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Optical Materials for High Power Lasers

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Conference 8206: Pacific Rim Laser Damage: Optical Materials for High Power Lasers

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8206-01, Session 1

Large-aperture laser resistant optics for inertial fusion lasers

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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.

8206-02, Session 1

3D microstructuring inside glass by ultrafast laser

K. Sugioka, K. Midorikawa, RIKEN (Japan)

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.

8206-03, Session 1

Progress of optical materials for high-power lasers in China

J. Shao, Y. Dai, Shanghai Institute of Optics and Fine Mechanics (China); Q. Xu, Chengdu Fine Optical Engineering Research Ctr. (China)

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.

8206-04, Session 2

Femtosecond laser interaction with glasses

J. Qiu, South China Univ. of Technology (China)

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.

8206-05, Session 2

Laser-induced fluorescence of UV materials irradiated by ArF excimer laser

Q. Lou, Shanghai Institute of Optics and Fine Mechanics (China)

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.

8206-06, Session 2

Compensation of nonlinear effects using different compensation techniques

S. Gupta, Guru Nanak Dev Univ. (India)

In this paper, an analysis of the performance limitations of SMF due to SPM, XPM and FWM effect is discussed. With the aid of OptiSystem simulation software, compensation of these nonlinear effects using DCF technology for SPM and XPM also FBG technique is used for compensation of FWM with equal and unequal channel spacing between them. The compensation of SPM, XPM with proper choice of SMF length and its positive dispersion w.r.t DCF length and its negative dispersion i.e. L1D1=L2D2. For the compensation of FWM with equal and unequal channel spacing, FBG technique have chosen with particular center frequency. Better results are achieved with unequal channel spacing for compensation of FWM as compared to equal channel spacing between them. The BER, Q-Factor and eye diagram technique have been used for evaluating the system performance. The BER and Q-Factor 2.345e-107 and 21.975 respectively for compensated SPM for fiber length(450Km) is achieved. The BER, Q-Factor for compensated XPM 9.68e-16 and 7.89 resp. is achieved. The BER, Q-Factor for compensated FWM with unequal channel spacing 5.37e-16 and 7.96 resp. is achieved.

8206-07, Session 2

Surface and interface study of SiO_2 coated InP/InGaAs/InGaAsP semiconductor laser microstructures in the soft KrF laser irradiation regime

J. J. Dubowski, N. Liu, S. Blais, Univ. de Sherbrooke (Canada)

Surface study of laser irradiated dielectric films on hard substrates, including sapphire, fused silica, or SiC, is important for the understanding and development of damage-resistant coatings, as illustrated by numerous investigations devoted to this problem. However, relatively few results have been published that concern semiconductor substrates (wafers) coated with Si3N4 or SiO2 films and irradiated with ultraviolet lasers at the material near-ablation threshold. Our interest in this topic is driven primarily by the ability of a laser to create important defects at the dielectric-semiconductor interface that are known to promote the process of quantum well intermixing (QWI) during high-temperature rapid thermal annealing.

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 SiO2, and irradiated with a KrF excimer laser delivering up to 100 pulses at 124 and 155 mJ/cm2. We have investigated both the surface morphology of the SiO2 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 SiO2 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.

The up to date x-ray photoelectron spectroscopy experiments point out to the negligible participation of impurities in the KrF laser induced QWI process in the investigated QW microstructures. Our ellipsometry measurements suggest that optical densification of SiO2 films takes as a result of the irradiation with the KrF laser operating in the investigated window of parameters. These findings have provided significant arguments to the physical model that we build addressing formation of the SiO2/InP interface and its stability upon irradiation with the KrF laser.

8206-08, Session 2

Review of femtosecond laser-induced refractive index change in transparent materials

Q. Zhao, G. Lin, Shanghai Institute of Optics and Fine Mechanics (China); J. Qiu, South China Univ. of Technology (China)

The growing compact integrated photonic devices need the propagted optical field to be tightly confined in three-demension (3D), which requires a refractive index difference between the 3D waveguides and the surrounding matrix. As well known, femtosecond laser processing has offered new prospects to miniaturize and integrate highly functional photonic devices directly inside transparent materials. Nonlinear optical interactions induce strong refractive-index changes in sub-micron volumes that permit the generation of 2D and 3D refractive-index structures inside various glasses or crystals.

