SPIE. | PACIFIC RIM
SIOM | LASER DAMAGE

2016

PACIFIC-RIM LASER DAMAGE TECHNICAL PROGRAM.

WWW.SPIE.ORG/PLD

Conferences: 18–20 May 2016
Pacifico Yokohama, Yokohama, Japan

SPIE. | SIOM


4.46

SPIE. SIOM | PACIFIC RIM LASER DAMAGE

Conferences: 18–20 May 2016
Pacifico Yokohama, Yokohama, Japan

Welcome

Pacific-Rim Laser Damage (PLD) was initiated by Professor Jianda Shao of the Shanghai Institute of Optics and Fine Mechanics, China in 2011. This conference was held as a satellite meeting of SPIE Laser Damage Symposium in Boulder, Colorado, USA. The purpose of this meeting is to communicate with researchers in the field of laser damage and related phenomena especially in the Pacific-rim area. Normally, the PLD meeting was held biannually in Shanghai, China in 2011, 2013, and 2015. At the intermediate year, PLD'14 was held in Japan, and this PLD'16 meeting is also being held in Japan.

We are pleased the 5th Pacific-Rim Laser Damage (PLD'16) will be held at Pacifico Yokohama, Yokohama, Japan from 18-20 May 2016. PLD '16 provides good opportunities to exchange the results of research and discussions in close fields in laser damage research.

ORGANIZERS

Institute of Laser Engineering, Osaka Univ.

SPIE

SIOM

COOPERATING ORGANIZATIONS

Institute for Laser Technology

Laser Society of Japan

Japan Laser Processing Society

CONFERENCE CHAIRS

Takahisa Jitsuno
Osaka Univ.

Jianda Shao
SIOM

Wolfgang Rudolph
Univ. of New Mexico

CO-CHAIRS

Kunio Yoshida, Okamoto Opt. Works

Masataka Murahara, Tokai Univ.

Shinji Motokoshi, Institute for Laser Technology

MEMBERS

Hidetsugu Yoshida, Osaka Univ.

Jyunji Kawanaka, Osaka Univ.

Hajime Nishioka, Tokyo Elec. Comm. Univ.

Tomozui Kamimura, Osaka Inst. of Tech.

Norihiko Yamamura, Showa Optronics Co., Ltd.

Kiyoshi Suda, Sigma Koki Co. Ltd.

Minako Azumi, Nikon Corp.

Atsushi Yokotani, Miyazaki Univ.

Ryo Yasuhara, National Institute for Fusion Science

Masayuki Fujita, Institute for Laser Technology

PROGRAM COMMITTEE

Norbert Kaiser, Fraunhofer-Institut fur Angewandte Optik und Feinmechanik, Germany

Efim A. Khazanov, Institute of Appl. Phys., Russia

Zunqi Lin, SIOM, China

Yongfeng Lu, Univ. of Nebraska-Lincoln, USA

Richard Moncorge, ENSICAEN, France

Jean-Yves Natoli, Institut Fresnel, France

Valdas Sirutkaitis, Vilnius Univ., Lithuania

Christopher J. Stolz, LLNL, USA

Koji Sugioka, Riken, Japan

Takunori Taira, Institute. for Molecular Science, Japan

Mauro Tonelli, Univ. di Pisa, Italy

Eric W. Van Stryland, CREOL, Univ.of Cent. Florida, USA

Zhouling Wu, Rx Techn. Ltd., China

Xiaomin Zhang, China Acad. of Eng. Phys., China

Jiping Zou, Ecole Polytechnique, France

Seong-Ku Lee, GIST-APRI, South Korea

Karol Adam Janulewicz, GIST-APRI, South Korea

Plenary Presentation

Thursday 19 May · 09:00 to 09:30
Location: Room 413

Coatings for high power laser system in China

Jianda Shao
Shanghai Institute of Optics
and Fine Mechanics, China

ORGANIZERS

OSAKA UNIVERSITY
INSTITUTE OF LASER ENGINEERING

SIOM 中国科学院上海光学精密机械研究所
Shanghai Institute of Optics & Fine Mechanics Chinese Academy of Sciences

SPIE.

INVITED SPEAKERS

Invited speaker	Institute	Country	Title	Paper No.
A. Melninkaitis	University Vilnius	Lithuania	Femtosecond laser-induced damage: lessons learned from time-resolved measurements	PLD5-1
J. Krueger	BAM	Germany	Nanosecond laser damage of optical multimode fibers	PLD8-2
J. Du	Shanghai Institute for Optics and Fine Mechanics	China	Ultrafast carrier dynamics related to fs lasers-induced damage in optical coatings	PLD5-2
A. Fürbach	Macquarie University	Australia	Refractive index change mechanisms in different glasses induced by femtosecond laser irradiation	PLD9-1
C. Menoni	Colorado State University	USA	High performance interference coatings for near infrared high energy lasers	PLD1j-1
Z. Liao	Lawrence Livermore National Lab.	USA	Modeling of Laser Induced Damage and Usage at National Ignition Facility (Tentative)	PLD1j-2
K. Chen	Pittsburgh University	USA	Adaptive Laser Beam Forming for Laser Shock Micro-Forming for 3D MEMS Devices Fabrication	PLD8-3
Denis Penninckx	CEA	France	Laser damage measurement of thick silica plates using a new laser injection scheme	PLD8-1
A. Hervy	REOSK	France	Developments of high damage threshold meter-scale optical components for multi-PW lasers	PLD6-1

PLD16 TECHNICAL CONFERENCE

Thursday–Friday 19–20 May 2016
Proceedings of SPIE Vol. 9983

Pacific-Rim Laser Damage 2016: Optical Materials for High Power Lasers

Conference Chairs: **Takahisa Jitsuno,** Osaka Univ. (Japan); **Jianda Shao,** Shanghai Institute of Optics and Fine Mechanics (China); **Wolfgang Rudolph,** The Univ. of New Mexico (USA)

WEDNESDAY 18 MAY

OPIC PLENARY SESSION

Room: 501 + 502 . . . . . Wed 9:00 to 12:10

Lunch Break . . . . . Wed 12:10 to 13:30

PLD16 TECHNICAL CONFERENCE

OPENING REMARKS

Room: 301 . . . . . Wed 13:30 to 13:45

Session Chair: **Takahisa Jitsuno,** Osaka Univ. (Japan)

PLD1: LIC+PLD+SLPC JOINT SESSION I

Room: 301 . . . . . Wed 13:45 to 15:15

Session Chair: **Kunihiko Washio,** Paradigm Laser Research Ltd. (Japan)

13:45: **Optimized design and performance of laser ablation system for paint and coating removal for manufacturing and maintenance of vehicles and airplanes** *(Invited Paper)*, Young K. Kwon, Powerlase Photonics Ltd. (United Kingdom) . . . . . [SLPC5j-1]

No Abstract Available

14:15: **High performance interference coatings for near infrared high energy lasers** *(Invited Paper)*, Carmen S Menoni, Drew Schiltz, Dinesh Patel, Cory Baumgarten, Brendan Reagan, Colorado State Univ (USA) . . . . . [PLD1j-1]

We have recently demonstrated a diode pumped chirped pulse amplification system producing Joule-level pulses of picosecond pulse duration at repetition rates of 100 Hz. The development of this type of lasers which have numerous scientific and technological applications motivates our work in interference coatings for operation in the 1-2 μm wavelength range. This talk will describe the behavior of Ta_2O_5/SiO_2 interference coatings grown by ion beam sputtering under intense laser illumination at 1 and 1.6 μm. The laser damage behavior of these coatings will be compared to similar structures based on HfO_2/SiO_2.

14:45: **Modeling of laser-induced damage and optic usage at National Ignition Facility** *(Invited Paper)*, Zhi M Liao, Mike Nostrand, Jeffrey Bude, Tayyab Suratwala, Lawrence Livermore National Lab (USA) . . . . . [PLD1j-2]

Modeling for laser-induced optics damage would be introduced to benchmark existing damage usage at the National Ignition Facility (NIF) such as the number of optics exchanges and the number of damage sites requiring damage mitigation. NIF has pioneered a optics recycle strategy to allow it to run the laser at capacity while keeping the cost of optics usage manageable since fully commissioned in 2009. As we strive to increase the laser shot rate while maintaining the same cost, we will show how the damage model is being used to evaluate various strategies to streamline our optics loop efficiency.

