25, Session 7

Characterization of spectral optical responsivity of Si-photodiode junction combinations available in a 0.35µm HV-CMOS technology

Andrea Kraxner, austriamicrosystems AG (Austria) and Graz Univ. of Technology (Austria); Ewald Wachmann, Ingrid Jonak-Auer, Jordi Teva, Jong Mun Park, Rainer Minixhofer, austriamicrosystems AG (Austria)

The 0.35µm HV-CMOS process technology from ams AG accessible via foundry customer services utilizes several junctions with different doping levels and depths. This process supports complete modular

3V and 5V standard CMOS functionality and offers a wide set of HV transistor types capable for operating voltages from 20V to 120V made available with only 2 more mask adders [1].

Compared to other reported integration of photo detection functionalities in normal CMOS processes [2] or special modified process technologies [3] a much wider variety of junction combinations is already intrinsically available in the investigated technology. Such junctions include beside the standard n+ and p+ source/drain dopings also several combinations of shallow and deep tubs for both p-wells and n-wells.

The availability of junction from submicron to 7µm depths enables the selection of appropriate spectral sensitivity ranging from ultraviolet to infrared wavelengths. On the other side by appropriate layouts the contributions of photocurrents of shallower or deeper photo carrier generation can be kept to a minimum.

We also show that by analytically modelling the space charge regions of the selected junctions the drift and diffusion carrier contributions can be calculated with a very good match indicating also the suppression of slow diffusion current contribution.

We present examples of spectral responsivity of junction combinations optimized for peak sensitivity in the ranges of 380-450nm, 450-600nm or 700-900nm. By appropriate junction choice the ratios of the generated photo currents in their respective peak zones can exhibit more than a factor of 10 compared to the other photo diode combinations. This enables already without further filter implementation a very good spectral resolution for colour sensing applications. Finally the possible junction combinations are also assessed by the achievable dark current for optimized signal to noise characteristic.

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8767-26, Session 8

A dense spot size converter array fabricated in a generic process on InP

Domenico D’Agostino, Emil Kleijn, Rui Santos, Huub P.M.M. Ambrosius, Meint K. Smit, Technische Univ. Eindhoven (Netherlands)

Integrated Spot Size Converters (SSCs) are key components for efficient coupling between Photonic Integrated Circuits (PICs) and fibre-arrays. We report a compact SSC which is suitable for integration into dense arrays with a pitch down to 25 µm and compatible with our generic InP-based platform technology, which supports integration of SOAs and Electro Optical Modulators with a range of passive components. The small pitch supports coupling tens of on-chip optical waveguide ports to fiber arrays via a low-loss dielectric interposer chip. The density allows the design of a customized optical bus between the InP PIC and the interposer chip. The dielectric chip may simply expand to the pitch of a fiber array but also contain low-loss passive circuitry like delay-lines, high Q-filters and multiplexers. The latter enables the formation of a hybrid integration platform with our InP-based technology. Efficient coupling is obtained by adiabatically transforming the sub-micron modes of the InP waveguides to the 3 µm diameter mode of the interposer. We tested our SSCs by coupling to a lensed fibre with a mode field diameter of 2.5 µm. Coupling losses were found to be as low as 0.7 dB per fiber chip coupling for device lengths of a few 100 µm. We also measured the crosstalk from one input port to output ports adjacent to the targeted output port. We present simple design rules for reducing the crosstalk to neighbouring output ports below -50 dB. The quality and uniformity of the SSCs is demonstrated by fabrication of an 8 x 8 AWG demultiplexer between two SSC arrays placed at input and output ports. We measured an insertion loss between fibres of 4 dB for the central channel of the AWG, which is record low for an InP-based device.