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, the efforts for tuning the refractive index and some new findings regarding the refractive index change 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.

8206-09, Session 2

Optical damage in fused silica induced by tightly focused femtosecond laser

K. Wang, Shanghai Institute of Optics and Fine Mechanics (China)

The optical damage of fused silica induced by femtosecond laser (800nm, ~100fs) has been studied. Under the threshold of breakdown, the generation of color centers and glass structural change is observed after femtosecond laser irradiation. In order to get more details of these changes, we analyzed several spectra of the sample before and after the laser irradiation. First of all, the two peaks around 248 and 215nm in the optical absorption (OA) spectra, which due to the color center of oxygen deficient defects (ODC) and Si:E’ respectively, increase with the enhancement of the incident laser pulse energy. We also analyzed the photoluminescense spectra of the samples: the enhancement of peaks at 286 and 486nm means a larger amount of ODC. And the ESR (electron spin resonance) spectra suggest that there are two variants of Si:E’ center, with g = 2.006 and 2.0021 respectively. In addition, with the increasement of laser energy, the peaks at 400 and 1200cm-1 in Raman spectra move towards higher wavenumber, which indicate the modifications of glass structure, especially the number of 3- and 4-membered rings and the change in Si-O-Si bond angle.

8206-10, Session 2

Pulse-length effect on laser-induced thermal damage of optical thin films

B. Wang, X. Ni, Z. Shen, J. Lu, Nanjing Univ. of Science & Technology (China)

The laser damage in optical thin films with pulse duration of nanosecond or below has been studied more than 40 years, while with pulse duration longer than that was little mentioned. In this paper laser damages in optical thin films with different pulse durations from nanosecond to millisecond are investigated. The damage is believed to be a thermally dominant process when the irradiating laser is infrared and its pulse-length is nanosecond or longer. So the damage phenomena can be investigated through thermal effects in these cases. 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. For nanosecond laser, the trend of temperature rise at the end of laser pulse is in accord with that of the standing-wave electric field in films. As different films have different electric field peak locations, the most easily damage part of single layer film, HR, AR, and interference filter are different, and the substrate is usually not affected. However, for millisecond laser, the temperature distributions in all films along the depth direction are almost uniform, which means that the substrate is easily affected. Finally, we carry out the damage experiments of optical thin films induced by 10 ns and 1 ms lasers. The experimental results meet the thermal analytical ones.

8206-47, Session 8

Silica ablation process induced by focused laser plasma soft x rays

T. Makimura, S. Torii, Univ. of Tsukuba (Japan); H. Niino, National Institute of Advanced Industrial Science and Technology (Japan); K. Murakami, Univ. of Tsukuba (Japan)

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 Nd:YAG laser light. The laser plasma soft X-rays have a pulse duration of 10 ns. The soft X-rays were focused on silica surfaces at up to 1E8 W/cm2. We found that silica glass can be ablated at up to 150 nm/shot by X-ray irradiation. Typically, the ablated surface have a roughness of 1 nm after ablation by 500 nm in depth. Further, trenches with a width of 50 nm can be clearly fabricated on silica surface. Thus, high quality, practical micromachining can be achieved by the X-ray technique. It is remarkable that more precise features can be fabricated on silica surface than the thermal diffusion length. The results implies non-thermal ablation process. We observed ionic and neutral species ejected from silica surfaces during the irradiation and found that both neutrals and ions are almost atomic species such as Si, O, Si2, O2, SiO; Si+, O+, (Si2)+, (O2)+, (SiO)+. The results revealed that silica surfaces are broken into atomic species by X-ray irradiation. Among X-ray ablated species, 0.5-15 % are estimated to be ionized. Even though 0.5 % atoms are ionized in silica surface, the energy density of Coulomb repulsive force is higher than the energy density of binding energy of silica glass. Therefore, we can conclude that Coulomb repulsion between X-ray generated ions are essential for X-ray ablation of silica glass.