Coffee Break . . . . . Wed 15:15 to 15:45

PLD2: LIC+PLD+SLPC JOINT SESSION II

Room: 301 . . . . . Wed 15:45 to 17:15

15:45: **Fiber delivery of ultrafast lasers**, Eric P. Mottay, Amplitude Systèmes (France). . . . . [SLPC6j-1]

No Abstract Available

16:15: **The latest technology demand of the internal processing type laser dicing technology**, Noaki Uchiyama, Hamamatsu Corp. (USA) . . . . . [LICj-1]

No Abstract Available

16:45: **Micro-laser based material processing**, Denis Barbier, Antoine P. Kevorkian, Teem Photonics S.A. (France). . . . . [LICj-2]

No Abstract Available

CLOSING REMARKS

Room: 301 . . . . . Wed 17:15 to 17:30

Session Chair: **Kunihiko Washio,** Paradigm Laser Research Ltd. (Japan)

OPIC Reception. . . . . 18:00 to 20:00

THURSDAY 19 MAY

SESSION PLD3

Room: 413 . . . . . Thur 9:00 to 10:15

Plenary and Coatings

Session Chair: **Takahisa Jitsuno,** Osaka Univ. (Japan)

9:00: **Coatings for high power laser system in China** *(Plenary)*, Jianda Shao, Shanghai Institute of Optics and Fine Mechanics (China) . . . . . [PLD3-1]

Optical coatings are essential components for laser systems. The rapid improvement of laser technology in recent years has driven the unprecedented development of optical coatings. Coatings for laser systems present requirements including transmission/reflection requirements at certain wavelength range, low wave-front distortion, as well as high laser-induced damage threshold (LIDT). Many works have been done to improve coating performance. The developments of the coating design, deposition process and post treatment process, as well as the understanding of mechanical and laser damage mechanism have promoted the advance the laser coatings. Large aperture mirror with reflectance higher than 99.8% at 1064 nm, and LIDT higher than 30 J/cm^2 (1064 nm, 5 ns) have been demonstrated. Large aperture polarizer with transmittance of p polarized light higher than 98% and reflectance of s polarized light higher than 99% at 1064 nm, as well as LIDT higher than 14 J/cm^2 (1064 nm, 5 ns) has been prepared.

9:30: **Laser-induced damage performance of high-reflectance coatings with co-evaporated interfaces at 1064nm**, Huanbin Xing, Jian Sun, Yingjie Chai, Meiping Zhu, Jianda Shao, Shanghai Institute of Optics and Fine Mechanics (China) . . . . . .[PLD3-2]

A type of innovative 1064nm high reflectance coatings with co-evaporated interfaces (CEI) was prepared by electron beam (EB) evaporation using Hf and SiO_2 as the starting materials. In contrast, conventional (CON) high reflectance coatings were also fabricated under the same deposition condition. Spectra, mechanical stress properties were evaluated and the chemical composition was studied using X-ray photoelectron spectroscopy. The laser induced damage performance was also investigated with 1-on-1 and s-on-1 test for both CEI and CON coatings. By using a scanning electron microscope, the damage morphologies were obtained. The damage threshold indicated that the laser damage resistance was improved obviously using the interface co-evaporation technique.

9:45: **Non-destructive investigations to highlight first stages of fatigue effect under multiple laser irradiations**, Jean-Yves Natoli, Frank R. Wagner, Alexandre Beaudier, Laurent Gallais, Konstantinos Iliopoulos, Institut Fresnel (France) . . . . . .[PLD3-3]

Under multiple laser irradiations it is often observed a decreased of LIDT versus the shot number. This decrease is identified as a “fatigue effect” in the material. In previous studies, we have highlighted that the origins of this “fatigue effect “ could be attributed to two main causes. The first one is due to a statistic effect of the multiple irradiations by increasing the probability to exhibit a damage precursor in the material. The second one is clearly due to a modification in the material induced by the multiple irradiations. Moreover, the results highlight a long incubation time of the induced modification in the material regarding the shot frequency.

In order to study the mechanism involved in the case of material modification in S:1 mode, it is interesting to undertake a non-destructive approach on the first stages, before breakdown. A first interesting result has been recently obtained by the observation of time-resolved images using pump-probe experiments in fs regime on thin films under repetitive irradiations.

In this paper, we will discuss different possibilities to observe the first stages of the material modification in fs and ns with examples on thin film and silica substrate. Technics as Z-scan, Pump-Probe or local fluorescence are respectively used to highlight local changes that operate in the irradiated area

10:00: **Ion-assisted coating for large-scale Bimorph deformable mirror**, Takuya Mikami, Takayuki Okamoto, Kunio Yoshida, Okamoto Optics Works, Inc. (Japan); Takahisa Jitsuno, Institute of Laser Engineering, Osaka University (Japan); Shinji Motokoshi, Institute for Laser Technology (Japan); Vadim Samarkin, Active Optics NightN Ltd (Russian Federation); Alexis Kudryashov, Moscow State University of Mechanical Engineering (Russian Federation); Jyunnji Kawanaka, Noriaki Miyanaga, Institute of Laser Engineering, Osaka University (Japan) . . . . . .[PLD3-4]

We have fabricated 410 x 468 mm size DFM with 100 Bimorph actuators for LFEX laser system in Osaka University. DFM substrate with the actuators was polished, and MLD coatings were deposited in our 80-inch ion assist coating chamber. Coating deposition was performed at the substrate temperature below 60 degree Celsius for protecting the actuators. The wavefront of the mirror was 7 μm just after coating, and reduced by aging to 1.6 um when the mirror was assembled. We will report details of fabrication such as the damage threshold of the mirror coating and the wavefront characteristics at the conference.

Coffee Break . . . . . .Thu 10:15 to 10:45

SESSION PLD4

Room: 413 . . . . . 10:45 to 11:45

Nonlinear Materials

Session Chair: **Jianda Shao,**
Shanghai Institute of Optics and Fine Mechanics (China)

10:45: **Dielectric coatings as frequency converters - the Frequency Tripling Mirror (FTM)** *(Invited Paper)*, Wolfgang Rudolph, Cristina Rodriguez, Luke A. Emmert, Univ of New Mexico (USA); Detlev Ristau, Stefan Günster, Laser Zentrum Hannover (Germany); Farzin Beygi Azar Aghbolagh, Amir Khabbazi Oskouei, Univ of New Mexico (USA) . . .[PLD4-1]

Dielectric thin films have exceptionally high sub picosecond laser damage thresholds and consequently can sustain high laser intensities. All materials have nonzero nonlinear optical susceptibility of third-order and can therefore generate third-harmonic (TH) radiation. Stacks of films can be designed to enhance TH generation by many orders of magnitude compared to single films. We demonstrate the first mirror of this kind showing conversion efficiencies at the percent level for subpicosecond pulses. Simulations indicate that scaling to more than ten percent is possible for incident fluences well below the laser damage threshold.

11:15: **Multilayer technology for terahertz pulse generation**, Yoshihiro Ochi, Keisuke Nagashima, Masaaki Tsubouchi, Fumiko Yoshida, Momoko Maruyama, Japan Atomic Energy Agency (Japan) . . . . . .[PLD4-2]

We have developed a new device for intense terahertz (THz) pulse generation due to the optical rectification in $LiNbO_3$ (LN) crystal. In order to satisfy the phase matching condition, the pulse front of a pump laser has to be tilted in the crystal by using a diffraction grating. The contact grating scheme in which the diffraction grating was directory fabricated on the LN crystal was proposed, however the diffraction efficiency was too small to generate THz pulse. To overcome this difficulty, we designed a new device with a multilayer composing Fabry-Perot resonator between the grating and LN substrate. The device was carefully designed so that the enhanced electric field in the multilayer did not exceed the damage threshold. We made prototype and confirmed that the diffraction efficiency was increased to 80% and THz pulse was generated by this device.