8767-27, Session 8

SWG dispersion engineering for ultra-broadband photonic devices

Robert Halir, Univ. de Málaga (Spain) and Andalusian Ctr. for Nanomedicine and Biotechnology (Spain); Alejandro Maese-Novo, Sebastián Romero-García, Diego Pérez-Galacho, Luis Zavargo-Peche, Univ. de Málaga (Spain); Alejandro Ortega-Moñux, Iñigo Molina-Fernandez, Univ. de Málaga (Spain) and Andalusian Ctr. for Nanomedicine and Biotechnology (Spain); Juan G. Wangüemert-Pérez, Univ. de Málaga (Spain); Pavel Cheben, National Research Council of Canada (Canada)

In most integrated optics platforms device design is restricted to variations in the lateral dimensions, and a small set of etch depths. Sub-wavelength gratings (SWGs) in silicon-on-insulator enable engineering of refractive index in a wide range ($\Delta n>1$), resulting in a variety of innovative high performance devices, ranging from waveguide-crossings to fiber-to-chip couplers [1]. SWGs exhibit a pitch smaller than the wavelength of light propagating through them, thereby suppressing diffraction and acting as a homogenous medium with an equivalent refractive index controlled by the duty-cycle [2]. Here, we propose to not only engineer refractive index, but to control SWG dispersion. We use this concept to design ultra-broadband directional couplers (DCs) and multimode interference couplers (MMIs) with a fivefold bandwidth enhancement compared to conventional devices.

The operation of DCs is governed by the beat-length of the even and odd supermodes propagating in the coupling region, and coupler bandwidth is ultimately limited by the variation of this beat-length with wavelength. We show that by judiciously embedding a SWG in the coupling region this variation can be significantly reduced, extending DC bandwidth from 20nm (conventional design) to up to 100nm (SWG assisted design).

In our ultra-broadband MMI design, the multimode region is completely substituted by a wide multimode SWG. In order to achieve ultra-broadband operation, flattening the beat-length with wavelength does not suffice, since the higher order modes must also follow specific phase relations to ensure good device performance. This is achieved with especially designed SWG tapers that launch light into the multimode region. The resulting structure operates over a 450nm bandwidth, while conventional MMIs cover only around 100nm.

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8767-28, Session 8

Theoretical model of an interleaved-chirped array waveguide grating (IC-AWG)

Bernardo Gargallo, Pascual Muñoz, Univ. Politécnica de Valencia (Spain)

In this paper, we propose a theoretical model for an Interleave-Chirped Arrayed Waveguide Grating (IAWG), modifying the already existing formulation based on Fourier optics. With the IAWG is possible to achieve several functionalities in only one device, such as channel demultiplexing, polarization splitting and 90º optical hybrid operation. Introduction of an incremental (or decremental) pattern in the length of the waveguide array, also known as “chirp”, allows for a non-destructive interference in spatial positions that are a fraction of the Brillouin Zone (BZ), as opposed to the non-chirped case. Moreover, this pattern can be designed so as to obtain four outputs per channel with the necessary relative phases of a 90º optical hybrid. By using large birefringence waveguides, is also possible to split both polarizations, focusing each one in a different point of the output plane. Our model corroborates that polarization dispersion as a function of wavelength, named as “Polarization-Dependent Wavelength Shift” (PDWS) in the literature, only depends on the effective refractive index of the waveguide array for each polarization. Moreover, the number and width of the IAWG channels is limited by

this parameter. We also elaborate on the developed model to present a design procedure for the IAWG. Finally, model validation through numerical simulations using real physical parameters obtained from manufactured devices available in the literature is performed.

8767-29, Session 8

Metamaterial-based sensor for skin disease diagnostics

Luigi La Spada, Renato Iovine, Richard Tarparelli, Lucio Vegni, Univ. degli Studi di Roma Tre (Italy)

In this paper the design of a multi-resonant metamaterial-based sensor operating in the optical frequency range is presented. The sensor consists of metallic resonating inclusions arranged in a planar array configuration.

It's well known that structural modifications of chromophores and pigments in skin produce variations of the optical properties of skin layers. In particular their absorption properties are modified.

A change in the electromagnetic properties, related to the the size and shape variation of chromophores and pigments, can be a useful tool for the recognition of different skin diseases.

The resonances of the sensor are designed to coincide with the aforementioned skin compounds spectral characteristics.

In case of skin diseases, the response of the sensor is greatly modified in terms of magnitude and amplitude width. In particular, a change in the frequency amplitude of the sensor response is related to the different absorption rate of skin chromophores and pigments.