8206-48, Session 8

Progress in advanced laser processing for manufacturing of high-efficiency silicon solar cells

J. Chen, L. Chen, Z. Wu, RX Technologies Co., Ltd. (China)

To reduce manufacturing costs and to improve electrical efficiency of solar cells are top priorities of the whole photovoltaic (PV) industry. The success of laser processing techniques in the integrated circuits industry indicates that such techniques could also be adapted in the PV industry. In this paper, we presented recent progress in advanced laser processing for manufacturing of high efficiency silicon solar cells at RX Technologies, especially the application of picosecond laser pulses for grooving and doping on crystalline silicon solar cells. A system based on 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.

8206-49, Session 8

Spatiotemporally focused femtosecond laser direct-write of microfluidic channels with a circular cross section

Q. Cui, F. He, L. Yang, Y. Cheng, Shanghai Institute of Optics and Fine Mechanics (China)

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. Furthermore, spatiotemporally focused femtosecond laser direct-write allows for fabrication of hollow optical waveguides and we show that in such hollow waveguides,high-intensity femtosecond laser beams can be guided with low optical loss.Besides microfluidic channels, micro-optical structures such as waveguide with perfectly circular cross sections can also be formed in fused silica, which facilitates incorporating optical functions into photonic and fluidic micro-systems. Lastly,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. Thus, spatiotemporally focused femtosecond laser micromachining will open up a broad spectrum of opportunities in the microfluidics, microoptics and strong-field physics applications.

8206-50, Session 8

Fabrication of hollow structures with arbitrary configurations embedded in glass using three-dimensional femtosecond laser micromachining

Y. Ju, Y. Liao, Shanghai Institute of Optics and Fine Mechanics (China)

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. After the postannealing process, all the nanopores in the mesoporous glass disappeared; however, the fabricated microstructures could survive due to their large diameter. By use of this technique, we illustrate that a square-wavelike channel with a total length of 3.6 cm and a diameter of ~12 μm and a 1 mm×1 mm×100 μm microchamber connected to four microfluidic channels can be easily produced, showing that our technique allows for fabrication of not only thin channel structures with arbitrary lengths and configurations, but also hollow structures with infinitely large sizes. Furthermore, the main mechanism of formation of hollow microstuctures is also discussed as following: water continuously infiltrates into the porous glass through the networks formed by the nanopores, indicating that the bubbles generated in the microchannel will always be surrounded by water from all directions. For this reason, it will be much easier to drive the bubbles out from the channel because the water pressures exerted on the bubbles will be the same in all directions.

8206-51, Session 8

Efficient surface processing by ultrafast XUV/NIR dual action

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With the advent of table-top, high-repetition-rate, near-infrared (NIR) femtosecond laser systems, there has been a broad interest in the field of materials processing using ultrashort laser pulses motivated by nanotechnology and industrial applications. Unfortunately, a number of materials that often exhibit great technological and scientific importance are transparent in NIR, making it very difficult to process them by laser radiation in this spectral range. We have demonstrated a new method for efficient structuring of the surface of materials by applying femtosecond NIR laser pulses simultaneously with a weak extreme ultraviolet (XUV) beam, which leads to very strong radiation-matter interaction, bringing a dramatic increase in the surface processing speed. A laser system providing 5 mJ, 820 nm, 32 fs, 10 Hz pulses was used to generate high-order harmonics at 21 nm. The two beams were focused on the samples by using an off-axis paraboloidal multilayer mirror. In this contribution we will present our recent experimental results of the surface nanostructuring of thin films of amorphous carbon (a-C) and polymethyl methacrylate (PMMA) deposited on bulk substrates and discuss the underlying physical mechanisms. XUV radiation-induced formation of defects and free-charge carriers leads to alteration of the NIR optical properties of the processed material. In the case of a-C, large areas of laser-induced periodic surface structures with a spatial period of 550 nm are created that have their origin in laser-induced convective currents. Their formation is a proof of the occurrence of melting in the near-surface carbon layer.

8206-11, Session 3

Subpicosecond laser breakdown in optical thin films

W. Rudolph, The Univ. of New Mexico (United States)

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.

8206-12, Session 3

The laser-induced damage of multilayer optical films

Q. Xu, W. Zhang, Y. Liu, Xidian Univ. (China)

As the essential basic component of almost all optical components, optical film is the most fragile. Thus, it is very significant to research the damage mechanism of optical film and improve laser induced damage threshold (LIDT).