11:30: **Real-time analysis and mitigation of laser damage initiators on the surface of DKDP crystals**, Guohang Hu, Yuanan Zhao, Yueliang Wang, Dawei Li, Xiaofeng Liu, Zhen Cao, Shanghai Institute of Optics and Fine Mechanics (China) . . . . . .[PLD4-3]

A reliable method, combining raster scan process and real-time laser damage event imaging, has been developed to accurately determine the initiator inducing low-density laser damage at 355nm on the surface of DKDP crystals. It's revealed that there were three kinds of distinct initiators: fractures, digs and invisible defects. The fractures could produce laser damage at lowest fluence, but they had a few density. Most of laser damage sites were initiated at invisible defects. Furthermore, the density of invisible defects was decreased by laser conditioning process. But the scratches and digs cannot be mitigated by laser conditioning process. Based on these results, the composition of invisible defects were analyzed and discussed.

Lunch Break . . . . . .Thu 11:45 to 13:00

SESSION PLD5

Room: 413 . . . . . .Thu 13:00 to 15:15

Short Pulse Phenomena

13:00: **Femtosecond laser-induced damage: lessons learned from time-resolved measurements** *(Invited Paper)*, Andrius Melninkaitis, Balys Momgaudis, Linas Smalakys, Robertas Grigutis, Julius Vaicenavičius, Vilnius Univ (Lithuania); Stéphane Guizard, CEA-IRAMIS/CNRS/Ecole Polytechnique (France); Laurent Gallais, Institut Fresnel (France); Valdas Sirutkaitis, Vilnius Univ (Lithuania). . . . . .[PLD5-1]

No Abstract Available

13:30: **Ultrafast carrier dynamics related to fs lasers-induced damage in optical coatings** *(Invited Paper)*, Juan Du, Zehan Li, Shanghai Institute of Optics and Fine Mechanics (China); Bing Xue, Takayoshi Kobayashi, The Univ. of Electro-Communications (Japan); Fanyu Kong, Yunxia Jin, Yuanan Zhao, Yuxin Leng, Jianda Shao, Shanghai Institute of Optics and Fine Mechanics (China). . . . . .[PLD5-2]

Femtosecond laser-induced damage of dielectric coatings seriously restricts the development of laser systems with ever higher average powers and peak intensities, and optical components like dielectric mirrors and gratings with higher breakdown thresholds are highly desired. It has been proved that in the femtosecond pulse regime, the damage of optical materials displays highly deterministic damage performance, which is considered to be closely related to the nonlinear ionization processes, such as multiphoton ionization (MPI), avalanche ionization (AI), and decays of electrons associated with the diffusion and recombination of electrons. Therefore, it is of great importance to research on the intrinsic response dynamics inside the dielectric coating materials after ultrashort intense laser excitation and have an understanding of the origin and mechanism of laser-induced damage threshold (LIDT) in UV HR coatings, which is desirable for improving the LIDT. In the present study, femtosecond laser pulses are used in femtosecond laser damage test and ultrafast laser spectroscopy experiments in high dielectric reflectors and dielectric gratings. Laser-induced damage threshold and ultrafast carrier dynamics related to the laser-induced damage processes inside the dielectric layers has been investigated.

14:00: **In situ imaging and control of layer-by-layer femtosecond laser thinning of graphene**, Yongfeng Lu, Dawei Li, Yunshen Zhou, Xi Huang, Univ. of Nebraska-Lincoln (USA); Lan Jiang, Beijing Institute of Technology (China); Jean-Francois Silvain, Institut de Chimie de la Matière Condensée de Bordeaux (France) . . . . . .[PLD5-3]

Graphene as a archetypical two-dimensional (2D) nanomaterial exhibits unique and fascinating physical properties, which makes graphene suitable use in a wide variety of applications, such as transistors, transparent conducting electrodes, optoelectronics, Hall effect sensors. To realize the use of graphene in these applications, the most important challenge is controlled fabrication. Although existing methods (chemical vapor deposition, mechanical exfoliation, etc.) are available to produce graphene, the lack of thickness control limits further graphene applications.

Laser-thinning is a new technique for modifying graphene and other related 2D layered nanomaterials. In this work, we demonstrate an approach to precise thinning of graphene films to a specific thickness using a femtosecond (fs) laser raster scanning. By controlling laser fluence and scanning duration, graphene thinning with an atomic layer precision, namely layer-by-layer graphene removal, has been realized. Graphene with smooth surface and controlled thickness is produced. An fs-laser-based four-

wave mixing (FWM) system is developed that is capable of distinguishing graphene of different thicknesses and counting the number of layers using the linear relationship between the FWM signal intensity and the graphene thickness, which is more accurate and much faster than Raman microscopy. Furthermore, FWM imaging has been successfully applied to achieve in situ, real-time monitoring of the fs laser graphene thinning process based on the large optical nonlinearity of graphene. This method can not only realize large-scale thinning of various 2D nanomaterials with atomic layer precision, but also provide in situ, rapid imaging capability of 2D nanomaterials for accurate assessment of the number of layers.

14:15: **Confined Ablation on the SiO_2/Si Interface with Embedded Nanoparticles**, Zia U. Rehman, Le T. Na, Gwangju Institute of Science and Technology (Korea, Republic of); Chee Leong Tan, Northwestern Univ. (USA); Karol A. Janulewicz, Gwangju Institute of Science and Technology (Korea, Republic of). . . . . .[PLD5-4]

Laser-induced micro-explosion produced by tightly focused femtosecond laser pulse inside a transparent material generates extreme conditions with a very high pressure and temperature potentially offering a more favorable route to study formation of new metastable states of material. In our experiment, a composite material consists of a 10 μm-thick layer of SiO_2 covering monocrystalline silicon (c.Si). The interface between them was doped with metal nanoparticles. A confined micro-explosion at the SiO_2/Si interface was initiated by a tightly focused femtosecond laser pulse of ~40 fs duration. A mixture of Au and Ag nanoparticles was used as the doping material. Intensity on the order of ~10^{14} Wcm^{-2} , well above the optical breakdown of SiO_2 and Si, was used to drive the breakdown. The layer of silica in front of the crystalline silicon gave an interaction geometry converting ablation of silicon to the confined one. Additionally, it generated conditions with a high temperature and pressure, easily exceeding those in the classical ablation of silicon. Inclusion of Au-Ag nano-particle aimed to benefit from plasmonic effect by further enhancement of the field intensity. This would offer favorable conditions to the formation of new metastable states of silicon. Transmission electron microscopy (TEM) were used to investigate structural modification at the sites of the laser-induced damage. Irradiation results for SiO_2 /Si without Au-Ag nanoparticles was used as a reference. TEM analysis revealed presence of a laser-modified volume in SiO_2 and Si with dramatically different features, if compared to the pristine region. High resolution transmission microscopy (HRTEM) and selected area electron diffraction patterns (SAED) applied to the region of the modified Si showed amorphisation, nano-crystalisation and crystal twining. Experiments with two different energies irradiating the SiO_2/c-Si interface with and without nanoparticles show clear dependence of morphology on the driving energy. Presence of nanoparticles causes the phenomenon of crystal twining even at very modest energy.

