2011 Pacific-Rim Laser Damage

Optical Materials for High Power Lasers

Technical Program

6–9 November 2011
Blue Palace Hotel
Shanghai, P.R. China

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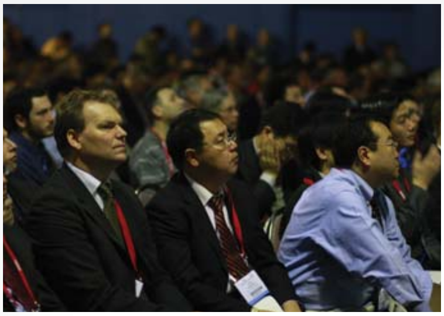

SPIE/SIOM Pacific-Rim Laser Damage

6–9 November 2011
Blue Palace Hotel
Shanghai, P.R. China

Welcome to Shanghai

On behalf of the Organizing Committee and the International Advisory Committee, we cordially welcome you to SPIE/ISOM Pacific-Rim Laser Damage 2011.

Please enjoy your week of hearing novel and fundamental advances in the fields of optical materials for high power lasers. We also hope you will take advantage of opportunities to communicate efficiently and to exchange information on new problems, solutions, and technologies in the field of laser damage as well as optical materials. We hope that this conference will contribute to an enhancement of understanding and facilitate closer collaborations among participating researchers.

We are looking forward to a productive week in Shanghai!

Conference Chair:

Jianda Shao
Shanghai Institute of Optics and Fine Mechanics (China)

Cochairs:

Christopher J. Stolz
Lawrence Livermore National Lab. (United States)

Koji Sugioka
RIKEN (Japan)

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Koji Sugioka, RIKEN (Japan)

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Jianda Shao, Shanghai Institute of Optics and Fine Mechanics (China)
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Qiao Xu, Chinese Academy of Engineering Physics (China)
Kui Yi, Shanghai Institute of Optics and Fine Mechanics (China)
Long Zhang, Shanghai Institute of Optics and Fine Mechanics (China)
Xiaomin Zhang, Chinese Academy of Engineering Physics (China)

Onsite Registration

Blue Palace Hotel

Sunday 6 November . . . . .13.00 to 17.00
Monday 7 November . . . . .08.00 to 16.00
Tuesday 8 November . . . . .08.00 to 16.00
Wednesday 9 November . . Registration closed

Social Mixer

Sunday 6 November · 18.00 to 20.00

Be sure to come to the social mixer Sunday in the Helen Hall on the first floor of the Blue Palace Hotel to network with other conference guests. Tickets are included in the conference registration fee.

Lunches

Monday and Tuesday 7–8 November

Lunches are included on Monday and Tuesday for attendees, held in Helen Hall. Lunch tickets are furnished and will be included in the registration packet.

Welcome Reception and Dinner

Monday 7 November · 18.30 to 20.30

All registered conference attendees are invited to attend the welcome reception and dinner on Monday night. Held in the Blue Palace Hotel's Helen Hall, the event will allow time to meet others at the conference and learn more about the research going on across the Laser Damage field.

SIOM Tour and excursion to beautiful Zhouzhuang, China

Wednesday 9 November · 08.00 to 17.00
The cost for the all-day tour is $40 US
Entrance ticket, lunch, transportation and tour guides included in your registration

The conference organizers will be leading a brief tour of the SIOM laser facility followed by an excursion to Zhouzhuang, an ancient town sometimes called "Venice of China."

Located about 35 minutes from Shanghai, Zhouzhuang dates back to 1086 A.D. and features a waterway transport system of canals cutting through traditional architecture and under elegantly crafted bridges dating back to the Yuan, Qing and Ming dynasties. Many of the old houses are open to the public.

The city has been shortlisted as a possible UNESCO World Cultural Heritage Site. It has been chosen the "No. 1 Water Town of China." It is considered one of the top tourist destinations in China.

SPIE would like to express its deepest appreciation to the symposium chairs, conference chairs, program committees, session chairs, and authors who have so generously given their time and advice to make this symposium possible.

The symposium, like our other conferences and activities, would not be possible without the dedicated contribution of our participants and members. This program is based on commitments received up to the time of publication and is subject to change without notice.

Daily Schedule of Events

TIME	Sunday 6 November	
13.00 to 17.00	**Registration and Material Pick-Up** (Lobby, Front Office Area of Blue Palace Hotel)	
18.00 to 20.00	**Social Mixer**	
	Monday 7 November	
08.00 to 16.00	**Registration Open**	
08.15 to 08.45	**Opening Remarks**	
08.45 to 09.00	**Photographs**	
09:00 to 12.20	SESSION 1: **Plenary Session**	
	SESSIONS RUN CONCURRENTLY	
13.30 to 15.45	SESSION 2: **Ultrafast Through CW Laser Irradiation Effects**	SESSION 8: **Laser Ablation and Laser Machining**
16.05 to 18.20	SESSION 3: **High Laser Damage Resistant Coatings I**	SESSION 9: **Characterization Techniques and Measurement Protocols**
18.30 to 20.30	**Welcome Reception and Dinner**	
	Tuesday 8 November	
08.00 to 16.00	**Registration Open**	
	SESSIONS RUN CONCURRENTLY	
08.00 to 10.00	SESSION 4: **High Laser Damage Resistant Coatings II**	SESSION 10: **Laser Ceramics I**
10.20 to 12.20	SESSION 5: **High-Power Laser Damage: UV Through IR I**	SESSION 11: **Optical Glass and Fiber** SESSION 12: **Laser Ceramics II** SESSION 13: **Nonlinear Laser Crystal I**
13.30 to 15.15	SESSION 6: **High-Power Laser Damage: UV Through IR II**	SESSION 14: **Nonlinear Laser Crystal II**
15.30 to 18.50	SESSION 7: **Defects, Contamination, Polishing, and Surface Damage**	SESSION 15: **Nonlinear Laser Crystal III**
18.50 to 19.00	**Closing Remarks**	
	Wednesday 9 November	
08.00 to 17.00	**SIOM Tour and Excursion to Zhouzhuang** (Optional Tour for Attendees)	

SPIE/SIOM Pacific-Rim Laser Damage

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Pacific Rim Laser Damage 2011: Optical Materials for High Power Lasers

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Member: $105 USD

Non-member: $140 USD

Symposium Plenary Session

Monday 7 November · 09.00 to 12.20

Session Chairs: **Jianda Shao,** Shanghai Institute of Optics and Fine Mechanics (China); **Christopher J. Stolz,** Lawrence Livermore National Lab. (USA)

Large-aperture laser resistant optics for inertial fusion lasers

Christopher J. Stolz
Lawrence Livermore National Lab.(USA)

Inertial fusion lasers are actively being built and operated internationally in multiple laser programs including the National Ignition Facility at Lawerence Livermore National Laboratory (USA), Omega EP at the Laboratory for Laser Energetics (USA), Laser Megajoule (France), SGIII & SG-IV (China), Vulcan & Orion (UK), and LFEX & GEKKO (Japan). These machines will enable exploration of scientific problems in international strategic security, basic science, and fusion energy. One of the early goals of the National Ignition Facility which was completed in 2009, centers on achieving laboratory-scale thermonuclear ignition and energy gain to demonstrate the feasibility of laser fusion as a viable source of clean, carbon-free energy. Since the 1970's materials, finishing, and coating research has focused on increasing the laser resistance of optical materials to build progressively larger and more powerful laser systems. Through partnerships with industry, low platinum Nd-doped phosphate glass, potassium dihydrogen phosphate (KDP) crystals, and inclusion free fused silica are readily manufactured. Precision optical fabrication for ultraviolet laser resistance has resulted in reduction of initiating flaws by several orders of magnitude. Post processing techniques for optical surfaces and coatings such as laser conditioning, chemical etching, CO2 laser processing, and femtosecond laser machining can be used to reduce the impact of the few remaining flaws. These fabrication strategies necessary for routine megajoule operations will dictate a path to the high repetition rate operational requirements of a Laser Inertial Fusion Energy (LIFE) plant.

Biography: **Christopher Stolz** has been in the laser program at Lawrence Livermore National Laboratory (LLNL) since 1989 researching high-power laser coatings. He is currently responsible for the Optics Production group for the National Ignition Facility (NIF). Chris has served as a cochair or program chair for numerous conferences including Laser Induced Damage in Optical Materials (a.k.a. Boulder Damage Symposium) and Optical Interference Coatings. He has coauthored over 80 journal and proceeding articles and 2 book chapters.

3D microstructuring inside glass by ultrafast laser

Koji Sugioka
RIKEN (Japan)

Abstract: Over the past few decades, the rapid development of ultrafast lasers has opened up new avenues for materials processing in micro and nano scales. The extremely short pulse width of the ultrafast laser minimizes the formation of heat-affected zone in the processed region, allowing for high-quality microfabrication of soft materials as well as hard or brittle materials. In addition, the extremely high peak powers generated can induce strong absorption, even in transparent materials including glass, due to multiphoton absorption. By focusing the laser beam inside the transparent materials with moderate pulse energy, the multiphoton absorption can be confined to a region near the focus point, and thereby internal processing of transparent materials including refractive index modification, precipitation of metal atoms, fabrication of 3D microfludic structures, etc. is carried out. This paper presents 3D integration of different functions created by the ultrafast laser inside glass to fabricate microchips used for biochemical analysis. The substrate used is photosensitive glass. By the ultrafast laser direct writing, refractive index at the laser-exposed regions can be increased, resulting in formation of 3D optical waveguides. Thermal treatment after the laser irradiation grows a crystalline phase of lithium metasilicate and transforms the laser-exposed regions to visible brown color. This transformation can be used for formation of variable optical filters. Furthermore, the grown crystalline phase can be preferentially etched away by succeeding wet etching in HF solution. In this way, 3D hollow microstructures can be embedded in the glass, which can be adapted to fabricate microoptics such as mirrors and lenses as well as microfludics. These different structures and functions can be easily integrated in a single glass chip. The integrated microchips are applied to efficient analysis of chemical fluid samples and exploration of dynamics and functions of aquatic microorganisms and bacteria.

Biography: **Koji Sugioka** is a senior research scientist at RIKEN - Advanced Science Institute and a guest professor at Tokyo University of Science and Tokyo Denki University. He received B.E., M.E. and Ph.D degrees in electronics form Waseda University in 1984, 1986 and 1993, respectively. Sugioka joined RIKEN in 1986. At RIKEN, he has worked on doping, etching and deposition of semiconductors and surface modification of metals by using excimer lasers. He also studied on microfabrication of hard materials like glass by using VUV and ultrafast lasers. His current interests center on the development of advanced laser microprocessing techniques for performing surface and 3-D microstructuring of transparent materials, with applications to lab-on-a-chip, photonic and electronic devices. Sugioka has received seven awards for his research, inventions and contributions in the area of laser microprocessing. He published more than 130 articles, gave more than 80 invited talks at international conferences and about 90 invited talks at domestic conferences, and has about 30 patents or pending patents.