The interaction of laser and film materials is analyzed and the laser damage mechanism of optical films is roundly introduced in microcosmic and macroscopic aspects in this paper. Some influence factors of LIDT are introduced .Based on thermal conduction theory, the physical model of the temperature field of multiplayer films illuminated by laser is built. The numerical calculation program is built up by using alternating direction-implicit technique, showing the validity and credibility. On that basis, temperature field of several conditions and material film is simulated and analyzed. The application of finite element method (FEM) in thermal conduction is introduced. Transient temperature field of Al2O3 film based on K9 as substrate is simulated by using FEM software ANSYS.

The results obtained in this thesis would be of both theoretical significance and practical interest in the fabrication of thin films.

8206-13, Session 3

Heat conductivity and laser damage characteristic of particle stacking structured cellular films

Z. Xia, Wuhan Univ. of Technology (China) and Chinese Academy of Sciences (China)

Cellular materials having nanometer scale of voids and particles present some outstanding performances. For example, SiO2 cellular anti-reflective coating with high laser damage threshold has been firstly prepared in Lawrence Livermore National Laboratory (LLNL). The improvement of the anti-laser damage performance of cellular structured films can be realized based on cognizing the laser damage mechanism. Thermal action is the inevitable phase in laser damage process. In this paper, 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. The heat conductivity of films with particle stacked structure is very small. The contact point is the origin point of the laser induced damage. Damage spot size is decided by the laser beam radius and the laser energy density. The damage processes derived from different impurities are independent.

8206-14, Session 3

Investigation of laser-induced damage threshold of hafnia/silica high reflectors at 1064nm

W. Ai, Institute of Optics and Electronics (China) and Chinese Academy of Sciences (China); S. Xiong, Institute of Optics and Electronics (China)

In this study, HfO2 single layers and HfO2/SiO2 high reflectors with standard 1/4 wavelength design were prepared by ion assisted deposition (IAD) with APS ion source and ion beam sputtering (IBS). The starting materials for IAD technology were hafnium and granulated hafnia, and the target for IBS technology was hafnium. Characterization of HfO2 single layers such as crystal structure, optical properties, surface topography and absorption have been studied via x-ray diffraction, lambda 900 spectrophotometer, variable angle spectroscopic ellipsometry, zygo interferometer, and laser calorimeter. 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. The results of HfO2 single layers are useful to investigate the LIDTs of the high reflectors. Furthermore, the reflectivity, total integrated scattering and absorption of the high reflectors have played significant part in the LIDT. All the results used to analyze the LIDT of high reflectors have been discussed and interpreted in literature.

8206-16, Session 3

Interface damage study of dielectric coatings by nanosecond laser pulses

X. Cheng, Z. Shen, H. Jiao, J. Zhang, B. Ma, T. Ding, Z. Wang, Tongji Univ. (China)

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.

8206-17, Session 3

Coupling effect of multiwavelength laser pulses to damage in multilayer mirrors

L. Yan, Shanghai Institute of Optics and Fine Mechanics (China) and Graduate School of Chinese Academy of Science (China); C. Wei, D. Li, G. Hu, Z. Fan, Shanghai Institute of Optics and Fine Mechanics (China)

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%, which is similar to a recent multi-wavelength damage study about KDP/DKDP crystals.

Damage morphologies are also studied to explore the damage mechanism at respective wavelength. For the entirely different electric field distribution, 355 nm laser induced damages are mainly from nano-sized absorbers at upper interfaces while initiators for 1064 nm laser locate at deeper layers of the multilayer films, substrates or subsurface of the substrates.Under simultaneous illumination, the sensitive defects are still the precursors, but the damages were more catastrophic compared with the damage induced by 355 nm laser alone or 1064 nm laser alone. The possible explanation is that the absorbing of 1064 nm laser can be promoted by the plasma formed from damage process induced by 355 nm laser.