14:30: **Interferometric analysis of optical breakdown dynamics in bulks of transparent dielectrics induced by sub-nanosecond laser pulse**, Vinh H. Nguyen, Na T. Le, Zia U. Rehman, Karol A. Janulewicz, Gwangju Institute of Science and Technology (Korea, Republic of) . . . . . .[PLD5-5]

The femtosecond time-resolved interferometry in Nomarski arrangement using a Fresnel-biprism was applied to study dynamics of laser-induced optical breakdown in bulks of fused-silica glass and sapphire when irradiated by a sub-nanosecond laser pulse at 790 nm. Formation of the breakdown plasma resulted from an efficient laser energy deposition in a limited volume (confined geometry). The extreme conditions (very high p and T) forced ultra-fast plasma heating and further, a fast expansion of the breakdown-affected area. The interferograms were processed by a dedicated numerical fast-Fourier-transform-based code. The transient electron density distribution in the plasma produced by the laser beam in bulk of fused-silica glass was reconstructed from the phase shift map by the inverse Abel transform. The plasma channel core exhibited a strong and fast change of the induced refractive index resulting from a growth in plasma electron density up to 1020 cm^{-3} and was expanding with supersonic (~102 km/sec) speed in the axial direction. It was found that the plasma channel dynamics and the generated shock waves fulfill the theoretical predictions by Sedov developed for the classical detonation. In the recorded interferograms of sapphire an anomalous fringe shift (in the opposite direction than expected) was observed in the central part of the plasma channel. This may imply contribution of the bound electrons to the refraction index of laser-induced plasma in bulk of sapphire due to significant amount of highly ionized Aln+ ions.

14:45: **Plasma dynamics and phase transitions in optical breakdown of transparent dielectrics**, Karol A. Janulewicz, Zia U. Rehman, Na T. Le, Vinh H. Nguyen, Khoa A. Tran, Gwangju Institute of Science and Technology (Korea, Republic of) . . . . . .[PLD5-6]

Dynamics of an optical breakdown was investigated by femtosecond time-resloved shadowgraphy and interferometry. The velocities of the plasma expansion and the generated shock waves suggest detonation-like character of the breakdown. Extreme conditions connected with the occurring processes resulted in a very rich spectrum of the morphological changes with a special focus on the phase transitions. The morphological changes were investigated by photoluminescence, X-ray diffraction, Raman scattering and different forms of microscopy.

15:00: **Spatial-temporal distortions and calibration of ultrashort pulses in complex optical systems**, Jing Liu, Zhenrong Zheng, Linjing Zhu, Shengqian Chang, Anqiu Chen, Siqi Liu, Fei Yuan, Haiyu Zhang, Zhejiang Univ. (China) . . . . . .[PLD5-7]

Ultrashort laser pulse has been widely used in various applications. Its parameters, such as the pulse duration and the spectral bandwidth, should be controlled accurately in order to achieve high spatial and temporal resolution, as well as high local field intensity. In this paper, we proposed a powerful method to trace the propagation of ultrashort pulses through the optical system, especially the complex optics, whose elements' properties might greatly influence the spatial-temporal performances of pulses. The approach was developed based on the geometrical ray-tracing method combined with wavefront theories, in which the material's dispersion and optical aberrations were both taken into consideration. In the simulation, the spatial-temporal characteristics of a femtosecond laser pulse after passing through a specific practical imaging system were calculated and analyzed. As the numerical result of spatial-temporal performances showed great deviation from the initial one, the calibration arrangement was employed to compensate for those undesired distortions. The negative dispersion of the optical grisms (the combination of gratings and prisms) was utilized in the process of calibration to offset the positive dispersion introduced by lens. The final result showed good correction of the dispersion and verified the effectiveness of the proposed method, so it might be an effective alternative in the practical application of ultrashort pulses.

Coffee Break . . . . . .Thu 15:15 to 15:45

SESSION PLD6

Room: 413 . . . . . Thur 15:45 to 17:15

High Power Resistant Coatings

Session Chair: **Shinji Motokoshi,** Institute for Laser Technology (Japan)

15:45: **Developments of high damage threshold meter-scale optical components for multi-PW lasers** *(Invited Paper)*, Adrien Hervy, REOSC (France); Laurent Gallais, Institut Fresnel (France); Gilles Chériaux, Lab. pour l'Utilisation des Lasers Intenses (France); Daniel Mouricaud, Slimane Djidel, REOSC (France); Antoine Fréneaux, Lab. pour l'Utilisation des Lasers Intenses (France); Jean-Paul Chambaret, Catherine Leblanc, Matthieu Somekh, François Mathieu, Laboratoire d'Utilisation des Lasers Intenses, Ecole Polytechnique (France); Nicolas Bonod, Institut Fresnel (France); Arnaud Cotel, HORIBA Jobin Yvon S.A.S. (France); Frédéric Desserouer, HORIBA Jobin Yvon (France); Olivier Utéza, Raphael Clady, Marc Sentis, Aix Marseille Université, CNRS, LP3 UMR 7341 (France). . . . . .[PLD6-1]

Number of multi PW lasers is being built over the world in the coming years. The laser pulses will exhibit high energy up to few hundreds of joules with their duration down to 15 fs. This means that mirrors or gratings used for these systems have to present high reflectivity in large spectral bandwidth, low GDD (Group Delay Dispersion) and at the same time an excellent laser-induced damage threshold (LIDT). Moreover, the stress of the coated stack has to be controlled in order to keep the wave front of the laser beam as flat as possible.

An intensive study of material behaviors, as single layer and into stacks, in the femtosecond regime, has been performed on sample prior to the production of the real optical components with optimized design. Layers are deposited by electron beam deposition technology with ion assistance.

We will present exhaustive results on dielectric coated and hybrid metal-dielectric coated mirrors suitable for 10 PW laser beam transport in p and s polarizations with LIDT between 0.5 and 1 J/cm^2. Results will also be presented on a new generation of hybrid metal-dielectric gratings with its damage threshold 3 times higher than gold gratings.

16:15: **Revealing the nature of laser-induced damage from ultra-fast response of dielectric coatings**, Andrius Melninkaitis, Balys Momgaudis, Linas Smalakys, Robertas Grigutis, Julius Vaicenavičius, Vilnius Univ (Lithuania); Stéphane Guizard, CEA-IRAMIS/CNRS/Ecole Polytechnique (France); Laurent Gallais, Institut Fresnel (France); Valdas Sirutkaitis, Vilnius Univ (Lithuania) . . . . . .[PLD6-2]

Vast majority of ultra-short (fs) lasers operate under extreme load of high peak- or average- optical power: close to so called laser-induced damage threshold (LIDT) limit. It causes a risk of failure for of built in dielectric optical components and coatings. In case of failure sufficiently high optical energy is transferred to material via nonlinear absorption process within a short time corresponding to laser pulse duration. As multiple events happening at the same time are very fast thus making direct observation of damage process rather complicated. We applied principles of commonly used experimental techniques and namely digital holographic microscopy and pump-probe to reveal the nature of laser-induced damage in dielectric coatings with sub pump pulse temporal resolution. Experimentally observed data from damage process were then reproduced numerically by considering kinetic rate equations of material response as well asdynamics of standing wave effects within coatings.

16:30: **Study on the laser induced damage of low dispersion mirrors**, Jinlong Zhang, Bin Ma, Xinbin Cheng, Zhanshan Wang, Tongji Univ. (China) . . . . . .[PLD6-3]

The femtosecond-pulsed, petawatt laser facilities are under construction worldwide for a number of research projects. In order to generate shorter and higher power pulses, one need broadband transport mirrors with high reflectivity, relatively low dispersion and practical resistance to high intensity. In this paper, we pursue the aim of developing low-dispersion mirrors for a 30-fs laser system that affords high damage threshold both in the sub-nanosecond laser and femtosecond laser pulse. Low-dispersion mirrors with different materials and electric field distribution were designed and manufactured by electron beam evaporation. One mirror consists of alternating quarter-wave Ta_2O_5, HfO_2 and SiO_2 layers to achieve the spectral bandwidth and high laser damage resistant. The other one is composed of non-periodic HfO_2 and SiO_2 layers to optimize the electric field distribution together with the required spectral and dispersion property. The sub-nanosecond and femtosecond laser induced damage tests show that the HfO_2/ SiO_2 low-dispersion mirror possesses relatively higher laser induced damage threshold than the three-materials mirror. The influence of the coating materials, the E-field distribution and the defects to the laser induced damage threshold is analyzed to understand the laser damage mechanism of the low-dispersion mirrors.