Progress of optical materials for high-power lasers in China

Jianda Shao
Shanghai Institute of Optics and Fine Mechanics (China)

Abstract: The talk summarizes the recent progress on the optical materials and components for the high power laser system in China. The amplifier material, Nd glass, has been developed with continuous melt. Nonlinear crystals, KDP/DKDP, have been grown with rapid and traditional growth method. Fused silica and K9 glass has been achieved high quality. Meanwhile various advanced optical fabrication processes are employed for different optical components, especially with home-made facilities and equipments. Some potential materials, for next generation high power laser system, such as large-size Ti:sapphire, Yb:crystal, laser ceramics, crystalline-glass nano-composite materials, coatings, new nonlinear crystals and so on also are evinced in this summary. The talk is to discuss how to face the challenge of the high cost-performance of these components for the laser system wtih an ICF driver scale.

Biography: **Jianda Shao** is a senior researcher and a deputy director of Shanghai Institute of Optics and Fine Mechanics (SIOM), Chinese Academy of Sciences (CAS). He has been being involved in research on high power laser mirrors and laser induced damage of optical materials since the 1990s, and is the chief scientist of the research group of the optical components for the high power laser system. He earned his PhD degree in optical engineering at SIOM in 1998.

Conference 8206

Sunday-Wednesday 6-9 November 2011 • Proceedings of SPIE Vol. 8206

Pacific Rim Laser Damage: Optical Materials for High Power Lasers

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

Conference Co-Chairs: **Christopher J. Stolz,** Lawrence Livermore National Lab. (USA); **Koji Sugioka,** RIKEN (Japan)

Program Committee: **Takahisa Jitsuno,** Osaka Univ. (Japan); **Norbert Kaiser,** Fraunhofer-Institut für Angewandte Optik und Feinmechanik (Germany); **Zunqi Lin,** Shanghai Institute of Optics and Fine Mechanics (China); **Richard Moncorgé,** ENSICAEN (France); **Detlev Ristau,** Laser Zentrum Hannover e.V. (Germany); **Wolfgang Rudolph,** The Univ. of New Mexico (USA); **Takunori Taira,** Institute for Molecular Science (Japan); **Zhouling Wu,** Rx Technologies Co. Ltd. (China); **Xiaomin Zhang,** China Academy of Engineering Physics (China); **Jiping Zou,** Ecole Polytechnique (France)

Sunday 6 November

Registration and Material Pick-Up

Sun. 13.00 to 17.00

Blue Palace Hotel (Lobby, Front Office Area of Blue Palace Hotel)

Social Mixer

Sun. 18.00 to 20.00

Tickets for the Social Mixer will be included in the conference registration fee.

Monday 7 November

Registration Open . . . . Mon. 08.00 to 16.00

Opening Remarks . . . . Mon. 08.15 to 08.45

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

Photographs . . . . Mon. 08.45 to 09.00

A photographer will take pictures of all conference attendees. Each attendee will receive one copy at no additional charge.

SESSION 1

Room: Multifunctional Hall . . . . Mon. 09.00 to 12.20

Plenary Session

Session Chairs: **Jianda Shao,** Shanghai Institute of Optics and Fine Mechanics (China); **Christopher J. Stolz,** Lawrence Livermore National Lab. (USA)

09.00: **Large-aperture laser resistant optics for inertial fusion lasers**, Christopher J. Stolz, Lawrence Livermore National Lab. (USA). . . . . [8206-01]

Inertial fusion lasers are actively being built and operated internationally in multiple laser programs including the National Ignition Facility at Lawerence Livermore National Laboratory (USA), Omega EP at the Laboratory for Laser Energetics (USA), Laser Megajoule (France), SGIII & SG-IV (China), Vulcan & Orion (UK), and LFEX & GEKKO (Japan).

These machines will enable exploration of scientific problems in international strategic security, basic science, and fusion energy. One of the early goals of the National Ignition Facility which was completed in 2009, centers on achieving laboratory-scale thermonuclear ignition and energy gain to demonstrate the feasibility of laser fusion as a viable source of clean, carbon-free energy. Since the 1970's materials, finishing, and coating research has focused on increasing the laser resistance of optical materials to build progressively larger and more powerful laser systems.

Through partnerships with industry, low platinum Nd-doped phosphate glass, potassium dihydrogen phosphate (KDP) crystals, and inclusion free fused silica are readily manufactured. Precision optical fabrication for ultraviolet laser resistance has resulted in reduction of initiating flaws by several orders of magnitude. Post processing techniques for optical surfaces and coatings such as laser conditioning, chemical etching, CO_2 laser processing, and femtosecond laser machining can be used to reduce the impact of the few remaining flaws. These fabrication strategies necessary for routine megajoule operations will dictate a path to the high repetition rate operational requirements of a Laser Inertial Fusion Energy (LIFE) plant.

Coffee Break. . . . . 10.00 to 10.20

10.20: **3D microstructuring inside glass by ultrafast laser**, Koji Sugioka, Katsumi Midorikawa, RIKEN (Japan) . . . . [8206-02]

Ultrafast laser can perform internal processing of transparent materials including refractive index modification, precipitation of metal atoms, fabrication of 3D microfludic structures, etc due to multiphoton absorption. This paper presents 3D integration of different functions created by the ultrafast laser inside photosensitive glass to fabricate microchips used for biochemical analysis. The integrated microchips are applied to efficient analysis of chemical fluid samples and exploration of dynamics and functions of aquatic microorganisms and bacteria.

11.20: **Progress of optical materials for high-power lasers in China**, Jianda Shao, Yaping Dai, Shanghai Institute of Optics and Fine Mechanics (China); Qiao Xu, Chengdu Fine Optical Engineering Research Ctr. (China) . . . . [8206-03]

The talk summarizes the recent progress on the optical materials and components for the high power laser system in China. The amplifier material, Nd glass, has been developed with continuous melt. Non-linear crystals, KDP/DKDP, have been grown with rapid and traditional growth method. Fused silica and K9 glass has been achieved high quality. Meanwhile various advanced optical fabrication processes are employed for different optical components, especially with home-made facilities and equipments. Some potential materials, for next generation high power laser system, such as large-size Ti:sapphire, Yb:crystal, laser ceramics, crystalline-glass nano-composite materials, coatings, new nonlinear crystals and so on also are evinced in this summary. The talk is to discuss how to face the challenge of the high cost-performance of these components for the laser system wtih an ICF driver scale.

Lunch Break . . . . 12.20 to 13.30

Session 2 will run concurrently with Session 8.

SESSION 2

Room: Multifunctional Hall . . . . Mon. 13.30 to 15.45

Ultrafast Through CW Laser Irradiation Effects

Session Chairs: **Tetsuya Makimura,** Univ. of Tsukuba (Japan); **Yuxin Leng,** Shanghai Institute of Optics and Fine Mechanics (China)

13.30: **Femtosecond laser interaction with glasses** *(Invited Paper)*, Jian-Rong Qiu, South China Univ. of Technology (China). . . . . [8206-04]

Femtosecond laser has apparent features of ultrafast, ultra-high light intensity and ultrabroad bandwidth compared with CW and other long pulsed lasers. It shows different behaviors when interacts with glasses. In this paper, we review the basic principles and mechanisms of femtosecond laser interaction with glasses. We will also introduce various phenomena and their promising applications of femtosecond laser induced microstructures in glasses, e.g. refractive index change, valences state change, elemental distribution change, polarization-dependent nanograting, nano-void array along the light propagation direction of the laser beam.

14.00: **Laser-induced fluorescence of UV materials irradiated by ArF excimer laser** *(Invited Paper)*, Qihong Lou, Shanghai Institute of Optics and Fine Mechanics (China) . . . . [8206-05]

Laser-induced fluorescence (LIF) of high-purity fused silica irradiated by ArF excimer laser is studied experimentally. LIF bands of the fused silica centered at 281 nm, 478 nm, and 650 nm are observed simultaneously. Furthermore, the angular distribution of the three fluorescence peaks is examined. Microscopic image of the laser modified fused silica indicates that scattering of the generated fluorescence by laser-induced damage sites is the main reason for the angular distribution of LIF signals. Finally, the dependence of LIF signals intensities of the fused silica on laser power densities is presented. LIF signals show a squared power density dependence, which indicates that laser-induced defects are formed mainly via two-photon absorption processes.

14.30: **Compensation of nonlinear effects using different compensation techniques**, Sahil Gupta, Guru Nanak Dev Univ. (India) . . . . [8206-06]

14.45: **Surface and interface study of SiO_2 coated InP/InGaAs/InGaAsP semiconductor laser microstructures in the soft KrF laser irradiation regime**, Jan J. Dubowski, Neng Liu, Sonia Blais, Univ. de Sherbrooke (Canada) . [8206-07]

In this report, we discuss the results of surface and interface study of InP/InGaAs/InGaAs quantum well (QW) microstructures, coated with a plasma-enhanced-chemical vapor-deposition (PECVD) fabricated 240-nm thick layer of SiO_2, and irradiated with a KrF excimer laser delivering up to 100 pulses at 124 and 155 mJ/cm^2. We have investigated both the surface morphology of the SiO_2 films deposited atop the InP layer that caps the InGaAs/InGaAsP quantum well (QW) microstructure, and the chemical composition of a laser induced layer of the altered material between SiO_2 and InP. Of particular interest to this study is an investigation of the ability to induce formation of a “defective layer” that would promote QWI without participation of impurities that, usually, contribute to the reduced performance of a device fabricated from the QWI material.

15.00: **Review of femtosecond laser-induced refractive index change in transparent materials**, Quan-Zhong Zhao, Geng Lin, Shanghai Institute of Optics and Fine Mechanics (China); Jian-Rong Qiu, South China Univ. of Technology (China) . . . . [8206-08]

In this talk, three aspects of femtosecond laser induced refractive index change in transparent materials will be introduced. Firstly, the history of refractive index change in femtosecond laser induced transparent materials is reviewed. The state-of-the-art applications and the mechanisms of femtosecond laser induced refractive index change in transparent materials are discussed. Secondly, recent efforts for tuning the refractive index are introduced in femtosecond laser induced transparent materials. At last, the future trends of femtosecond laser induced refractive index change in transparent materials will be given.

15.15: **Optical damage in fused silica induced by tightly focused femtosecond laser**, Kangpeng Wang, Shanghai Institute of Optics and Fine Mechanics (China) . . . . [8206-09]

The optical damage of fused silica induced by femtosecond laser (800nm, ~100fs) has been studied.