8206-89, Session 3

The study on high laser damage threshold biochamatic coatings fabrication

F. Pan, Chengdu Fine Optical Engineering Research Ctr. (China)

1 AR/2 HR bichromatic coatings were fabricated on the UBK7 substrate using electron beam evaporation technique.The optical property and wavefront of the coatings met the goals. The laser-induced damage threshold (LIDT) of the coatings under the irradiation of 1053nm and 527nm were tested ,and the damage morphology of the caotings were investigated by the AFM and optical microscope. The measurements revealed that the damage behaviors of biochromatic coatings were different under the irradiation of 1053nm and 527nm. Due to the different damage mechanisms of the bichromatic coatings, corresponing fabrication techniques were used to improve the damage threshold of the coatings under the irradiation of 1053nm and 527nm. It is found that the electrical standing wave optimization and the introduction of low absorptivity outer layers can reduce the absorption of the bichromatic coatings , as a result the the LIDT of bichromatic coatings at reflective 527nm improved. The results also showed that the reduction of surface defects and subsurface after MRF process are the main reasons for the improvement of the LIDT of bichromatic coatings at transmissive 1053nm.The related damage mechanisms under the two wavelength irradiation are also discussed respectively.

8206-52, Session 9

Direct and absolute absorption measurements in optical materials and coatings by laser-induced deflection (LID) technique

C. Mühlig, Institut für Photonische Technologien e.V. (Germany)

In the last decade, direct absorption measurements have been more and more evolved into a major tool to characterize optical materials and coatings. The sensitive proof of residual absorptions and their possible changes with (laser irradiation) time play an important role in the prediction of an optical system's performance since absorption induced effects like optic heating, thermal lens generation, depolarization etc. may yield functional damage, i.e. the change of the required optical system parameters. Furthermore, characterizing the absorption of optical materials and coatings is one central task for manufacturers e.g. to ensure stability in the production process, to verify functionalities and to understand possible performance changes and limitations during their use in high power laser applications.

After a short review of current direct absorption measurement techniques I will introduce the laser induced deflection (LID) technique for highly sensitive direct absorption measurements. In contrast to most photo-thermal measurement techniques the LID method allows an independent absolute calibration, thus giving absolute absorption data without the actual knowledge of the material's thermo-optical properties. In this context I will summarize different absolute calibration approaches and give examples to point out the importance of an independent calibration procedure.

The main part of the talk will focus on different strategies to measure bulk and coating absorptions that have been developed to ensure a high data accuracy. A new strategy will be introduced allowing the transfer of the LID technique to very small samples and to significantly increase the sensitivity for materials with a very weak photothermal response. Various experimental results are presented for optical materials and coatings covering a wide range of applications from optics for deep UV laser lithography at 193 nm, nonlinear crystals for frequency conversion, laser active/optical materials and coatings for high power material processing in the NIR to the estimation of loss-limits in high power laser fibers by characterizing the doped raw materials at 1550 nm.

Finally, for industrial application an LID prototype is presented that has been realized to combine high sensitivity and improved handling. Moreover, a modular setup allows the use of all presented measurement strategies to ensure high accuracy combined with high a sample throughput.

8206-53, Session 9

Relevance of the choice of diagnostic methods to investigate laser damage resistance in optical material

J. Natoli, M. Commandré, L. Gallais, F. R. Wagner, Institut Fresnel (France)

Laser induced damage in optical material in nanosecond regime is widely attributed to local precursors in range of nanometer to micrometer size. The damage precursors nature strongly depend on materials (coatings, non linear crystals, substrates,..), location of breakdowns (bulk, surface, interface) and irradiation parameters (wavelength, pulse duration...). The weakness of a priori knowledge on parameters as sizes, densities and natures of precursors, let think that the choice of the diagnostic method which reveals laser damage has to be adapted to each situation of irradiation.

Concerning the LIDT determination, destructive methods are usually involved : we can cite full size test using the “real” final configuration of irradiation, raster scan method using a focused laser beam allowing laboratory test and statistic approach allowing study with different beam sizes in order to probe the material homogeneity in terms of precursors. This multi-scale approaches give relevant post mortem information on material properties regarding high power laser irradiation.

In order to investigate the laser damage initiation mechanisms and also the fatigue or conditioning effects on materials, it appears necessary to involve non destructive diagnostics. These diagnostics permit to highlight modifications linked to precursors before material breakdown. The main difficulty here is the local character of the diagnostic added to often low density of initiating center. A multi-scale approach is thus also well adapted to the non destructive case. Interest of diagnostics as local fluorescence and high resolution photothermal deflexion both correlated with LIDT results will be discussed. To illustrate the purpose, examples on non linear crystals and coatings will be shown.