16:45: **The investigation of laser induced damage threshold of multilayer mirrors under the simultaneous irradiation of two wavelengths**, Muneo Sugiura, Koichi Tamura, Tokai Optical Co., Ltd. (Japan); Mitsunobu Kobiyama, Tecwave Co., Ltd. (Japan); Shinji Motokoshi, Institute for Laser Technology (Japan); Takahisa Jitsuno, Institute of Laser Engineering, Osaka University (Japan) . . . . . .[PLD6-4]

Many solid state lasers emit near-infrared pulses, and the harmonics are used for microfabrication, high-rate processing and so on. In the harmonic generation processes, multilayer coatings must withstand the high power density of the fundamental and the harmonic pulses.

Recently, it has been reported through experimentation that multiple wavelengths of irradiation degrade the laser damage resistance of the coatings. In this study, while noting the interference between the two pulses with different wavelengths, the laser induced damage threshold (LIDT) of a multilayer mirror was investigated. We have designed a mirror for high power laser by extending the conventional design method to accommodate multiple irradiation cases, while considering electric field intensities in the mirror. For single wavelength irradiation, the LIDT of the mirror is 112J/cm^2 for a λ=1064nm pulse, and is larger than 180J/cm^2 for a λ=532nm pulse, where the pulse width is 10ns. In the 1064nm and 532nm simultaneous irradiation experiment, the fluence of the 1064nm pulse was increased step by step while setting the fluence of the 532nm pulse at 165J/cm^2, where the polarized states of the pulses are the same. Damage occurred at 97 J/cm^2. The decrease of the LIDT compared to

only that of the 1064nm pulse could be caused by the interaction with the 532nm pulse. To clarify the interference effect between the two pulses, we are planning an experiment where we examine how the LIDT's changes occur by changing the relative polarized states of the two incident pulses.

17:00: **The damage characteristics of the high -reflection coatings irradiated from the active gain medium**, Xiaofeng Liu, Shanghai Institute of Optics and Fine Mechanics (China) . . . . . .[PLD6-5]

The active-mirror architechture is used widely in high power laser systems and is being extended to larger aperture high power laser system. It is characterized by the pump laser input (or heat sink) from the HR-coated surface of the active gain medium, and the amplified laser output from the opposite surface . It can make the laser system size compact, the pump easy, multi-pass convenient, and so on. This paper focuses on the damage characteristics of high -reflection coatings deposited on the active gain medium . The active gain medium used is Nd glass. One surface of it is HR-coated for1053nm, and its other surface is uncoated. The nanosecond laser, with a wavelength of 1053nm at a 56.5° incidence angle with "P" polarization, irradiates the active mirror from the Nd glass. The experimental results show that the damage thresholds(LIDTs) of the coatings are lower than those irradiated from the HR-coated surface. When irridiated from the Nd glass,the damage morphologies behave as flat bottom pits. The impurities or defects on the substrate surface as well as the high electric field on the interface between the coating and the substrate, are proved to be contributed to the low LIDTs. The LIDTs of the coatings deposited on the ultrasonic are higher than those deposited on the hand-wiping Nd glasses.After optimizing the coating design to decrease the electric field on the interface between the coating and the substrate, the LIDT is improved obviously.

FRIDAY 20 MAY

PLD7: POSTER SESSION

Room: Exhibition Hall A . . . . . .Fri 9:00 to 10:15

Improvement of resist stripping efficiency without causing laser-induced surface damage, Kosuke Nuno, Yuta Kuroki, Osaka Institute of Technology (Japan); Seizi Takagi, Osaka City Univ. (Japan); Takanobu Yamashiro, Singo Tuzimoto, Osaka Institute of Technology (Japan); Ryosuke Nakamura, Osaka Univ. (Japan); Takashi Nishiyama, Osaka City Univ. (Japan); Tomosumi Kamimura, Osaka Institute of Technology (Japan); Hideo Horibe, Osaka City Univ. (Japan) . . . . . .[PLDp7-1]

Removal of the resist by laser irradiation instead of chemicals has the advantage of reducing environmental risks. An advanced laser resist stripping method for the positive-tone diazonaphthoquinone (DNQ) / novolak resist was successfully developed without causing the laser damage to the Si wafer. To improve processing speed, it is necessary to enlarge the beam size from current 0.2 mm in diameter. In this study, we have investigated the relationship of the beam size and the resist stripping efficiency in an advanced laser resist stripping method.

The beam size on the resist surface was changed from 0.3 mm to 3.0 mm. An intensity shape of the laser beam was Gaussian shape. At a beam diameter of 0.3mm, the stripped resist area in a beam was 15 % of 0.01 mm^2. In the case of beam diameter of 3.0 mm, the stripped resist area in a beam was 5 % of 0.38 mm^2. The stripped area improves 38 times for scale-up of the beam area of 100 times. The resist stripping efficiency was thought to depend on the heat stress due to a temperature gradient between the beam center and the regions without laser irradiation. Irradiation with multiple laser beam by small beam diameter was confirmed as one of the methods for improvement of a resist stripping rate with high efficiency. Laser beam was divided into four and irradiated the neighboring resist surface at the same time. The resist was stripped at four irradiated spots. For the improvement of processing speed with high resist stripping efficiency, the simultaneous irradiation with multiple beams by small beam size will be one of the candidates.

Laser beam holographic patterning for thin film epitaxial growth monitoring with rheed for using as mev laser compound nuclear cavity material, Mohammad M. Anwar, Asiatic Society of Bangladesh (Bangladesh) . . . . . .[PLDp7-2]

Laser beam stimulated emission of radiation can be possible to have high energy as mev range by using compound nuclear material cavity for laser and pumping using gamma radiation and we can make such compound nuclear material using laser beam patterning for some semi conducting material as compound material active laser cavity by using laser beam

3 d holographic patterning and designing using standard model so that by population inversion using laser beam we may have mega electron volt laser energy and the epitaxial thin film growth for compound nuclear active material we can monitor the growth using reflection high energy electron diffraction monitoring system.

Effect of Laser Beam Parameters on Melt Mobilization and LIBS Analysis of a Special Aluminum Alloy Containing Zeolite, Osama M. Khalil, Cairo Univ. (Egypt); Nakimana Agnes, Changchun Univ. of Science and Technology (China). . . . . .[PLDp7-3]

Aluminum alloy containing zeolite was analyzed by using nanosecond and femtosecond laser-induced breakdown spectroscopy (ns and fs-LIBS). The results reveal that Laser parameters, target physical properties, and ambient conditions affect the laser ablation process. The aluminum silicate minerals present in the alloy under investigation enable material volume expansion under compression. In laser interaction with this alloy, it has been observed that the crater depth decreases with the increase of the surface hardness. In ns –LIBS, it is noted that the ablation speed decreases with time and suddenly decreases with less sharp slope and after that the ablation speed increases slightly. In additional the results show the vanishing and reform of the crater rim with the increase of ablation time. Furthermore, a comparison between ns and fs-LIBS analysis has been done. Ns-LIBS analysis reveals that both spectra intensity and lines detection are significantly influenced by the ambient conditions. However in fs-LIBS, the ambient conditions affect the presented lines amplitude and width with the same effect on all lines.

Ultrashort pulse laser slicing of semiconductor crystal, Eunho Kim, Yasuhiko Shimotsuma, Masaaki Sakakura, Kiyotaka Miura, Kyoto Univ. Graduate School of Engineering (Japan). . . . . .[PLDp7-4]

Silicon carbide (SiC) is one of the key materials which have excellent characteristics of its wide band gap semiconductor. Meanwhile, it is difficult to slice of SiC crystal without the reserving space for cutting by the wire-saw technique, owing to its extremely high hardness. In this study, we have achieved exfoliation of 4H-SiC single crystal by femtosecond laser induced slicing method. By the femtosecond laser slicing technique, the exfoliated surface with the root-mean-square roughness of 3μm and the cutting-loss thickness smaller than 20μm was successfully demonstrated. We have also observed the nanostructure on the exfoliated surface in SiC crystal.