15.30: **Pulse-length effect on laser-induced thermal damage of optical thin films**, Bin Wang, Xiaowu Ni, Zhonghua Shen, Jian Lu, Nanjing Univ. of Science & Technology (China) . . . . [8206-10]

Laser damages in optical thin films with different pulse durations from nanosecond to millisecond are investigated. The transient temperature rises of single layer film, high-reflection (HR) film, anti-reflection (AR) film and interference filter are calculated for analyzing their thermally laser damage properties. It is found that the laser field effect gradually weakens and the thermal diffusion length extends, as the laser pulse-length increases. Finally, the damage experiments of optical thin films induced by 10 ns and 1 ms lasers are carried out. The experimental results meet the thermal analytical results.

Coffee Break . . . . 15.45 to 16.05

SESSION 8

Room: Multifunctional Hall . . . . Mon. 13.30 to 15.00

Laser Ablation and Laser Machining

Session Chairs: **Koji Sugioka,** RIKEN (Japan); **Zhouling Wu,** Rx Technologies Co., Ltd. (China)

13.30: **Silica ablation process induced by focused laser plasma soft x rays** *(Invited Paper)*, Tetsuya Makimura, Shuichi Torii, Univ. of Tsukuba (Japan); Hiroyuki Niino, National Institute of Advanced Industrial Science and Technology (Japan); Kouichi Murakami, Univ. of Tsukuba (Japan). . . . . [8206-47]

We have investigated ablation process of silica glass induced by X-ray irradiation. X-rays around 100 eV were generated by irradiation of Ta targets with nanosecond Nd:YAG laser light. The soft X-rays were focused on silica surfaces beyond the ablation threshold power density. Silica glass can be ablated at up to 150 nm/shot by X-ray irradiation. We oabserved ions and neutrals ejected by X-ray irradiation and found that silica surfaces are broken into atomic species by X-ray irradiation. We can conclude that Coulomb repulsion between X-ray generated ions in the surface layer are essential for X-ray ablation of silica glass.

14.00: **Progress in advanced laser processing for manufacturing of high-efficiency silicon solar cells**, Jian Chen, Li Chen, Zhouling Wu, RX Technologies Co., Ltd. (China) . . . . [8206-48]

Progress in laser processing for manufacturing of high efficiency silicon solar cells, especially the application of picosecond laser pulses for grooving and doping on crystalline silicon solar cells, has been achieved at RX Technologies, A system using this technique has been employed in production line by one of the leading manufacturers of solar cells. Efficiencies of 19.2% and 17.5% for monocrystalline silicon and polycrystalline silicon have been achieved under the condition of volume production. This result shows a great improvement, compared with results obtained from traditional manufacturing techniques.

14.15: **Spatiotemporally focused femtosecond laser direct-write of microfluidic channels with a circular cross section**, Qiannan Cui, Fei He, Liao Yang, Ya Cheng, Shanghai Institute of Optics and Fine Mechanics (China) . . . . [8206-49]

We report on the fabrication of hollow microfluidic channels with a circular cross-sectional shape embedded in fused silica by spatiotemporally focusing the femtosecond laser beam. We show that high-aspect-ratio microfluidic channels with perfectly circular cross sections and smooth inner walls can be directly embedded in fused silica by focusing femtosecond laser pulses in both spatial and temporal domains.We demonstrate both theoretically and experimentally that the spatiotemporal focusing of femtosecond laser beam allows for the creation of a three-dimensionally symmetric spherical intensity distribution at the focal spot by use of combination of a slit beam shaping technique and a temporal focusing technique.

14.30: **Fabrication of hollow structures with arbitrary configurations embedded in glass using three-dimensional femtosecond laser micromachining**, Yongfeng Ju, Yang Liao, Shanghai Institute of Optics and Fine Mechanics (China) . . . . [8206-50]

We demonstrate that both 3D homogeneous microchannels and large-volume hollow chambers can be fabricated inside glass by femtosecond laser direct writing in porous glass immersed in water followed by a postannealing process.

14.45: **Efficient surface processing by ultrafast XUV/NIR dual action**, Tomas Mocek, Krzysztof Jakubczak, Jaromír Chalupský, Institute of Physics of the ASCR, v.v.i. (Czech Republic); S. B. Park, G. H. Lee, T. K. Kim, C. H. Nam, KAIST (Korea, Republic of); Vera Hajkova, Martina Toufarova, Libor Juha, Bedrich Rus, Institute of Physics of the ASCR, v.v.i. (Czech Republic) . . . . [8206-51]

We demonstrate a new method for efficient structuring of the surface of materials by applying femtosecond NIR laser pulses simultaneously with a weak XUV beam, which leads to very strong radiation-matter interaction, bringing a dramatic increase in the surface processing speed. We present our recent experimental results of the surface nanostructuring of thin films of amorphous carbon (a-C) and PMMA deposited on bulk substrates and discuss the underlying physical mechanisms. In the case of a-C, large areas of laser-induced periodic surface structures with a spatial period of 550 nm are created, having their origin in laser-induced convective currents.

Coffee Break . . . . 15.00 to 15.20

Session 3 will run concurrently with Session 9.

SESSION 3

Room: Multifunctional Hall . . . . Mon. 16.05 to 18.05

High Laser Damage Resistant Coatings I

Session Chairs: **Qiao Xu,** Chengdu Fine Optical Engineering Research Ctr. (China); **Zhanshan Wang,** Tongji Univ. (China)

16.05: **Subpicosecond laser breakdown in optical thin films** *(Invited Paper)*, Wolfgang Rudolph, The Univ. of New Mexico (USA). . . . . [8206-11]

Experimental and theoretical progress on subpicosecond laser pulse breakdown in dielectric films is reviewed. The single pulse threshold fluences can be related to fundamental material properties and scaling laws with respect to pulse duration and material bandgap are discussed. Multiple pulse thresholds are controlled by native and laser induced defects. A phenomenological model is introduced that describes the accumulation and relaxation of such defects. The model is able to explain the experiments and can be used to assess relevant defect parameters. Experimental results are presented that exemplify how the ambient atmosphere affects the multiple pulse laser damage thresholds.

16.35: **The laser-induced damage of multilayer optical films**, Qiang Xu, Wei Zhang, Yang Liu, Xidian Univ. (China) . . . . [8206-12]

As an important part of almost all laser systems, optical film is so fragile that easy to damage because of temperature rise. Based on temperature field theory and thermal conduction equation, the physical model of temperature field of multiplayer films illuminated by Gaussian laser is built. By solving the Maxwell equation, the average energy flow rate of plane wave with unit intensity propagation through the films is obtained. The numerical calculation program of the temperature field of multiplayer films illuminated by 1064nm laser is built using alternating direction-implicit technique.

16.50: **Heat conductivity and laser damage characteristic of particle stacking structured cellular films**, Zhilin Xia, Wuhan Univ. of Technology (China) and Chinese Academy of Sciences (China) . . . . [8206-13]

Aiming at particle stacking structured cellular material, a model has been established to analyze the heat conductivity. It is assumed that heat energy mainly transfers through particles and their contact points. In particle stacking structured materials, a particle contacts with twelve contiguous particles, and there is twelve heat conduction branches. The model is suit to the conditions that: the size of particles in cellular material is uniform; heat conductivity of particle skeleton is much greater than that of the clearance; all contact area between particles is approximately equal. The results show that: heat conductivity of the particle stacked cellular material is anisotropic; heat conductivity depends on that of the particle skeleton and the ratio of radius of particle contact area and particle radius.

17.05: **Investigation of laser-induced damage threshold of hafnia/silica high reflectors at 1064nm**, Wanjun Ai, Institute of Optics and Electronics (China) and Chinese Academy of Sciences (China); Shengming Xiong, Institute of Optics and Electronics (China) . . . . [8206-14]

HfO_2 single layers and HfO_2/SiO_2 high reflectors with standard 1/4 wavelength design were prepared by ion assisted deposition and ion beam sputtering. Characterization of HfO_2 single layers such as structural and optical properties, surface topography and absorption have been studied. The laser-induced damage thresholds (LIDTs) of the high reflectors with different multilayer stacks at 1064nm were tested with S-on-1 testing mode according to ISO-11254. In addition, optical properties, surface topography and absorption of these testing high reflectors have also been investigated in our experiments. All the results used to analyze the LIDTs of high reflectors have been discussed in literature.

17.20: **Interface damage study of dielectric coatings by nanosecond laser pulses**, Xinbin Cheng, Zhengxiang Shen, Hongfei Jiao, Jinlong Zhang, Bin Ma, Tao Ding, Zhanshan Wang, Tongji Univ. (China) . . . . [8206-16]

Interfacial damage of the dielectric coatings that were prepared using electron beam evaporation process was investigated by implanting gold nano-particles into the film-film interfaces and film-substrate interfaces. The dielectric coatings were damage tested with 10-ns, 1064nm pulses. Flat bottom pits initiating from gold nano-particles were observed using Nomarski microscope and scanning electron microscope. A model based on ultraviolet radiation and plasma induced film bucking was used to interpret the damage morphologies. The dependence of damage morphologies on the coating material properties was also studied and the possible reasons for the observed dependence were discussed.

SESSION 9

Room: Multifunctional Hall . . . . Mon. 15.20 to 18.20

Characterization Techniques and Measurement Protocols

Session Chairs: **Jean-Yves Natoli,** Institut Fresnel (France); **Christian Mühlig,** Institut für Photonische Technologien e.V. (Germany)

15.20: **Direct and absolute absorption measurements in optical materials and coatings by laser-induced deflection (LID) technique** *(Invited Paper)*, Christian Mühlig, Institut für Photonische Technologien e.V. (Germany) . [8206-52]

Direct absorption measurements have been evolved into a major tool to characterize optical materials and coatings. Characterizing the absorption of optical materials and coatings is a central task for manufacturers to ensure stability in the production process, to verify functionalities and to understand possible performance changes and limitations, e.g. thermal lens generation, depolarization, during their use in high power laser applications. Here, the laser induced deflection (LID) technique, its absolute calibration, and several measurement strategies are introduced for sensitive direct absorption measurements. Various experimental results are presented covering a wide range from deep UV to IR applications. A new strategy is introduced allowing a significant increase in the sensitivity for materials with a weak photothermal response.

15.50: **Relevance of the choice of diagnostic methods to investigate laser damage resistance in optical material** *(Invited Paper)*, Jean-Yves Natoli, Mireille Commandré, Laurent Gallais, Frank R. Wagner, Institut Fresnel (France) . . . . [8206-53]

Laser damage in optical material in nanosecond regime is widely attributed to local precursor centers. The weakness of knowledge on sizes, densities and natures of precursors, let think that the choice of the diagnostic method has to be adapted to each situation of irradiation. For LIDT determination, destructive methods are usually involved (full size test, raster scan method and statistic approach). This multi-scale approaches give relevant information on material properties. In order to investigate the laser damage initiation mechanisms, fatigue or conditioning effects, non destructive diagnostics as fluorescence and photothermal deflexion appear necessary to highlight modifications before breakdown. To illustrate the purpose, examples on non linear crystals and coatings will be shown.