8206-54, Session 9

High reflectivity scan measurment on large-aperture laser optics with OF-CRD instrument

L. Gao, B. Li, Institute of Optics and Electronics (China)

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.The measurement is repeated several times by distroying and then restoring the cavity alignment. The result show the technique is highly sensitive and reproducile for ultra-high reflecitivity measurement.A motion controller has been used in the instrument to control displacement for auto scan on the large-aperture optics.A 200mm diameter mirror has been measured in this experiment.The reflectivity of a point on the mirror is 99.991%,and the error is 0.0002%.The rusult of auto scan and auto point on the mirror has been compare with the reflectivity of measurement by manual movement.The result show perfect conformity on reflectivity for each measurement point.The reflectivity of the whole mirror show agree uniformity.In conclusion , The instrument can be used for judge the reflectivity uniformity and surface condition of the ultra high reflective large-aperture optics.

8206-55, Session 9

Image denoising based on wavelet transform algorithm

Y. Ha, Hebei Univ. (China)

Vision is the main organ that we use to perceive the objects, which makes up more than 70% that we contact, so it is one of the main measures to get information of the world around us through images. With the development of information science and technology, digital image processing has become an important subject, which is widely used in some aspects such as communication, production, multimedia and medical treatment. The procedure of image acquisition or transmission is usually easily interfered by noise. The noise of images will greatly decrease images’ quality, thus directly influencing our analysis and usage of the images. So it is quite important to execute denoising. There are many image denoising methods and our goal is to eliminate image noise to the greatest extent while keeping image details.

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.

8206-56, Session 9

Measurement of losses in optical components using filtered optical feedback cavity ring down technique

Z. Qu, B. Li, Y. Han, Institute of Optics and Electronics (China)

A filtered optical feedback cavity ring down (FOF-CRD) technique employing a continuous wave Fabry-Perot diode laser is employed to measure the total optical losses, i.e., 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 diode laser, and the coupling efficiency of the laser into the RDC is significantly enhanced due to the FOF effect. In the experiment, an optical component having optically flat parallel surfaces is inserted exactly normal to the light beam in the RDC. According to Beer’s law, 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.

8206-57, Session 9

Investigation of optical surface damage detection with laser-induced fluorescence mircroscopy

Z. Gao, X. Tang, China Institute of Atomic Energy (China)

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 .

8206-58, Session 9

Extrapolation from small area test of laser-induced damage to the large area

W. Wang, D. Liu, J. Zhu, J. Zhang, P. Sun, Y. Zhang, K. Xiao, J. Miao, Shanghai Institute of Optics and Fine Mechanics (China)

Due to the limits of experimental conditions the laser damage test is confined to small area sample. By small area damage test, some characteristics of the material can be described in qualitative. But 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 more than 250mm in diameter. Statistical approach is an important method to extrapolate the data of small area test to large area performance in order to create the damage probability curve of large scale material.

In this article, we represent a revised statistical representation of the damage probability which can be extended to large scale material. Meanwhile, based on Monte Carlo method, the corresponding numerical calculation is also given to verify the accuracy and reliability of the extrapolation results.

8206-59, Session 9

Damage measurement of large-aperture diffraction grating at 10ps

X. Hao, X. Wang, W. Huang, K. Zhou, L. Zhao, X. Zeng, China Academy of Engineering Physics (China)

One of the primary performance limiters for ultra-short high power laser based on chirped pulse amplification technique (CPA) is the damage threshold of the final grating in the pulse compressor. Therefore, it is important to design and develop high-damage-threshold , gratings. An accurate measurement of damage threshold for the diffraction gratings can not only improve the manufacture process, but also supply the basis for designing high-energy short-pulse laser systems. Here we propose a novel measurement, by which the exact correlation between local fluence and local damage characteristics would be established.

Figure 1 shows the procedure of the measurement. A CCD camera and a numeric camera were utilized to record the spatial profile of the beam and its corresponding damage photograph. First, before carrying out the measurements, calibrate both the CCD and the camera.The distortion coefficients which would be used to calibrate the CCD and camera were obtained from standard bitmaps.