In this paper, a new analytical model, describing the multi-resonant sensor behaviour, is developed. Then, by using the proposed analytical model, the sensor has been designed, in order to have multiple specific resonant frequencies, tuned to the skin components spectral characteristics.

Full-wave simulations have confirmed the capability of the proposed sensor to identify different skin diseases.

8767-30, Session 9

Low-loss SiNx waveguides in polymer

Ziyang Zhang, Dongliang Liu, Norbert Keil, Norbert Grote, Fraunhofer-Institut für Nachrichtentechnik Heinrich-Hertz-Institut (Germany)

Silicon (oxy) nitride optical waveguides featuring ultra low propagation loss have gained much research attention in recent years [1-2]. These investigations are mostly based waveguides embedded in silica-on-silicon material, usually involving high deposition temperature (> 500°C). In particular, those waveguide structures are not useful when thermo-optically tunable devices are to be realized, in contrast to polymer waveguides. Recently, at HHI we have developed a polymer-based hybrid integration platform [3-4]. Amongst other components, a very efficient thermally tunable waveguide grating laser was developed [5] exploiting the relatively large thermo-optical coefficient of polymers. Besides this and other advantageous features, polymers can be easily combined with virtually any other material to form inorganic/organic layer structures, which may significantly enhance the versatility of the integration platform.

In pursuit of this approach, we have developed a technology to deposit silicon nitride (SiNx, refractive index >1.83) directly on top of a polymer cladding layer (index 1.45) using low temperature plasma enhanced chemical vapor deposition (PECVD). Single-mode SiNx channel waveguides are then structured using conventional optical contact lithography. These waveguides show on average a propagation loss of ~ 0.7 dB/cm at 1550 nm as derived from cut-back measurements, with the polymer material absorption coefficient amounting to about 0.5 dB/cm. Depending on the thickness of the SiNx waveguide core, the optical mode can be designed to expand largely into the surrounding polymer cladding, such that the optical waveguide properties are essentially determined by the polymer material. In this way, a thermally tunable SiNx / polymer waveguide Bragg grating filter has been fabricated exploiting the relatively large thermo-optical coefficient of the polymer. Apart from waveguide fabrication, the main advantage of this approach is the enhanced selection of applicable polymer materials. The heating electrode is buried inside the polymer cladding to reduce the heating power. Despite the relative weak thermo-optic coefficient (TOC) of SiNx and its opposite sign compared to polymer material TOCs, the Bragg-grating wavelength could be tuned over more than 50 nm at a heating power of ~ 200 mW. Using the proven concept of coupling such a waveguide to a gain chip [5] a tunable laser will be demonstrated.

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8767-31, Session 9

Colloidal PbS nanocrystals integrated to Si-based photonics for applications at telecom wavelengths

Markus Humer, Romain Guider, Wolfgang Jantsch, Thomas Fromherz, Institute of Semiconductor and Solid State Physics (Austria)

In the last decade, Si photonics technology has made major advances in terms of design, fabrication, and device implementation. But due to Silicon's indirect bandgap, it still remains a challenge to create efficient Si-based light-emitting devices. In order to overcome this problem, an approach is to develop hybrid systems integrating light-emitting materials into Si.

A promising class of materials for this purpose is the class of semiconducting nanocrystal quantum dots (NQDs) that are synthesized by colloidal chemistry. As their absorption and emission wavelength depends on the dot size, which can easily be controlled during synthesis, they are extremely attractive as building blocks for nanophotonic applications and, for applications in telecom wavelength, Lead based colloidal NQDs are optimum materials due to their unique optical, electronic and nonlinear properties.

In this work, we experimentally demonstrate the integration of PbS nanocrystals into Si-based photonic structures like slot waveguides and ring resonators as optically pumped emitters for room temperature applications. In order to create such hybrid structures, the NQDs were dissolved into polymer resists and drop cast on top of the device. Upon optical pumping, intense photoluminescence emission from the resonating modes is recorded at the output of the waveguide with transmission quality factors up to 30000.

The polymer host materials were investigated as function of their stability confront to the photoluminescence emission. The waveguide–ring coupling efficiency was also investigated as function of the NQDs concentrations blended into the polymer matrix.