16.20: **High reflectivity scan measurment on large-aperture laser optics with OF-CRD instrument**, Lifeng Gao, Bincheng Li, Institute of Optics and Electronics (China) . . . . [8206-54]

An optical feedback cavity ring-down techinque(OF-CRD),in which the retro-reflection of the ring-down cavity (RDC) is re-injected into the oscillator cavity of a Fabry-Perot diode laser and causes the spectral fluctuation of the diode laser,is developed for high reflectivity scan measurement of large-aperture laser optics.In the CRD instrument, a pair of cavity mirrors,with reflectivities high than 99.99% is used. Both V-shape and Z-shape RDC are constructed to measuer the reflectivity of cavity mirrors and samples. Autoscan and auto point have been used in this instrument for reflctivity scan measurement of large aperture components. For cavity mirrors with reflectance large than 99.99%,the measurent error is less than 1ppm.

16.35: **Image denoising based on wavelet transform algorithm**, Yan Ha, Hebei Univ. (China) . . . . [8206-55]

In this paper, a new wavelet threshold denoising algorithm has been proposed based on the correlation characteristics between layers coefficient and the inner-layer coefficient. For each wavelet coefficient, a corresponding threshold is constructed according to the wavelet coefficients between layers and layer-related features. The experimental results show that the ability of this algorithm is better than the traditional algorithm in the aspect of image denoising.

16.50: **Measurement of losses in optical components using filtered optical feedback cavity ring down technique**, Zhechao Qu, Bincheng Li, Yanling Han, Institute of Optics and Electronics (China) . . . . [8206-56]

A filtered optical feedback cavity ring down (FOF-CRD) technique employing a continuous wave diode laser is employed to measure the total optical losses, absorption and scattering in optical components with arbitrary thickness. The FOF from the ring down cavity (RDC) is re-injected into the oscillator cavity of the laser, and the coupling efficiency of the laser into the RDC is significantly enhanced. An optical component having optically flat parallel surfaces is inserted exactly normal to the light beam in the RDC. The optical losses in the component are obtained from the change in the decay time of the light in the RDC containing the component with respect to that of the empty RDC. The measurement results for different samples are good agreement with conventional laser calorimetry data. The experimental results have demonstrated the FOF-CRD technique is very simple, inexpensive and fast for measuring optical losses of optical components used in high-power laser system.

Session 3 will run concurrently with Session 9.

SESSION 3 (Continued)

Room: Multifunctional Hall . . . . Mon. 16.05 to 18.05

17.35: **Coupling effect of multiwavelength laser pulses to damage in multilayer mirrors**, Lei Yan, Shanghai Institute of Optics and Fine Mechanics (China) and Graduate School of Chinese Academy of Science (China); Chaoyang Wei, Dawei Li, Guohang Hu, Zhengxiu Fan, Shanghai Institute of Optics and Fine Mechanics (China) . . . . [8206-17]

The coupling effect of multilayer mirrors under simultaneous irradiation by 355 nm laser and 1064 nm laser are investigated. A critical fluence of 1064 nm laser is found. When the fluence is lower than it, 1064 nm laser does not contribute to 355 nm laser induced damage, otherwise, the LIDT in 355 nm laser decreases with the growth of 1064 nm laser fluence and the coupling efficiency is about 5%. Damage morphologies are also studied to explore the damage mechanism at respective wavelength. Under simultaneous illumination, the sensitive defects are still the precursors, but the damages were more catastrophic compared with the damage induced by 355 nm or 1064 nm laser alone. The possible explanation is also discussed.

17.50: **The study on high laser damage threshold biochamatic coatings fabrication**, Feng Pan, Chengdu Fine Optical Engineering Research Ctr. (China) . . . . [8206-89]

SESSION 9 (Continued)

Room: Multifunctional Hall . . . . Mon. 15.20 to 18.20

17.05: **Investigation of optical surface damage detection with laser-induced fluorescence mircroscopy**, Zhi-Xing Gao, Xiuzhang Tang, China Institute of Atomic Energy (China) . . . . [8206-57]

Fluorescence microsopy is a useful tool to image defect nanostructures in the bulk of dielectric materials. The application of microcopy with KrF laser induced fluorescence on optics to detect the damage of opticcal film was explore. A fluorescence image system was built that incorporated in-situ damage testing capabilities.The experimental results was checked under an ex-situ Normaski microscope .

17.20: **Extrapolation from small area test of laser-induced damage to the large area**, Wei Wang, Dean Liu, Jianqiang Zhu, Junyong Zhang, Pingping Sun, Yanli Zhang, Kun Xiao, Jie Miao, Shanghai Institute of Optics and Fine Mechanics (China) . . . . [8206-58]

Due to the limits of experimental conditions the results of the small area damage testing cannot represent the performance of the material illuminated by large scale high power laser whose typical scale is usually a few decimeters in diameter. By use of statistical approach, extrapolation from small area test of laser induced damage to the large area is provided, and damage probability curve is obtained to describe the characteristics of large-scale material. Furthermore, the Monte Carlo simulation is also given to verify the reliability of the extrapolation results. The above-mentioned revised approach can be suitable for large scale material.

17.35: **Damage measurement of large-aperture diffraction grating at 10ps**, Xin Hao, Xiao Wang, Wan-qing Huang, Kainan Zhou, Lei Zhao, Xiaoming Zeng, China Academy of Engineering Physics (China) . . . . [8206-59]

In chirped pulse amplification laser systems, the damage threshold of the final grating in the pulse compressor may ultimately limit the energy output. Here we propose a novel measurement, by which the exact correlation between local fluence and local damage characteristics would be established. This method , though online monitoring, collecting the near-field intensity distribution of a cm-sized beam spot and its corresponding raster damage image, also including a series of image post-processing, does not strictly require the spatial uniformity of the beam. Furthermore, the damage densities versus fluence would be extracted with one shot.

17.50: **Influence caused by spacing and angle misalignment of the 4f setup on the femtosecond pulse temporal properties**, Yongming Nie, Junli Qi, Jiankun Yang, Wenhua Hu, Xiujian Li, National Univ. of Defense Technology (China) . . . . [8206-60]

Based on zero-dispersion 4f ultra-fast pulse shaping system, the relation between the resolution and the mismatched spacing of the system components was analyzed in theory. The effect of mismatched spacing and angle on the system efficiency was discussed. Moreover, pulse temporal expansion caused by the misalignment was analyzed in detail. The experimental results indicate that lens misalignment will broaden the pulse temporal width and the influence of the first grating was symmetrical with the influence of the second one. When the second grating was misaligned more than 0.5 cm, the pulse broadening will become faster. The influence on system's efficiency of angle misalignment is more serious than spacing misalignment. If 600 lines per millimeter grating and lens with 30 cm focal length were used, when the angle misalignment was smaller than 9 degree and the spacing misalignment was smaller than 0.5 cm, the changing of system's efficiency and the pulse width were both smaller than 5%.

18.05: **The simple theoretical analysis of optical absorption coefficient (OAC) in optical nanomaterials in the presence of laser**, Subhamoy Singha Roy, JIS College of Engineering (India) . . . . [8206-88]

I have given away on the origin of operator algebra that the optical absorption coefficient (OAC) in optical nano compounds, whose ($E - \vec{k}$) energy band structures are defined by the three band model of Kane, is proportional to square root of ($(\omega)^2 - E_g^2$) (ω and E_g are the energy of incident radiation and band-gap respectively) instead of ($(\omega) - E_g$) as glowing known in the content. The optical absorption coefficient (OAC) of optoelectronic materials within the frame work of the three band model of Kane in the presence of an laser for modified photon energy (ω_1) below and above the band gap (E_g) respectively. The optical matrix element (OME) depends on the electron wave vector $k = 2\pi/\lambda$ and this practical aspect has been incorporated in the present analysis. It has been invent taking $Hg_{1-x}Cd_xTe$, $In_{1-x}Ga_xAs_yP_{1-y}$, InAs and InSb lattice matched to InP as examples of optoelectronic nano materials for mathematical computations that, for the modified energy (ω_1) below the band gap, the exhibits an exponential fall off with the laser and the photon energy in that order. For the opposite inequality, the OAC oscillates with the modified photon energy without the consideration of the Wannier-Stark levels (WSL), which generally exists in a band due to the presence of a laser. In both the cases, the OAC exhibits the singularity when the incident photon energy (ω_0) tends to E_g and the magnitude of the OAC depends to a large extent on the numerical values of the energy band constants of the said nano materials.

Welcome Reception and Dinner

Mon. 18.30 to 20.30

All registered conference attendees are invited to attend the Welcome Reception and Dinner. A ticket will be included in the conference registration fee.

Tuesday 8 November

Registration Open . . . . 08.00 to 16.00

Session 4 will run concurrently with Session 10.

SESSION 4

Room: Multifunctional Hall . . . . Tues. 08.00 to 10.00

High Laser Damage Resistant Coatings II

Session Chairs: **Wolfgang Rudolph,** The Univ. of New Mexico (USA); **Hongbo He,** Shanghai Institute of Optics and Fine Mechanics (China)

08.00: **Determination of optimal mitigation geometries for improving laser damage resistance in dielectric mirrors** *(Invited Paper)*, Siping R. Qiu, Justin E. Wolfe, Lawrence Livermore National Lab. (USA); Anthony M. Monterrosa, Univ. of California, Berkeley (USA); Michael D. Feit, Lawrence Livermore National Lab. (USA); Thomas V. Pistor, Panoramic Technology Inc. (USA); Christopher J. Stolz, Lawrence Livermore National Lab. (USA) . . . . [8206-18]

The performance of meter-scale multi-layer dielectric mirrors is fluence-limited by growing damage sites. We combine finite-difference time-domain method with femtosecond laser machining to determine optimal mitigation geometries that improve the laser damage resistance of mirrors by replacing a damage site. The field intensification induced by the mitigation pit is dependent on the polarization and the angle of incidence (AOI) and an optimal mitigation structure can also be achieved by matching the cone angle of the structure with the AOI. Damage testing shows that these mitigation features created by femtosecond laser machining can double the fluence-handling capability of multilayer mirror coatings.

08.30: **Multiple pulse laser-induced damage investigation of 1064nm reflection coatings**, Zhichao Liu, Jin Luo, Songlin Chen, Feng Pan, Chengdu Fine Optical Engineering Research Ctr. (China) . . . . [8206-19]

Damage properties of the hafnia-silica reflection coatings under multi-pulse laser irradiation in vacuum were studied in this work. The behaviors of LIDT against increases in shot number were discussed by S/1 test. Results indicate that there are two dominant damage morphologies on coatings surface, scalds and delaminates respectively. Scalds have a lower LIDT but maintaining stable with shot number increasing. However, the LIDT of delaminates shows an exponential decay behavior at higher fluence level. Finite element method was employed to simulate the thermal accumulation process. Finally, a simple function based on simulation result for fitting the decay law of LIDT was discussed.