Second, record the damage image on the sample, its corresponding spatial intensity distribution as well as other parameters of the beam (such as pulse duration and total energy). Then extract the useful images from backgrounds. Data treatments, for example, image Enhancement, Otsu method , one-dimensional projection and morphological method, were used to segregate the image data from the photographs.

Third, distortion coefficients, which were got from the first step, were used to correct the distortion of the extracted images. Figure 3 shows the exacted spatial profile and its corresponding damage after corrected.

Finally, match fluence and damage images (image superposition is realized by means of reference points in the beam, hot spots). The beam profile and absolute energy measurement give access to the energy density F(x,y) locally in the beam:

Where, Etot is the total energy of the spot, Spix is the CCD pixel area, and i(x, y) is the pixel gray level.

The locations of damage points can be calculated by the CCD pixel, so can the damage morphology be reported by the microscope. Here we define the proportion of damage as the damage area account for the percentage of the local area. Figure 4 shows the proportion of damage on the sample grating versus the fluence. The damage threshold of the sample grating at 10ps, 1053nm is 0.57J/cm2, the proportion of damage is about 10% with the fluence range from0.75 J/cm2 to 1J/cm2, about 33% with the fluence range from 1.5 J/cm2 to 2.5J/cm2.

8206-60, Session 9

Influence caused by spacing and angle misalignment of the 4f setup on the femtosecond pulse temporal properties

Y. Nie, J. Qi, J. Yang, W. Hu, X. Li, National Univ. of Defense Technology (China)

Based on zero-dispersion 4f ultra-fast pulse shaping system, the relation between the resolution and the mismatched spacing of the system's components was analyzed in theory. And then the effect of mismatched spacing and angle on the system's 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%. All the results are helpful to the in-depth study on the zero-dispersion pulse shaping system and to arbitrary waveforms generation in reality.

8206-88, Session 9

The simple theoretical analysis of optical absorption coefficient (OAC) in optical nanomaterials in the presence of laser

S. Singha Roy, JIS College of Engineering (India)

The optical matrix element (OME) depends on the electron wave vector and this practical aspect has been incorporated in the present analysis. It has been invent taking Hg1-xCdxTe, In1-x¬GaxAsyP1-y,

InAs and InSb lattice matched to InP as examples of optoelectronic nano materials for mathematical computations that, for the modified energy ( ) 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 ( ) tends to 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.

8206-18, Session 4

Determination of optimal mitigation geometries for improving laser damage resistance in dielectric mirrors

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The performance of meter-scale multi-layer dielectric mirrors is often fluence-limited by damage sites which grow upon repeated exposure to high fluence laser irradiation. One approach for increasing the laser operational fluence is to replace the growing damage sites with predesigned benign mitigation structures. By mitigating the weakest sites on the optic, the large-aperture mirror will have a significantly improved laser damage resistance. In this study, theoretical calculations utilizing the finite-difference time-domain (FDTD) method combined with femtosecond laser machining are used to determine optimal mitigation geometries. We use FDTD to quantify the electric-field intensification within the multilayer in the presence of different conical pits. We find that the field intensification induced by the mitigation pit is strongly dependent on the polarization and the angle of incidence (AOI) of the incoming wave. Therefore, the optimal mitigation conical pit geometry is application specific. Simulation also illustrates an alternative means of achieving an optimal mitigation structure by matching the cone angle of the structure with the AOI of the incoming wave. Laser damage testing shows that these mitigation features created by femtosecond laser machining can double the fluence-handling capability of large-aperture optical multilayer mirror coatings. Our results demonstrate that femtosecond laser macromachining is a promising means for fabricating optimal mitigation geometry in multilayer coatings to increase mirror performance under high-power laser irradiation. This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