Synthesis of fluorescent nanocarbons by femtosecond laser induced plasma in liquid, Naoki Agatsuma, Yusei Fujimatsu, Yasuhiko Shimotsuma, Masaaki Sakakura, Kiyotaka Miura, Kyoto Univ. Graduate School of Engineering (Japan). . . . . .[PLDp7-5]

Fluorescent Carbon nanoparticles (CNPs) with tunable emission are expected as the next generation green nanomaterials for the useful applications ranging from bioimaging probes, photocatalysts, to optoelectronic devices. Meanwhile, the emission properties of CNPs are not fully understood yet. Here we report that the synthesis of CNPs from the water suspension of graphene oxide by the femtosecond-laser induced plasma. Furthermore, the luminescence properties are controllable by doping nitrogen into CNPs from ammonia solution. More interestingly, we have confirmed that CNPs with diamond structure can be precipitated from the organic solvent molecules.

Mitigation of BSG damage caused by upstream flaw in the final optics assembly, Zhaoyang Jiao, Mingying Sun, Dongfeng Zhao, Jianqiang Zhu, Shanghai Institute of Optics and Fine Mechanics (China) . . . . . .[PLDp7-6]

In high-power laser facilities for the inertial confinement fusion, there are many large-diameter optical elements, which inevitably have some flaws on the surface. The flaws can cause optical intensity intensification and therefore damage the optical elements in the downstream, especially for the beam sampling grating (BSG), which is an important element in the final optics assembly. In this paper, several physical models are established to study the optical field enhancement in the BSG position modulated by upstream flaw. Firstly, when only the linear transportation is considered, it is found that there is a peak or valley of the maximum intensity after the focus lens compared with the ideal wave front. Meanwhile the influence of flaw has a effective range. Secondly, when the nonlinear effect of the focus lens is also considered, the peak maximum downstream is much bigger than the one for the linear consideration and the damage risk of the BSG there is much higher too . From the simulation, we can see that it is important to place the BSG in a properly selected position to mitigate the laser induced damage. The results could give some references to the mitigation of BSG damage caused by upstream flaws and the layout of the final optics assembly.

Design and fabrication of random antireflective nanostructures on fused silica in the ultraviolet, Weili Zhang, Shanghai Institute of Optics and Fine Mechanics (China); Jiaoling Zhao, Shanghai Institute of Optics and Fine Mechanics (China) and University of Chinese Academy of Sciences (China); Hu Wang, Feifei Tu, Shanghai Institute of Optics and Fine Mechanics (China) and Univ. of Chinese Academy of Sciences (China); Xiaofeng Liu, Meiping Zhu, Shanghai Institute of Optics and Fine Mechanics (China) . . . . . .[PLDp7-7]

Antireflective nanostructures (ARNS) with enormous advantages of AR surface have many potential applications in high power laser system, solar cell and aerospace, which would be substitution for AR coatings in the ultraviolet. The effective media analysis and genetic algorithm were used to optimize the refractive index profile of the ARNS, and the structural parameters of the optimized ARNS were obtained for reducing the reflection

in the ultraviolet. Random antireflective structures were fabricated on fused silica by the thermal dewetting process and reactive ion etching. The structure properties of ARNS were studied by scanning electronic microscopy and atomic force microscopy, the transmittance and reflectance were measured by spectrophotometer. We can conclude that the structure quality is controlled by the film thickness and the annealing temperature respectively. The film thickness can control the surface coverage rate of the nanomask as well as the particle size. The annealing temperature can control the particle quality, in which an optimal anneal temperature exists for every coating thickness. The transmittance of ARNS in the ultraviolet is limited by the scattering from the etched structures. Finally, the laser damage of ARNS and AR coatings on fused silica were analyzed in the ultraviolet.

Damage analysis of CMOS electro-optical imaging system by a continuous wave laser, Sunghee Yoon, Kyung-Young Jhang, Hanyang Univ. (Korea, Republic of); Wan-Soon Shin, Agency for Defense Development (Korea, Republic of). . . . . .[PLDp7-8]

The studies on the interaction between laser and material have been conducted actively, whereupon the study of laser-induced damage to various materials is necessary. In this study, the damage of CMOS EOIS (electro-optical imaging system) induced by CW (continuous wave) NIR (near infrared) laser was experimentally investigated. When the laser was emitted to CMOS EOIS, the temporary damage was occurred first and then the permanent damage was followed as the increase of laser irradiance and irradiation time. Dazzling on the image was appeared as a temporary damage during the laser beam irradiation. But it disappeared immediatly when the laser was turned off. And by further increment of the laser irradiance and time, the blurring image and black screen as a permanent damage were occurred. The blurry image was caused by melting of camera lenses. When the lens melts, it is difficult to concentrate rays of light into focal-plane via lenses. And when the lens guide made of plastic melts, the lens was covered with black melted plastic debris. Therefore, although the CMOS image sensor has not broken down the black screen was appeared. If the EIOS equips with the optical equipment made of heat-resistant material, laser beam will penetrate the lens module without melting the lens and lens guide. Thus, it is necessary to investigate the damage of CMOS image sensor by the CW laser. The CMOS image sensor is composed of color filter, phododiode and substrate. On analysis, when the color filter was damaged, the discoloration was occurred and then the breakdown was happened when the photodiode and substrate were damaged. To summurize, we experimentally investigated the damages of CMOS EOIS and image sensor induced by CW NIR laser and then we could identify the damage of CMOS EOIS and image sensor.

Study on the data matching of Ground-based Radar and laser point cloud, Zhiwei Qiu, Hohai Univ (China); Chenxi Wang, Hohai University (China) . . . . . .[PLDp7-9]

Due to the unique imaging approach for ground-based radar, identification and classification in observation area is very difficult. In order to improve the accuracy of the calculation and application combine with other data resource. it is necessary to implement data matching of radar images and 3D laser point cloud. First, the 3D cloud should to be transformed to orthographic maps, and then the horizontal rotation and orbit attitude angle parameters would be estimated for similarity transformation according to the characteristics such as common points and lines. Finally, the same reference point of the ground-based SAR data and cloud data is employed to accomplished in a two-dimensional coordinate system (called local common coordinate system).

Substrate material dependence of the thin film stress and its control, Hiroki Omatsu, Masaya Akimoto, Takuma Murakami, Singo Tujimoto, Takayuki Yasasiro, Osaka Institute of Technology (Japan); Ryosuke Nakamura, Osaka University (Japan); Tomosumi Kamimura, Osaka Institute of Technology (Japan) . . . . . .[PLDp7-10]

As for multilayer coatings, the stress levels often exceed the breaking strength of the bulk of a material. The control of coating stress is significant in production of the multilayer coating. Relationship of substrate materials and the thin film stress was examined in this study. Ta_2O_s coatings were deposited by magnetron sputtering to fused silica and Zerodur substrate. The Ta_2O_s coatings deposited onto Zerodur showed a tensile stress. In the case of fused silica, a compressive stress was found. The kinds of coating stresses were different between substrate materials used. Then, the stress control was performed by using a combination of different deposition methods. In a prepared chamber, electron-beam evaporation and magnetron sputtering deposition can be used. SiO_2 and HfO_2 were deposited onto a fused silica substrate. In the case of electron-beam evaporation, the HfO_2 thin film showed a tensile stress of 2000 kgf/cm^2. In contrast, the HfO_2 thin film deposited by magnetron sputtering showed a compressive stress of 2500 kgf/cm^2. The stress of the SiO_2 film was approximately 0, and no difference between the deposition methods was found in this experiment. Then, the AR coatings with 4 layer structure was designed with a center wavelength 355 nm. At first, HfO_2 film was deposited onto the fused silica substrate by sputtering, and then SiO_2, HfO_2 and SiO_2 coatings were deposited by electron beam. As a result, the stress was controlled to 80 kgf/cm^2 as compared with a stress of 1810 kgf/cm^2 of the AR film which was produced by magnetron sputtering technique. These results indicated that the combination of different deposition methods is effective for stress control in a multilayer film deposition.