08.45: **Effect of substrate bias voltage on optical properties of pulsed DC magnetron sputtered niobium oxide coatings**, Yuchuan Shao, Kui Yi, Ming Fang, Junchao Zhang, Shanghai Institute of Optics and Fine Mechanics (China) . . . . [8206-20]

Abstract: Nb_2O_5 thin films at various substrate bias voltages were deposited by pulsed DC reactive magnetron sputtering of a metallic Nb target in a pure oxygen atmosphere.The characteristics of the films have been studied.Results indicate that substrate bias voltage has significant influence on the laser resistance of Niobium oxides films which can be contributed to the variation of stress in Nb_2O_5 films. The maximum laser induced damage threshold (LIDT) of 28.8 J/cm^2 was obtained for the film deposited at substrate bias voltage of -60V.

09.00: **Laser damage properties of thin films grown by atomic layer deposition**, Yaowei Wei, Chengdu Fine Optical Engineering Research Ctr. (China) . . . . [8206-21]

Atomic layer deposition (ALD) has been used to deposit films at different temperature on different substrate using organic and inorganic precursors. The LIDT of samples was measured by a damage test system. Damage morphology was studied under Normaski Differential Interference Contrast-Microscope, and further checked under the Atomic-Force-Microscope. The results show deposition temperature affects the deposition rate, the thin film microstructure and further influences the LIDT of the thin films. Organic residual affects the LIDT of the films. The film LIDTs can further increased when the technics condition were optimized. Therefore, ALD is a promising method for high power laser system.

09.15: **Effect of deposition process on micro-defect and LIDT of thin films**, Dongping Zhang, Ping Fan, Shenzhen Univ. (China) . . . . [8206-22]

Micro-defect is one of key limited factors in improving laser induced damage threshold (LIDT) of thin films. In this paper, thin films were prepared by e-beam evaporation with different HfO_2 material and pre-melting process, respectively. The experiments results indicate that some impurity elements play important roles on LIDT of the samples. Well pre-melting process is necessary to keep the deposition stable, which also could be reducing micro-defect density in thin films.

SESSION 10

Room: Multifunctional Hall . . . . Tues. 08.00 to 10.00

Laser Ceramics I

Session Chairs: **Richard Moncorgé,** ENSICAEN (France); **Jun Xu,** Shanghai Institute of Optics and Fine Mechanics (China)

08.00: **The transparent ceramics in SICCAS** *(Invited Paper)*, Yubai Pan, Shanghai Institute of Ceramics (China) . . . . [8206-61]

The transparent ceramics have widely used to laser materials. The fabrication and properties for the transparent with garent structure are introduced in SICCAS.

08.30: **Spin-orbit momentum controlled anisotropic laser ceramics** *(Invited Paper)*, Yoichi Sato, Jun Akiyama, Takunori Taira, Institute for Molecular Science (Japan). . . . . [8206-62]

Principles that enable to synthesize anisotropic laser ceramics have been established. Anisotropic laser ceramics contain micro domains made of anisotropic crystals, and we have invented the spin-orbit momentum control in order to obtain uniquely oriented micro domains. Our novel process is essentially superior to the traditional electromagnetic processing from the viewpoint of mass production. After discussing the significance of anisotropic laser ceramics, we show the result of evaluations to our orientation controlled RE:FAP ceramics.

09.00: **Investigation on the visible and infrared emission properties of Tm: Y_2O_3 transparent ceramic**, Qing Yi, Shengming Zhou, Shanghai Institute of Optics and Fine Mechanics (China). . . . . [8206-63]

With the purpose of investigation on the emission properties of Tm^{3+} ions, a Tm^{3+}-doped Y_2O_3 transparent ceramic was fabricated by sintering at 1800 °C for 20 hour with a vacuum degree of 1×10^{-3} Pa. 3 at% ZrO_2 was introduced as the sintering aid and the average grain size was measured to be 22 µm. The optical transmittance of the ceramic achieved 76.3 % at 1 µm. The PLE and PL spectra at room temperature and low temperature were measured. The ~453 nm, ~1270 nm and ~1450 nm emission bands were observed and the luminescence mechanisms were discussed.

09.15: **Preparation of $Tb_3Al_5O_{12}$ (TAG) transparent ceramics for potential magneto-optical applications in high-power laser systems**, Shengming Zhou, Shanghai Institute of Optics and Fine Mechanics (China) . . . . [8206-64]

09.30: **The study on light scattering and microstructure in laser transparent ceramics**, Guoxi Jin, Benxue Jiang, Shanghai Institute of Ceramics (China). . . . . [8206-65]

The relationship between light scattering and microstructure, especially pores distribution, was studied in laser transparent ceramics. Specimens with different transmittance value were prepared by the solid-state reaction and the vacuum-sintering technique. Light scattering defects were studied using UV-Vis spectrophotometer and micromechanism was characterized via high magnification optical microscope. The relation curve of transmittance and pores ratio was obtained. It makes judging transmittance or scattering of transparent ceramics from pores ratio possible.

09.45: **Effect of annealing on luminescence properties of vacuum sintered Ce:YAG transparent ceramic**, Hao Teng, Hui Lin, Qing Yi, Shengming Zhou, Shanghai Institute of Optics and Fine Mechanics (China) . . . . [8206-66]

Coffee Break. . . . . 10.00 to 10.20

Session 4 will run concurrently with Session 10.

SESSION 4 (Continued)

Room: Multifunctional Hall . . . . Tues. 08.00 to 10.00

09.30: **Laser-induced damage threshold of multilayer dielectric for broad band pulse compression gratings centered at 800nm**, Fanyu Kong, Shunli Chen, Shanghai Institute of Optics and Fine Mechanics (China) and Graduate School of Chinese Academy of Sciences (China); Yunxia Jin, Shijie Liu, Shanghai Institute of Optics and Fine Mechanics (China); Heyuan Guan, Ying Du, Shanghai Institute of Optics and Fine Mechanics (China) and Graduate School of Chinese Academy of Sciences (China); Chaoyang Wei, Hongbo He, Kui Yi, Shanghai Institute of Optics and Fine Mechanics (China). . . . . [8206-23]

The mirrors for broad bandwidth 800nm pulse compression grating were fabricated with optimized parameters by electron beam evaporation using three different kinds of materials ($Ta_2O_5/SiO_2/HfO_2$), which have more than 99% reflectance with band width larger than 200 nm around the center wavelength of 800 nm and high transmission at the exposure wavelength of 413 nm. Laser induced damage (LID) behaviors of the mirrors were investigated. It was found that the laser induced damage threshold (LIDT) of the samples can reach 1.0J/cm^2 and 2.0J/cm^2 (57 degrees, TE mode) at pulse width of 50fs and 120fs, respectively.

09.45: **Enhanced laser-induced damage threshold of antireflective porous glasses**, Ying Du, Yunxia Jin, Hongbo He, Lei Yan, Fanyu Kong, Heyuan Guan, Shanghai Institute of Optics and Fine Mechanics (China) . . . . [8206-24]

Porous nanostructures on glasses were produced by chemical treatment for antireflection and high laser-induced damage threshold (LIDT) purpose. Herein, the laser-damage properties of porous nanostructures on BK7 glasses which were manufactured in neutral solution were investigated. The porous glasses have transmittance above 99.7% and average LIDT by 12ns 1.064μm pulses of 58J/cm^2, by 10ns 0.532μm pulses of 20 J/cm^2 and by 8ns 0.355μm pulses of 12 J/cm^2. The treated surfaces with different experiment condition have variational LIDT compared with untreated substrates. Detailed mechanisms for the LIDT enhancement are discussed.

Coffee Break. . . . . 10.00 to 10.20

Session 5 will run concurrently with Sessions 11, 12, 13.

SESSION 5

Room: Multifunctional Hall . . . . Tues. 10.20 to 12.20

High-Power Laser Damage: UV Through IR I

Session Chairs: **Jiping Zou,** Ecole Polytechnique (France);
Ya Cheng, Shanghai Institute of Optics and Fine Mechanics (China)

10.20: **Research progress in laser-induced damage of optics for SG laser project** *(Invited Paper)*, Wanguo Zheng, China Academy of Engineering Physics (China). . . . . [8206-25]

The SG-III laser facility is a large aperture neodymium-glass based high-power solid state laser, and is composed of 48 beams in 6 bunldes to provide laser energy output of 150-200kJ (3ω) for square pulse of 3ns. The 48 beams of the SG-III have a right section of 40×40 cm^2 and equipped with about 40 optical parts of various types: laser slabs, lenses, mirrors, diffractive optics. All of them have to sustain high fluence inducd by laser beam. It is a real technological and economical challenge to construct, operate and maintain such a large laser facility under high laser fluence (4J/cm^2, 351nm, 3ns). Laser-induced damage of optics is a main concern. This presentation gives an overview of this activity we have encountered and details the main recent development realized.

10.50: **Laser damage performance of pulse compressor grating**, Weijin Kong, Shuhua Wang, Wenfei Zhang, Maojin Yun, Xin Sun, Qingdao Univ. (China). . . . . [8206-26]

SESSION 11

Room: Multifunctional Hall . . . . Tues. 10.20 to 10.50

Optical Glass and Fiber

Session Chairs: **Mauro Tonelli,** Univ. di Pisa (Italy);
Satoshi Wada, RIKEN (Japan)

10.20: **Er-doped fiber lasers operating at pulse duration from ps to ns** *(Invited Paper)*, Satoshi Wada, RIKEN (Japan) . . . . [8206-67]

High power pulsed operation of Er- and Yb- doped fiber lasers for industrial applications will be presented. We have developed the fiber lasers with the linear polarization and narrow bandwidth for harmonics generation in the UV region. High peak electrical field in the fiber induces several kind of nonlinear effect, which limits the high peak intensity. Control of nonlinear effect becomes to be key technology for high intensity fiber laser with short pulse width. We also develop the hybrid laser system with the solid-state amplifier for the ps-pulse fiber laser.

SESSION 12

Room: Multifunctional Hall . . . . Tues. 10.50 to 11.20

Laser Ceramics II

Session Chairs: **Mauro Tonelli,** Univ. di Pisa (Italy);
Satoshi Wada, RIKEN (Japan)

10.50: **Composite YAG/Nd:YAG transparent ceramics for high-power lasers**, Jiang Li, Wenbin Liu, Benxue Jiang, Xuewei Ba, Yiqiang Shen, Guoxi Jin, Yubai Pan, Xiqi Feng, Jingkun Guo, Shanghai Institute of Ceramics (China). . . [8206-68]

Compared with laser single crystal, one of the prominent advantages of laser ceramics is ease of achieving composite structure. This advantage provides more freedom in the design of laser systems, especially in the high power lasers. In the present work, composite YAG/Nd:YAG transparent ceramics were fabricated by solid-state reaction method using commercial--Al_2O_3, Y_2O_3 and Nd_2O_3 powders as starting materials. The microstructure and optical properties of the composite laser ceramics were also investigated. High quality composite YAG/Nd:YAG transparent ceramics might be a potential gain media for high power laser.