The integration of colloidal quantum dots into Silicon photonic structures as demonstrated in this work is a very versatile technique and thus opens a large range of applications based on the linear and non-linear optical properties of PbS NQDs at telecom wavelength.

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8767-32, Session 9

Experimental studies of cobalt ferrite nanoparticles doped silica matrix 3D magneto-photonic crystals

Elie Abou Diwan, François Royer, Renata Kekesi, Damien Jamon, Marie-Françoise Blanc-Mignon, Univ. Jean Monnet Saint-Etienne (France); Sophie Neveu, Univ. Pierre et Marie Curie (France); Jean-Jacques Rousseau, Univ. Jean Monnet Saint-Etienne (France)

Based on the non-reciprocity of magneto-optical interaction, the optical isolation function is particularly important to prevent unwanted light reflections. Although, it is not actually integrated since magnetic materials are difficult to integrate. Among several approaches, magneto-photonic crystals appear as a promising way to obtain efficient integrated isolators. In such systems, the periodic material structuration leads to the formation of photonic band gaps with an enhancement of the light-matter interaction near their edges. Building on our previous work on composite magneto-optical materials, three-dimensional magneto-photonic crystals based on magnetic nanoparticles-doped silica matrix were developed.

High-quality samples of 3D photonic crystals predicated on the self-assembling process of polystyrene spheres were prepared using the vertical deposition method. Then, these direct opals were impregnated with a homogeneous solution of sol-gel silica precursors doped by cobalt ferrite nanoparticles. Samples were later oven dried for 1 hour at 90°C. Afterwards the polystyrene spheres were dissolved in ethyl acetate. The resulting structure is a three-dimensional network of magnetic nanoparticles-doped silica matrix and spherical air voids.

SEM images of the prepared samples clearly show this periodic arrangement. The optical and the magneto-optical properties were measured with a classic spectrophotometer and a home-made spectral polarimeter. These optical benches enable us to measure the transmittance and the Faraday rotation of the non-doped and the cobalt ferrite nanoparticles-doped opals. Effectively, transmittance measurements evidence the existence of deep photonic band gaps. The spectral position of these band gaps is proportional to the diameter of the initial polystyrene spheres. The Faraday rotation measured as a function of the applied magnetic field clearly shows qualitative difference between the doped and the non-doped opals. Therefore the magnetic character of our samples is unambiguous. These are promising results to further study the behavior of the Faraday rotation near the edges of the photonic band gaps.

8767-33, Session 9

Direct imprinting on chalcogenide glass and fabrication of infrared wire-grid polarizer

Itsunari Yamada, Univ. of Shiga Prefecture (Japan); Naoto Yamashita, Toshihiko Einishi, Isuzu Glass Co., Ltd. (Japan); Mitsunori Saito, Ryukoku Univ. (Japan); Kouhei Fukumi, National Institute of Advanced Industrial Science and Technology (Japan); Junji Nishii, Hokkaido Univ. (Japan)

Infrared wire-grid polarizers are indispensable elements that are used in spectroscopic polarimetry and night-vision analysis. However, the current commercial infrared wire-grid polarizers that consist of metal wires with hundreds nanometer width become very expensive, since the fabrication process of them needs exposure, development and inductively coupled plasma reactive ion etching processes.

In this work, the infrared wire-grid polarizer consisting of an Al grating and a chalcogenide glass was fabricated by imprinting with the SiC mold and Al shadow coating processes. After coating a photoresist on a SiC substrate, we formed a grating pattern of 500-nm pitch by the two-beam interference of the He-Cd laser (325-nm wavelength). By using this photoresist grating as a mask, the WSi mask layer and the SiC substrate were etched using SF6 and CHF3 gases, respectively. To fabricate the subwavelength grating on a chalcogenide glass more easily, the sharp grating was formed on the mold surface. The imprinting temperature, pressure, and time were standardized at 253 °C, 3.8 MPa, and 90 sec, respectively. The gratings with 500-nm pitch and 260-nm depth were successfully obtained on the chalcogenide glass. The fabricated polarizer with Al grating thickness of 130 nm exhibited a polarization function with a transverse magnetic transmittance greater than 60% in the 5-9 μm wavelength range, and an extinction ratio greater than 20 dB in 3.5-11μm wavelength range.