Coffee Break . . . . . .Fri 10:15 to 10:30

SESSION PLD8

Room: 413 . . . . . Fri 10:30 to 12:15

Material Damage

10:30: **Laser damage measurement of thick silica plates using a new laser injection scheme** *(Invited Paper)*, Denis Penninckx, Romain Diaz, Odile Bonville, Roger Courchinoux, Laurent Lamaignère, Jacques Luce, Commissariat à l'Énergie Atomique (France) . . . . . .[PLD8-1]

Some silica plates of high power nanosecond lasers may be a few centimeter thick for instance because they should sustain vacuum. Measuring laser-induced damage thresholds at the output surface of these thick silica plates is a complex task because non-linear laser propagation effects may occur inside the plate which prevents knowing accurately the fluence at the output. Two non-linear effects have to be considered: stimulated Brillouin scattering (SBS) and Kerr effect. SBS is mainly driven by the spectral power density of the pulses: if the spectral power density is below a threshold, SBS is negligible. Thus, spectral broadening is required. Kerr effect depends on the instantaneous intensity. Hence, a smooth temporal shape without overshoots is required. However, both conditions (wide spectrum and no overshoots) are impossible to fulfill with standard lasers. As a matter of fact, an injected laser has a smooth temporal profile but is spectrally narrow. Without injection, the laser is multimode yielding a wide spectrum but a chaotic temporal profile.

We solved the problem by phase-modulating a continuous-wave seeder of our laser (patent pending). The phase-modulation frequency is adjusted to a multiple of the inverse of the round-trip time of the laser cavity. The laser pulses have a wide spectrum to suppress SBS and do not exhibit temporal overshoots to reduce Kerr effects. During the presentation, we will show the features of the laser pulses and laser-induced damage measurements of thick silica plates using this scheme.

11:00: **Nanosecond laser damage of optical multimode fibers** *(Invited Paper)*, Joerg Krueger, Guido Mann, BAM (Germany) . . . . .[PLD8-2]

For pulse laser materials processing often optical step index and gradient index multimode fibers with core diameters ranging from 100 to 600 µm are used. The design of a high power fiber transmission system must take into account limitations resulting from both surface and volume damage effects. Especially, breakdown at the fiber end faces and self-focusing in the fiber volume critically influence the fiber performance. At least operation charts are desirable to select the appropriate fiber type for given laser parameters.

In industry-relevant studies the influence of fiber core diameter and end face preparation on laser-induced (surface) damage thresholds (LIDT) was investigated for frequently used all-silica fiber types (manufacturer LEONI). Experiments on preform material (initial fiber material) and

compact specimens (models of the cladding and coating material) accompanied the tests performed in accordance with the relevant LIDT standards ISO 11254-1 and ISO 11254-2 for 1-on-1 and S-on-1 illumination conditions, respectively. The relation beam diameter vs. LIDT was investigated for fused silica fibers and preforms. Additionally, the laser-induced (bulk) damage threshold of fused silica preform material F300 (manufacturer Heraeus) in dependence on external mechanical stress simulating fiber bending was measured. All experiments were performed with 10-ns laser pulses at 1064 and 532 nm wavelength with a Gaussian beam profile.

11:30: **Adaptive laser beam forming for laser shock micro-forming for 3D MEMS devices fabrication** *(Invited Paper)*, Kevin P. Chen, Univ. of Pittsburgh (USA) . . . . . .[PLD8-3]

No Abstract Available

12:00: **A PHD filter for tracking mid-course group targets via space-based laser**, Haoyang Yu, Wei An, Weidong Sheng, Xueying Wang, National Univ. of Defense Technology (China) . . . . . .[PLD8-4]

A model for tracking mid-course group targets (such as formation satellites or space space debris) via space based laser is set up. The simulation laser detection data is processed by the “extended target probability hypothesis density filter, ET-PHD”, and the optical observation for same targets via an optical sensor carried by the same space-based platform is simulated, the optical observation is processed by ET-PHD too. Simulation results of the laser data and optical data are compared, and indicate that the tracking model via space based laser is more efficient than the model via optical sensors. Simulations verify the validity and the improved performance of the proposed technique over benchmark methods.

Lunch Break . . . . . .Fri 12:15 to 13:15

SESSION PLD9

Room: 413 . . . . . Fri 13:15 to 15:30

Defect, Contamination I

13:15: **Refractive index change mechanisms in different glasses induced by femtosecond laser irradiation** *(Invited Paper)*, Alexander Fürbach, Simon Gross, Douglas J. Little, Alexander Arriola Martiarena, Alexander Arriola Martiarena, Martin Ams, Peter Dekker, Michael J. Withford, Macquarie Univ. (Australia) . . . . . [PLD9-1]

Tightly focused femtosecond laser pulses can be used to alter the refractive index of virtually all optical glasses. As the laser-induced modification is spatially limited to the focal volume of the writing beam, this technique enables the fabrication of fully three-dimensional photonic structures and devices that are automatically embedded within the host material. While it is well understood that the laser-material interaction process is initiated by nonlinear, typically multiphoton absorption, the actual mechanism that results in an increase or sometimes decrease of the refractive index of the glass strongly depends on the composition of the material and the process parameters and is still subject to scientific studies.

In this paper, we present an overview of our recent work aimed at uncovering the physical and chemical processes that contribute to the observed material modification. Raman microscopy and electron microprobe analysis was used to study the induced modifications that occur within the glass matrix and the influence of atomic species migration forced by the femtosecond laser writing beam. In particular, we concentrate on borosilicate, heavy metal fluoride and phosphate glasses. We believe that our results represent an important step towards the development of engineered glass types that are ideally suited for the fabrication of photonic devices via the femtosecond laser direct write technique.

14:00: **Laser-induced damage thresholds by double pulses with interval time**, Shinji Motokoshi, Institute for Laser Technology (Japan); Yuki Takemura, Kinki University (Japan); Takahisa Jitsuno, ILE, Osaka university (Japan); Minoru Yoshida, Kinki University (Japan); Junji Kawanaka, ILE, Osaka university (Japan) . . . . . [PLD9-2]

Laser-induced damage thresholds by S-on-1 test method, for high-repetition pulses, are lower than that by 1-on-1 method. To be clarify the causes the damage thresholds by double pulses with different interval time, 0.01 to 1.0 seconds, were investigated. The damage threshold in silica glasses by 0.01s interval pulses was about 30% down to 1-on-1 threshold. The analyses of excited electrons with a rate equation were also discussed.

14:15: **Enhanced internal reflection microscopy for sub-surface damage inspection**, Longbo Xu, Nanjing Univ. of Science and Technology (China); Kaizao Ni, Shanghai Institute of Optics and Fine Mechanics (China); Ri Hong Zhu, Nanjing Univ. of Science and Technology (China); Shijie Liu, Shanghai Institute of Optics and Fine Mechanics (China) . . . . . .[PLD9-3]

With the rapid development of large high power laser systems, laser induced damage threshold (LIDT) of optics is one of the critical limitations to output power. The sub-surface damage (SSD) inspection and removal play an important role on the improvement of the LIDT of optics. The total internal reflection microscopy (TIRM), one of the non-destructive inspection methods for SSD, is non-costive and easily realized. However, the existing methods based on TIRM are qualitative or semi-quantitative and non-efficient.

In this paper, a new ideal is proposed based on TIRM to inspect the SSD of optics. The method combines total internal reflection microscopy and digital image processing technology. Both the position and the geometry information of optics SSD can be obtained. The measurement results agree well with the results measured by the destructive methods. Furthermore, the proposed method is employed to measure the defects of polished Nd-glass and UBK9 glass.