11.05: **Selection of different sintering aids and morphology modification of the Y_2O_3 powders for Yb^{3+}:$Y_3Al_5O_{12}$ transparent ceramics**, Hui Lin, Shanghai Institute of Optics and Fine Mechanics (China). . . . . [8206-69]

Session 5 will run concurrently with Sessions 11, 12, 13.

SESSION 5 (Continued)

Room: Multifunctional Hall . . . . Tues. 10.20 to 12.20

Laser damage performance of pulse compressor grating (PCG) is investigated with the method of rigorous coupled wave method. The factors such as groove depth, duty cycle, incident angle, residual thickness are researched in details to obtain optimized PCG with high laser induced damage performance. Simulation results show that the structure show great effect on laser induced damage of PCG.

11.05: **Comparative investigation of laser-induced damage on K9 and fused silica under 1064nm nanosecond laser irradiation**, Hongjie Liu, China Academy of Engineering Physics (China) . . . . [8206-27]

Laser damage performance of K9 and fused silica glass are tested respectively at the same experimental condition with 1064nm nanosecond laser. The initial damage threshold, the damage growth threshold and the damage growth laws of two optics are investigated comparatively. The results show that the initial damage threshold of the two glass is the same, the damage area growth both obey the exponential increase rule and that the damage depth growth obey the linear increase rule. However, there is apparent difference in the rule of damage growth, for example the lower damage growth threshold and the higher damage growth coefficient for K9 glass. This can be explained by the difference of the material's damage morphology, optical absorption, residual stress near damage site and emission spectra of damage area of the two optics. The research is very important to choose transparent optical material applied in high power laser.

11.20: **Investigation of laser damage mitigation pit induced beam modulation in fused silica**, Xibin Li, Consultant (China) . . . . [8206-28]

SG-99 simulator is adopted to simulating laser damage mitigation pit induced beam modulation at the wavelength of 1064nm, 532nm and 355nm in fused silica. It is showed that when mitigation pit is on the front surface, the most intense modulation distance is about 5cm to the front surface. Along with increase of distance, amplitude of modulation fluctuation decreases gradually and is prone to a constant when transmission distance is above 30cm.

11.35: **Research for ultra-short pulse ablation of dielectric film mirror**, Zhimin Xiong, Youen Jiang, Xiaochao Wang, Panzheng Zhang, Fan Wei, Xuechun Li, Shanghai Institute of Optics and Fine Mechanics (China) . . . . [8206-29]

By comparing the damage morphology and damage resistant threshold of the ablation pits at different pulses width, it show that it was superior to use ultra-short pulse to repair multi-layers optical components, and the shorter pulse width has been used, the better results will be got. Furthermore, the finite-difference time-domain method was used to simulate the electric-field intensification within the multilayer films, and the system parameters were optimized, including pulse width, energy, frequency, scanning speed, etc. Based on the testing of damage resistant and optical field distribution experiments, the most optimization parameters and the perfect damage morphology were determined.

11.50: **Incubation effect of laser-induced surface damage of HfO_2/SiO_2 HR coating in the femto-nanosecond region**, Shunli Chen, Yuanan Zhao, Fanyu Kong, Dawei Li, Hongbo He, Jianda Shao, Shanghai Institute of Optics and Fine Mechanics (China) . . . . [8206-30]

This paper is devoted to a long-term investigation into the nature of incubation effect of multilayer dielectric HR coatings. Accumulated damage behaviors of HfO_2/SiO_2 coatings for 800nm, 1053nm, and 1064nm, were investigated by ultra-short pulse, short pulse, and long pulse lasers, respectively. Incubation effect was found to be a universal phenomenon for HfO_2/SiO_2 coatings irradiating by the femto-nanosecond lasers. Besides, typical damage morphologies revealed intrinsic and determinate performance in the fs regime, while showing clear features of inclusion/defect-induced damage in the ns regime, and displaying the characteristics of the first two in the ps regime.

12.05: **Novel subwavelength microstructures for antireflection application**, Ye Xin, China Academy of Engineering Physics (China) . . . . [8206-31]

Light reflection occurs at the interface between two materials with different refractive indices. Subwavelength Microstructures (SWSs) built into the surfaces of an optic or window, which have a period sufficiently smaller than the wavelength of light, are an effective replacement for thin-film coatings in antireflection (AR) applications. AR SWSs exhibit particularly noteworthy performance where an average reflection loss of less than 0.3% over a four-octave range (800-1400nm) has been demonstrated. Recently, it was shown that the LIDT of the AR SWSs was much approaching to the fused silica without the AR coating.

Lunch Break . . . . 12.20 to 13.30

SESSION 13

Room: Multifunctional Hall . . . . Tues. 11.20 to 12.05

Nonlinear Laser Crystal I

Session Chairs: **Mauro Tonelli,** Univ. di Pisa (Italy); **Satoshi Wada,** RIKEN (Japan)

11.20: **Study on the weak absorption in KTP crystals**, Xiaomao Li, Technical Institute of Physics and Chemistry (China) and Graduate School of Chinese Academy of Sciences (China); Zhanggui Hu, Technical Institute of Physics and Chemistry (China) . . . . [8206-70]

In this study, the weak absorption coefficients of the flux-grown KTP crystals with titanium from TiO_2, $TiCl_4$ and $Ti(OC_4H_9)_4$ and the hydrothermal-grown KTP crystal have been measured at 1064nm and 532nm by Photothermal common-path interferometer. The values of four samples are 100ppm•cm^{-1}, 800ppm•cm^{-1}, 45ppm•cm^{-1}, 20ppm•cm^{-1} at 1064nm and 2.6×10^4ppm•cm^{-1}, 1.6×10^5ppm•cm^{-1}, 1.2×10^4ppm•cm^{-1}, 3.0×10^2ppm•cm^{-1} at 532nm. The results showed that the weak absorption coefficients of the flux-grown KTP with titanium from $Ti(OC_4H_9)_4$ and the hydrothermal-grown KTP were low values at 1064nm. In addition, the weak absorption coefficient of the hydrothermal-grown KTP was at least 2 orders of magnitudes lower than that of the flux-grown KTP at 532nm. From the results, we have concluded that the KTP grown by titanium from $Ti(OC_4H_9)_4$ represented a better quality than the other two flux-grown KTP crystals. The quality of the hydrothermal-grown KTP was obviously better than the flux-grown KTP.

11.35: **Structural and spectral investigations on heavily Er^{3+}-doped $ATaO_4$(A=Sc,Y,Gd,Lu) polycrystalline powders**, Pengyu Zhou, Qingli Zhang, Dunlu Sun, Shaotang Yin, Anhui Institute of Optics and Fine Mechanics (China) . . . . [8206-71]

30 at % Er:$ATaO_4$(A=Sc,Y,Gd,Lu) polycrystalline powders were synthesized by the solid-state method. Their structures were determined by Retvield refinement to XRD. The optical spectroscopy of the Er^{3+} in $ATaO_4$ polycrystalline was studied by absorption and emission measurements at room temperature. Under the excitation of 980nm light, the photoluminescence of 2H11/2,4S3/2→4I15/2 and the 1.5μm 4I13/2→4I15/2 emissions were observed. The decay times of Er^{3+} from the multiplets 2H11/2,4S3/2, and 4I13/2 were studied at room temperature. The 808nm laser-excited luminescence spectra around 2.8μm(4I11/2→4I13/2) has also been studied.

11.50: **Studies on the spectroscopic properties of Nd/Na-codoped CaF_2 single crystal**, Qingguo Wang, Shanghai Institute of Ceramics (China). [8206-72]

High optical quality Nd/Na co-doped CaF_2 crystal was grown by Modified Bridgman Method. The UV-VIR-NIR absorption spectra and the near-infrared emission spectra were measured and analysed in the framework of the Judd-Ofelt. The stimulated emission cross-section of 1.25×10^{-20}cm^2 at 1041 nm was calculated using F-L equation. The 4F3/2 luminescence lifetimes with 3.24 ms at 300K were determined from luminescence decay curves, indicating high quantum efficiency in Nd/Na co-doped CaF_2 crystal. All the results showed that Nd/Na co-doped CaF_2 crystal would be a promising gain media in solid-state lasers.

Lunch Break . . . . 12.05 to 13.30

Session 6 will run concurrently with Session 14.

SESSION 6

Room: Multifunctional Hall . . . . Tues. 13.30 to 15.30

High-Power Laser Damage: UV Through IR II

Session Chairs: **Roger Qiu,** Lawrence Livermore National Lab. (USA); **Xiaomin Zhang,** China Academy of Engineering Physics (China)

13.30: **Progresses of damage research in LFEX laser development** *(Invited Paper)*, Takahisa Jitsuno, Hidetoshi Murakami, Shinji Motokoshi, Eiji Sato, Katsuhiro Mikami, Kota Kato, Tetsuji Kawasaki, Yoshiki Nakata, Hiroyuki Shiraga, Noriaki Miyanaga, Hiroshi Azechi, Osaka Univ. (Japan) . . . . [8206-32]

In the activation of LFEX laser (1 ps, 10 kJ) system, we observed a heavy organic oil contamination in the compression chamber. The damage threshold (DT) of mirror dropped to 1/2 ~ 1/3 of the original value. This contamination was observed only on the IAD (Ion beam Assisted Deposition) coated mirrors and gratings, and the oil frost was not observed on the mirror sample made with normal e-beam deposition. Contamination materials were identified as Paraffin-oil and DBP (Di-Butyl Phthalate). We made several efforts to reduce this contamination, and succeeded to keep DT to original value using silica gel in vacuum.

14.00: **Current status of the LULI laser facilities request of appropriate optical components for high-energy ultra-intense lasers** *(Invited Paper)*, Jiping Zou, Ecole Polytechnique (France) . . . . [8206-33]

Founded in 1988, LULI is a French national scientific infrastructure dedicated to laser-generated hot and dense plasmas and applications. LULI develops and operates two large-scale laser facilities, LULI 2000 and ELFIE. Member of LASERLAB EUROPE, LULI is actively involved in the main high-peak-power laser projects in France and Europe. In this talk, an overview will be given on the LULI laser facilities and “Apollon 10PW”, the French project which aims at producing 150 J, 10-15 fs pulses.

Laser performance enhancement cannot be accomplished without the advance in laser technologies and laser materials. High-energy ultra-intense laser requests specific laser and optical components in excellent quality, including high laser damage threshold, broad-spectral response, low transmitted or reflected wavefront deformation, etc. In this talk, a complete analysis will be given on the specifications of the key elements for building new-generation laser systems.

14.30: **Multiscale study on laser-induced damage in fused silica optics by ns pulses at 355 nm: materials modification and damage structure** *(Invited Paper)*, Xin Ju, Chunhong Li, Univ. of Science and Technology Beijing (China); Jin Huang, Xiaodong Jiang, China Academy of Engineering Physics (China). . . . . [8206-90]

15.00: **Multi-shot 1064 nm laser-induced damage of glass substrate**, OuYang Sheng, Songlin Chen, Zhichao Liu, Chengdu Fine Optical Engineering Research Ctr. (China) . . . . [8206-34]

The properties of multi-shot laser-induced damage to glass substrate (fused silica and K9 glass) are investigated. 50 mm diameter, 5 mm thick test samples are manufactured by two different polishing processes. The test results suggest that: 1. Laser induced damage threshold is strongly correlated with subsurface damage. Samples polished by MRF have higher resistance to laser induced damage. 2. Acid etching does not improve the laser induced damage threshold of samples remarkably (an exception is a K9 glass sample polished by MRF). 3. The acid etched samples don’t have distinct accumulation effect of multi-shot laser induced damage.

15.15: **Research of damage characteristic of fused silica surface at UV pulse laser**, Jin Huang, China Academy of Engineering Physics (China) [8206-35]

Coffee Break. . . . . 15.30 to 15.50

SESSION 14

Room: Multifunctional Hall . . . . Tues. 13.30 to 15.15

Nonlinear Laser Crystal II

Session Chairs: **Zhanggui Hu,** Technical Institute of Physics and Chemistry (China); **Long Zhang,** Shanghai Institute of Optics and Fine Mechanics (China)

13.30: **Progress on large-scale LBO crystal growth** *(Invited Paper)*, Zhanggui Hu, Ying Zhao, Yinchao Yue, Xuesong Yu, Technical Institute of Physics and Chemistry (China) . . . . [8206-73]

14.00: **Fluoride crystals: exotic materials for optoelectronic applications** *(Invited Paper)*, Mauro Tonelli, Univ. di Pisa (Italy). . . . . [8206-74]

We developed high-quality single fluoride crystals by Czochralski technique. This activity covers different applications such as LIDAR, DIAL, high-resolution spectroscopy, metrology ,biology and optoelectronic. Among the crystals we can mention $LiYF_4$, $LiLuF_4$, BaY_2F_8 and $LiGdF_4$ doped with rare earth ions (Ho^{3+}, Tm^{3+}, Pr^{3+} and Yb^{3+}) to develop high efficiency tunable solid state laser in the near infrared (1 !m and 2 micron). Also we studied YLF crystal doped with Yb^{3+} and showed for the first time the development of solid state crycooler at 155 K temperature.

14.30: **Czochralski growth and optical investigations of Er^{3+}:$GdTaO_4$ crystal**, Huajun Yang, Qingli Zhang, Dunlu Sun, Shaotang Yin, Anhui Institute of Optics and Fine Mechanics (China). . . . . [8206-75]

Highly doped Er^{3+}:$GdTaO_4$ crystal was grown by the Czochralski(CZ) method and its structure was determined by Rietveld Refinement to X-ray powder diffraction. Its absorption, photoluminescence spectra and fluorescence decay curve at room temperature were measured and studied. The absorption cross-sections was evaluated and the Judd-Ofelt transition intensity parameters Ωt(t=2, 4, 6) were fitted to its absorption spectrum. With parameters Ωt, the oscillator strengths, fluorescence branching ratios, transition probabilities and the lifetimes of Er^{3+}:$GdTaO_4$ were calculated. The near-infrared and mid-infrared fluorescence properties were also discussed.

14.45: **Optical and lasing properties of disordered Nd: $SrLaGa_3O_7$ crystal**, Yuanyuan Zhang, Huaijin Zhang, Haohai Yu, Shangqian Sun, Jiyang Wang, Shandong Univ. (China) . . . . [8206-76]

A disordered Nd:$SrLaGa_3O_7$ laser crystal was grown by the Czochralski method. It was found that the thermal conductivity increases with increasing temperature. The absorption band around 808 nm is about 8 nm, and the 4F3/2→4I11/2 luminescence bandwidth is nearly 14 nm. Judd-Ofelt analysis was carried out to calculate the fluorescence branching ratios and the stimulated emission cross section. In continuous laser experiment, the output power was obtained to be 3.88 W with a slope efficiency of 14.8%. To our knowledge, this is the highest cw power with Nd: $SrLaGa_3O_7$ as the gain medium and a laser-diode as the pump source.

15.00: **Preparation, crystal structure, spectra and energy levels of the trivalent ytterbium ion-doped into rare earth stannates**, Kaijie Ning, Anhui Institute of Optics and Fine Mechanics (China) and Graduate Univ. of Chinese Academy of Sciences (China); Qingli Zhang, Anhui Institute of Optics and Fine Mechanics (China) . . . . [8206-77]

Yb^{3+}-doped Rare Earth Stannates $Ln_2Sn_2O_7$(Ln=Y, Gd) with space group Fd3m were synthesized by co-precipitation technique. Their structures were determined by Rietveld refinement to their X-ray diffraction, and their atom coordinates, lattice parameters and temperature factors were given. From photoluminescence, absorption and excitation spectra, the energy levels of Yb^{3+} in $Ln_2Sn_2O_7$(Ln=Y, Gd) were assigned and the crystal field parameters were fitted to energy splitting of Yb^{3+}-doped $Ln_2Sn_2O_7$ (Ln=Y, Gd).

Coffee Break. . . . . 15.15 to 15.35

Session 7 will run concurrently with Session 15.

SESSION 7

Room: Multifunctional Hall . . . . Tues. 15.50 to 18.50

Defects, Contamination, Polishing, and Surface Damage

Session Chairs: **Takahisa Jitsuno,** Osaka Univ. (Japan); **Wanguo Zheng,** China Academy of Engineering Physics (China)

15.50: **Long pulsed laser-induced damage in optical materials** *(Invited Paper)*, Zhonghua Shen, Xi Wang, Bin Wang, Xiaowu Ni, Jian Lu, Nanjing Univ. of Science & Technology (China). [8206-36]

Long pulsed Nd:YAG laser with pulse width of few milliseconds induced damage in optical materials and components, including semiconductors, optical films on substrates, were investigated experimentally.

The experimentally measured LIDT on silicon is 127.2 J /cm^2 and 4.8 J /cm^2 for 1 ms and 10 ns pulsed laser irradiation. The damage morphologies in silicon and optical films induced by long pulsed laser were observed. The damage threshold on optical films decreases to a minimum value when the laser spot size increases. A cone-shaped cavity was observed in the substrate. The damage morphologies of anti-reflection and high-reflection coatings are different.

16.20: **Mechanical polishing to improve uniformity of beam sampling grating and its effects on laser-induced damage**, Huanle Rao, Zhengkun Liu, Ying Liu, Shaojun Fu, Univ. of Science and Technology of China (China). . . . . [8206-37]

In this paper, a mechanical polishing process was proposed to improve uniformity of the diffraction efficiency of beam sampling grating (BSG). The effect of this process on the laser induced damage threshold (LIDT) of BSG will also be studied. In the processing, CeO_2 was used to polish the local areas of grating in order to reduce their higher diffraction efficiency and achieve similar efficiency with the surrounding areas. The RMS of diffraction efficiency of BSG after mechanical polishing shows great reduction from 11.3% to 5.3%. LIDT measurement will be carried out at wavelength of 355nm.

16.35: **Multiple-defect coupling effect of nanosecond-pulsed laser-induced damage in optical materials**, Zhenkun Yu, Hongji Qi, Yuanan Zhao, Hongbo He, Shanghai Institute of Optics and Fine Mechanics (China) . . . . [8206-38]

This study was undertaken to evaluate the laser-induced damage of fused silica at 355 nm. The laser-damage threshold of fused silica samples was studied using laser-damage testing (355 nm, 6 ns). A new model, which improved the theory of defect-related induced damage, was proposed to describe the multiple-defect coupling effect of the nanosecond-pulsed laser-induced damage. The correlation between the damage probability and the damage threshold of the model were also reported.

16.50: **Analysis of subsurface damage during fabrication process and its removal**, Kun Xiao, Lei Bao, Wei Wang, Jianqiang Zhu, Shanghai Institute of Optics and Fine Mechanics (China). . . . . [8206-39]

Subsurface damage appears inevitably during the shaping process, grinding process, polishing process and lapping process, which are essential in the production of defect-free optical components. In this study, we manage to detect the positions and depths of the SSDs via Total Internal Reflectance Microscopy. The lateral distribution of the SSDs is obtained. For both loose abrasive grinding, we found that rougher surface suggests deeper subsurface damage. The characteristics of subsurface damage during fabrication process are better known in this study, and we anticipate a final resolution to remove subsurface damage.

17.05: **The influence of laser plasma effects on the characteristics of silicon surface damage**, Jinghua Han, Weixing Fan, Sichuan Univ. (China); Liming Yang, Chengdu Fine Optical Engineering Research Ctr. (China); Guoying Feng, Xiang Gao, Yanyan Liu, Lingdong Bao, Yongzhong Huang, Sichuan Univ. (China) . . . . [8206-40]

Based on the laser plasma effects, the damage characters of silicon under high intensity nanosecond laser pulses have been investigated. The results show that laser plasma has the thermal effects, shock effects and spectral radiation effects, etc. These comprehensive effects combined together determinate the damage characters. The thermal effect of laser plasma makes the laser zone melting, vaporization and ionization; then the mixed mass will be pushed out by the effect of the shock wave. In this way, the pit can be formed at the laser irradiated area and the cooled ejected effluents are radial distributed. The silicon was melt at the bottom of the pit, meanwhile the incident laser was interfered with scattering light The temperature at the laser irradiated area is so high that not only the silicon was melt at the center, but also the heat spread like a wave that makes surface tension change and the periodic surface structures, like ripple, can be found after cooling..

SESSION 15

Room: Multifunctional Hall . . . . Tues. 15.35 to 18.20

Nonlinear Laser Crystal III

Session Chairs: **Jian-Rong Qiu,** South China Univ. of Technology (China); **Yubai Pan,** Shanghai Institute of Ceramics (China).

15.35: **Optical and thermo-mechanical properties of pure and Yb-doped fluoride crystals for high-power laser systems** *(Invited Paper)*, Richard Moncorge, ENSICAEN (France) . . . . [8206-78]

Optical and thermo-mechanical properties of pure and Yb doped fluoride crystals for high power laser systems

16.05: **Preparation and laser characterization of Cr^{2+}: ZnSe mid-infrared laser crystals**, Yongjun Dong, Hao Zhang, Wei Chen, Yi Xu, Yanyan Li, Yuxin Leng, Shanghai Institute of Optics and Fine Mechanics (China) . . . . [8206-79]

Cr^{2+}: ZnSe single crystals used for the generation of 2~3μm mid-infrared laser were successfully grown by the temperature gradient method. The relationship between different growth process and crystal quality was investigated, and the crystal defects and spectra performance of the Cr^{2+}: ZnSe single crystals were characterized. Using a widely tunable Tm:YAP laser as pumping sources, its laser performance was demonstrated.