14:45: **Laser damage mechanisms of different-sized substrate pits in high-reflective mirrors**, Yingjie Chai, Meiping Zhu, Kui Yi, Huanbin Xing, Jian Sun, Jianda Shao, Shanghai Institute of Optics and Fine Mechanics (China) . . . . . .[PLD9-5]

The laser damage resistance of high-reflective (HR) mirror in high-power-laser systems (National Ignition Facility (NIF), Shenguang (SG) and so on) depends significantly on the substrate surface quality. There is a general agreement that substrate structure defect is one of the major factors affecting the HR coating performance and laser-induced damage threshold designed for 1ω, nanosecond-scale, pulsed-laser applications. Recently, a new approach for studying laser interaction with micro-scale structure defects is implemented, by which well-characterized, precisely controlled isolated pits are introduced on the substrate surface. Different sizes of pits (2~8 μm) are fabricated on fused silica, by 520nm-femtosecond-laser to prevent the emergence of subsurface cracks. The HfO_2/SiO_2 HR coatings at 1064 nm were deposited by conventional e-beam evaporation onto fused silica substrates with/without femtosecond laser pits, respectively. After 1064 nm (10ns) high power laser irradiation, the different-sized substrate micro-pit sensitivity on the laser resistance of high-reflective coatings was investigated. Simulations by the finite element method are carried out and the results demonstrate the deformation of a multilayer geometry may lead to electrical-field amplification and poor localized mechanical stress reduce laser damage resistance. The damage mechanisms are introduced by analyzing the geometric model of deformational coatings.

15:00: **Multi-modality laser scanning microscopy at 355nm for defect characterization of optical materials**, Jian Chen, Bingbing Li, Jingtao Dong, Zhouling Wu, ZC Optoelectronic Technologies Ltd. (China) .[PLD9-6]

Photothermal microscopy, fluorescence microscopy and optical scattering microscopy are commonly used for studying defects in optical materials. However, each of them is only sensitive to a part of all defects in the optical materials. In this paper, we demonstrated a multi-modality laser scanning microscopic system which can obtain photothermal, scattering or fluorescence microscopic images of the measured sample in a single scan. The combination of photothermal response, scattering response or fluorescence response provides more comprehensive information about the defect characterization of optical materials. It will be very helpful for better understanding of the laser damage mechanism.

15:15: **Optimization Design and laser damage threshold analysis of pulse compression gratings**, Shuwei Fan, Liang Bai, Shenli Jia, Xi'an Jiaotong Univ. (China) . . . . . .[PLD9-7]

No Abstract Available

Coffee Break . . . . . .Fri 15:30 to 15:45

SESSION PLD10

Room: 413 . . . . . .Fri 15:45 to 16:45

Defect, Contamination II

15:45: **Effectiveness of substrate ion cleaning to improve the laser damage threshold of HfO_2/SiO_2 optical coatings for 527 nm and 1054 nm**, Ella S. Field, John C. Bellum, Damon E. Kletecka, Sandia National Labs. (USA) . . . . . .[PLD10-1]

Preventing contamination is vital to achieving high laser-induced damage thresholds in optical coatings. The importance of removing contamination from optical substrates has led to the development of many specialized cleaning processes, including the application of solvents, acids, mild detergents, and abrasives. To further enhance contamination removal, the substrate may be treated with ion cleaning just prior to depositing the optical coating. Ion cleaning is attractive thanks to the convenience of providing in-situ treatment to optical substrates, and also avoiding the hassle of managing hazardous chemicals or applying mechanical force to scrub off detergents and other cleaning agents. In this study, we compare the effectiveness of ion cleaning for increasing the laser-induced damage thresholds of high reflection (527 nm and 1054 nm) and antireflection (527 nm) coatings. Ion cleaning was performed using a radio frequency ion source with argon and oxygen. The coatings investigated were deposited with layers of HfO_2 and SiO_2 in an e-beam evaporation system, and are designed to withstand nanosecond pulses from a kJ-class laser.

16:00: **LIC and LID considerations in the design and implementation of the MEMS laser pointing mechanism for the EUSO UV laser altimeter**, Enrico Bozzo, ISDC Data Ctr. for Astrophysics (Switzerland); Thomas Burch, Ctr. Suisse d'Electronique et de Microtechnique SA (Switzerland); Alessandra Ciapponi, Clemens Heese, European Space Research and Technology Ctr. (Netherlands); Arno Hoogerwerf, Ctr. Suisse d'Electronique et de Microtechnique SA (Switzerland); Nicholas Lan, European Space Research and Technology Ctr. (Netherlands); Andrii Neronov, ISDC Data Ctr. for Astrophysics (Switzerland); Vincent Revol, Ctr. Suisse d'Electronique et de Microtechnique SA (Switzerland). . . . . .[PLD10-2]

The EUSO (Extreme Universe Space Observatory) project is developing a new mission concept for the scientific research of Ultra High Energy Cosmic Rays (UHECRs) from space. The EUSO wide-field telescope will look down from space onto the Earth night sky to detect UV photons emitted from air showers generated by UHECRs in our atmosphere. The EUSO instrument design includes a UV laser altimeter that will probe the atmospheric conditions in the vicinity of the showers and permit to correctly derive the parameters of the primary UHECR particles. A Micro-Electro-Mechanical Systems (MEMS) is currently being designed by CSEM (Switzerland), under the leadership of the University of Geneva and under an ESA PRODEX contract, in order to build a fast repointing system for the EUSO altimeter. As a result of the ESA experience in the framework of UV laser altimeter developments (in particular for the AEOLUS and Earthcare missions), risk mitigation strategies have been agreed and implemented within the development plan of the MEMS pointing device to address issues related to the Laser Induced Contamination (LIC) and Laser Induced Damage (LID). In this article we discuss mitigation strategies agreed so far, and in particular on the implementation of a careful early selection and testing of subsystem materials (including optics), design and interfaces of the subsystem and an optimization of the instrument operational concept.

16:15: **Source of contamination in damage-test sample and vacuum chamber**, Takahisa Jitsuno, Osaka Univ (Japan); Hidetoshi Murakami, Promotion Center of Laser Technology (Japan); Shinji Motokoshi, Institute for Laser Technology (Japan); Takuya Mikami, Okamoto Optics works (Japan); Tetsuji Kawasaki, Jyunji Kawanaka, Noriaki Miyanaga, Osaka Univ (Japan). . . . . .[PLD10-3]

We investigated the contamination problem on optics in vacuum chamber. Our conclusion is that the contaminants must come from outside of the chamber. The contaminant materials found on mirrors and gratings were dibutyl-phthalate (DBP) and Paraffin-oil. These materials are widely exists in room air, but not in the vacuum chamber. So these materials must come into vacuum chamber in long-term evacuation. We will describe the pass way of contaminants from room air to optical components in the vacuum chamber. We also report the effect of contamination in LIDT sample within a plastic container. Cleaning method will be also reported.

16:30: **How much laser Inferometry effective in the detection of Gravitational waves Used in LIGO at India and Elsewhere?**,
Umesh P Verma, Patna Science College (India) . . . . . .[PLD10-4]

Use of Laser in the LIGO at India and elsewhere have not been considered the effect and interference of variation of wave detected at terrestrial condition.Our globe is counter effective with the dynamics and position of celestial like solar and lunar position which has additional gravitational pull variation in respect to time of aphelion and perihelion that is 16 June and & 7 January. Variation in rotational speed and distances are quite natural in said period of dynamics whic are causing the relase of gravitational waves in proportionate manner of wavelength and time delay.But natural interfered ave detected are a short of higher or shorter in wavelength and slower or faster in frequency due to intermixing with the gravitational pull variation in the said period. Hence forth the detected waves are no more absolute presumed from the specific celestial or astral masses like two distinct black holes.experimentation made over vacuum space could have absolute free interference .Thus data record through LIGO and Hubble space telescopes on Astronomical dynamics are when added with the considerate effect of Solar prominence and Radio effect of NOAA GOES satellites data for solar Radio10.7 F an Xray fluctuations confirms about the anomalies expected.

PLD10: CLOSING REMARKS

Room: 413 . . . . . .Fri 16:45 to 17:00

Session Chairs: **Takahisa Jitsuno,** Osaka Univ. (Japan);
Jianda Shao, Shanghai Institute of Optics and Fine Mechanics (China)

INDEX OF AUTHORS, CHAIRS, PANELISTS, AND COMMITTEE MEMBERS

INDEX OF AUTHORS, CHAIRS, PANELISTS, AND COMMITTEE MEMBERS