16.20: **Study on the properties of the DKDP crystal with different deuterium content**, Mingxia Xu, Sun Xun, Liu Baoan, Shaohua Ji, Xinguang Xu, Shandong Univ. (China) . . . . [8206-80]

KH_2PO_4 (KDP) and its deuterated analogue $KD_xH_{2-x}PO_4$ (DKDP) are currently the only nonlinear materials suitable as frequency converters and Pockel cells in high-power large-aperture laser systems. In the third harmonic generation (THG) of Nd:glass laser, DKDP is preferred used to substitute KDP crystal for its weak stimulated Raman scattering (SRS) effect. In this paper, DKDP crystals were grown by traditional technique from different deuterated solution. The crystal samples were selected to test the rocking curves, transmission spectra, Raman spectroscopy and the laser damage thresholds (LDT) and so on. We studied the impact of deuterium element on the structure and the properties of DKDP crystal by these tests.

16.35: **Effecting of Na and K codoped on Yb: PbF_2 laser crystal**, Yin Jigang, Shanghai Institute of Optics and Fine Mechanics (China) . . . . [8206-81]

Lead fluoride crystals doped with YbF_3, NaF- and KF-codoped were grown using the vertical Bridgman method. Influence of the codoping with Na+ and K+ ions on the distribution coefficients and photoluminescence spectra of the Yb ions has been studied.

16.50: **Energy levels fitting and crystal-field calculations of Nd^{3+} doped in GYSGG crystal**, Jinyun Gao, Qingli Zhang, Dunlu Sun, Shaotang Yin, Jianqiao Luo, Wenpeng Liu, Anhui Institute of Optics and Fine Mechanics (China). . . . . [8206-82]

The single crystal $Nd_{0.03}Gd_{0.93}Y_{2.04}Sc_2Ga_3O_{12}$ (Nd^{3+}:GYSGG) was grown by Czochralski method successfully, and its absorption spectra was analyzed in a wider spectral wavelength range at 7.6K and 300K, respectively. The free-ions and crystal-field parameters were fitted to the experimental energy levels in 7.6K and 300K with the root mean square deviation of 11.25 and 12.48 cm^{-1}, respectively. According to the crystal-field calculations, 116 levels of Nd^{3+} in 7.6K and 114 levels of Nd^{3+} in 300K were assigned. Finally, the fitting results of free-ions and crystal-field parameters are compared with those already reported for Nd^{3+}:GSGG and Nd^{3+}:YSAG.

17.05: **Generation and mechanism discussion of multiwavelength garnet crystal lasers**, Haohai Yu, Kui Wu, Zhongben Pan, Huaijin Zhang, Zhengping Wang, Jiyang Wang, Shandong Univ. (China) . . . . [8206-83]

We report multi-wavelength lasers at about 1.06 μm with the three garnet laser crystals and discuss their generating mechanisms, which include frequency selector by a saturable absorber, generations by multi-emission centers and stark splitting. We also proposed that the multi-wavelength lasers should have applications in optical communications, optical instrumentation, probe-pump experiments, optical beating, remote sensing, and coherent terahertz generation.

17.20: **Study on the fourth harmonic frequency generation of DKDP crystal**, ShaoHua Ji, Shandong Univ. (China). . . . . [8206-84]

Compared to KDP crystal, DKDP has low laser-induced damage threshold,higher light transmittance,lower half-wave voltage and bigger electro-optical coefficient. With the development of ICF project,the requierment of output energy of DKDP crystal is imroving,so we carried out some related experiments in present work on the fourth harmonic frequency generation of DKDP crystal.

Session 7 will run concurrently with Session 15.

SESSION 7 (Continued)

Room: Multifunctional Hall . . . . Tues. 15.50 to 18.50

17.20: **Laser cleaning effect observed by laser calorimeter**, Hao Liu, Chengdu Fine Optical Engineering Research Ctr. (China) . . . . [8206-41]

Laser Calorimeter was chosen to measure the weak absorption of HfO_2 film.Three different wavelength laser was utilized, and each measurement was taken 20 times. Decreasing of absorption was recorded, and the data was carefully treated. Different cleaning methods were taken use of to compare with Laser cleaning. A Laser cleaning model was established.

17.35: **Laser-induced damage on 355 nm silica optics due to Fresnel diffraction on surface contamination particles**, Xinxiang Miao, China Academy of Engineering Physics (China) . . . . [8206-42]

To study Light intensity modulations caused by opaque obstacles, particles were sputter deposited on the input surface and irradiated with a 6.8 ns laser beam at 355nm. The results show that the LIDT of the fused silica decended to 7 J/cm^2 form 12 J/cm^2, and descend exponential with the sizes of the contamination particles. The relation between the depth and fluences is linear to the same contamination size. The experiments are modeled by calculating the light intensity distribution behind an obscuration by using of fresnel diffraction theory. The comparisons between calculated light intensity distribution and damage pattern show good agreement.

17.50: **Study of dust-pollution-induced laser damage on fused silica surface**, Xinda Zhou, Jin Huang, China Academy of Engineering Physics (China) . . . . [8206-43]

We report the experiment results of the study on dust pollution initiated damage in optical component of the ICF facilities and evaluate the influence of this kind damage on other optical component.

18.05: **Study on mechanisms of HF solution improving damage properties of fused silica subsurface cracks**, Fengrui Wang, China Academy of Engineering Physics (China). . . . . [8206-44]

Fused silica optic was etched by HF solution, the morphology and damage properties of micro subsurface cracks were studied. Experimental and theoretical results show that heat absorption of inclusions in cracks, and light field intensification caused by inclusions and the crack are critical roles which induces the low damage threshold. Etching with HF solution can eliminate the inclusions effectively, the cracks are passivated and transformed into different morphologies, and after the etching process, heat absorption and light intensification caused by cracks decreased dramatically, and the crack's damage threshold increased more than one time.

18.20: **Research of removing polishing powders from BK7 substrates by ultrasonic cleaning method**, Tao Ding, Xinbin Chen, Zhengxiang Shen, Bin Ma, Jinlong Zhang, Hongfei Jiao, Zhanshan Wang, Tongji Univ. (China) . . . . [8206-45]

The cleaning process of optical substrates plays an important role during the manufacture of high-power laser coatings. In this study, the polishing powders such as cerium dioxide were deposited on the cleaning substrates, and the ultrasonic cleaning method was employed to remove the particles. During this process, the ultrasonic frequencies were varied from 40KHz to 170KHz to detect the function between the removal efficiency and the ultrasonic frequency. Specifically, it was also found the PH value of the solvent have much influence to the cleaning efficiency.

18.35: **Reduction of the 355-nm laser-induced damage initiators by removing the subsurface defects in fused silica**, Minghong Yang, Hongji Qi, Yuanan Zhao, Shijie Liu, Kui Yi, Shanghai Institute of Optics and Fine Mechanics (China). . . . . [8206-46]

The laser damage resistance was improved more than 2.2-fold by removing the subsurface defects in fused silica. HF/NH4F etching and magneticrheological finishing were used to reduce the subsurface defects. The effect of the subsurface defects removal on laser damage resistance was characterized by measuring the laser-induced damage threshold (LIDT) at 355nm. Results show that the crack number density of the final treated sample decreased from ~103 to <10 cm^{-2}, and the surface-LIDT enhanced from 13.2 to 30 J/cm^2 compared with the un-treated sample.

SESSION 15 (Continued)

Room: Multifunctional Hall . . . . Tues. 15.35 to 18.20

17.35: **Laser damage threshold and nonlinear optical properties of large aperature elements of YCOB crystal**, Yanqing Zheng, Shanghai Institute of Ceramics (China); Xiaoyan Liang, Shanghai Institute of Optics and Fine Mechanics (China); Anhua Wu, Shanghai Institute of Ceramics (China); Liming Yang, Chengdu Fine Optical Engineering Research Ctr. (China); Tao Wang, Shanghai Institute of Optics and Fine Mechanics (China); Liejia Qian, Shanghai Jiao Tong Univ. (China); Erwei Shi, Shanghai Institute of Ceramics (China). . . . . [8206-85]

Large size of YCOB crystals were grown both by Czochralski and Bridgeman methods. Large size elements as large as 60 mm clear aperature were cut and polished with surface flatness of 1/5 wavelength. Optical homogeneity of YCOB crystal was found in the order of 10^{-6}. Laser damage thresholds of several YCOB crystal elements were tested using different laser facilities with different pulse widthes or wavelengths, with thresholds varied from 0.8 GW/cm^2 to more than 1 TW/cm^2. One SHG and two OPCPA experiments were excuted to characterize the nonlinear optical properties of YCOB crytals and the quality of the crystals. The results shown that YCOB had good performance in OPCPA application,especially with low content of parameter florescence. Combined with good NLO performance and possibility to grow large size crystals, YCOB crystal was a good choice for high power OPCPA applications.

17.50: **Study of the laser-induced damage in DKDP crystals**, Baoan Liu, Mingxia Xu, ShaoHua Ji, Xun Sun, Zhengping Wang, Xinguang Xu, Shandong Univ. (China) . . . . [8206-86]

By using the traditional temperature-reduction method, KD_2PO_4 (DKDP) crystals were grown from 87%-deuterated aqueous solution synthesized by different kind of KH2PO4 (KDP) raw materials. The crystals are cut to Z-plant and type tripler samples. The damage behavior of bulk DKDP samples under 1053nm and 351nm laser pulses was investigated. Morphology of laser-induced damage under different wavelength laser are observed with optic-microscope and SEM. Micro-Raman is applied to analyze damage sites at each wavelength, the result shows that there have been some changes about the nature of damage sites in material after laser irradiation, further research is being planed.

18.05: **Spectroscopic properties of Yb-doped $Ca_{1-x}Sr_xF_2$ laser crystals by γ-rays irradiation**, Yeqing Wu, Shanghai Institute of Ceramics (China) . [8206-87]

In this paper, the spectroscopic properties of Yb:$Ca_{0.5}Sr_{0.5}F_2$, Yb, Na:$Ca_{0.5}Sr_{0.5}F_2$ disordered crystals and Yb:CaF_2, Yb, Na:CaF_2 single crystals were studied after γ-rays irradiation. These crystals were grown by the Bridgman technique. Colour centres and Yb^{2+} formed in these crystals by γ-rays irradiation. The influence of codoping with Na+ on the spectra has been studied. The results showed that Na+ codoping with Yb^{3+} as charge compensators can suppress the deoxidization of Yb^{3+} to Yb^{2+}. The spectroscopic properties of these crystals were also studied after heating samples.

Closing Remarks . . . . Tues. 18.50 to 19.00

Wednesday 9 November

SIOM Tour and Excursion to Zhouzhuang

Wed. 08.00 to 17.00

The conference organizers will be leading a brief tour of the SIOM laser facility followed by an excursion to Zhouzhuang, an ancient water town short-listed as a possible UNESCO World Cultural Heritage Site. Attendees can register for this event at the registration desk for an additional $40 US.

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Notes