8206-19, Session 4

Multiple pulse laser-induced damage investigation of 1064nm reflection coatings

Z. Liu, J. Luo, S. Chen, F. Pan, Chengdu Fine Optical Engineering Research Ctr. (China)

Damage properties of the hafnia-silica reflection coatings under multi-pulse laser irradiation in vacuum were studied by using of small optic damage test facility. The result of the tests indicates that there are two dominant damage morphologies on coatings surface, scalds and delaminates respectively. The scalds trend toward delaminates under multi-pulse irradiation with certain fluence. The lateral scale of layer delamination shows an exponential growth behavior with the a few beginning shots and finally tends to stable. The final size of delaminate after 1000 shots has a linear function of fluence. In addition, the experiment result also indicates that scalds and delaminates have different growth behaviors, obviously effecting the value of laser induced damage threshold (LIDT) by S/1 test. Scalds have a lower LIDT but maintaining stable against increases in shot number. Conversely, the LIDT of delaminates shows an exponential decay behavior at the much higher fluence level and tend to a certain value under huge number of pulse shots. For further mechanism investigation of multi-pulse laser damage, finite element method was employed to simulate the thermal accumulation process during numbers of laser shots. Results show that the LIDT exponential decay behavior can be significantly affected by irradiation fluence, pulse-length, shot number and reputation rate. Finally, a simple function based on simulation result for fitting the decay law of LIDT was employed and the quantitative analysis of life time prediction of hafnia-silica mirror was discussed.

8206-20, Session 4

Effect of substrate bias voltage on optical properties of pulsed DC magnetron sputtered niobium oxide coatings

Y. Shao, K. Yi, M. Fang, J. Zhang, Shanghai Institute of Optics and Fine Mechanics (China)

Nb2O5 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 using spectrometer, interferometer, X-ray diffraction (XRD), atomic force microscopy (AFM), and field emission scanning electron microscopy (FE-SEM). Laser damage tests at 1064 nm wavelength with pulse duration of 12 ns were conducted on the single-layer systems. 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 Nb2O5 films. The maximum laser induced damage threshold (LIDT) of 28.8 J/cm2 was obtained for the film deposited at substrate bias voltage of -60V.

8206-21, Session 4

Laser damage properties of thin films grown by atomic layer deposition

Y. Wei, Chengdu Fine Optical Engineering Research Ctr. (China)

Atomic layer deposition (ALD) has been used to deposit TiO2/Al2O3 films at 110 and 280 on fused silica and BK7 substrates to study the relationship between the LIDT and deposition temperature. HfO2/Al2O3 films have been deposited by ALD using organic and inorganic precursors to study the relationship between the LIDT and the kind of the 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 that the films deposited by ALD had better uniformity and transmission, in this paper, the uniformity is better than 99% over 100 mm samples and the transmission is more than 99.8% at 1064 nm. Deposition temperature affects the deposition rate, the thin film microstructure and further influences the LIDT of the thin films. As to the TiO2/Al2O3 films, the LIDTs were 6.73±0.47 J/cm2 and 6.5±0.46 J/cm2 at 110 on fused silica and BK7 substrates, respectively. The LIDTs at 110 are notably better than 280 . Organic residual left on the thin films when using the organic precursors, which affects the LIDT of the films. As to the HfO2/Al2O3 films, the LIDTs were 7.3±0.51 J/cm2 and 13.5±0.95 J/cm2 measured by 1-on-1 and N-on-1 test manner, respectively. The LIDTs are notably worse than the thin films using inorganic precursors. The film LIDTs can further increased when the

technics condition were optimized. Therefore, ALD is a promising method for high power laser system.

8206-22, Session 4

Effect of deposition process on micro-defect and LIDT of thin films

D. Zhang, P. Fan, Shenzhen Univ. (China)

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 HfO2 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.

8206-23, Session 4

Laser-induced damage threshold of multilayer dielectric for broad band pulse compression gratings centered at 800nm

F. Kong, S. Chen, Shanghai Institute of Optics and Fine Mechanics (China) and Graduate School of Chinese Academy of Sciences (China); Y. Jin, S. Liu, Shanghai Institute of Optics and Fine Mechanics (China); H. Guan, Y. Du, Shanghai Institute of Optics and Fine Mechanics (China) and Graduate School of Chinese Academy of Sciences (China); C. Wei, H. He, K. Yi, Shanghai Institute of Optics and Fine Mechanics (China)

Manufacturing reflective mirror is one of the most critical steps for pulse compression grating used in the high energy ultrashort pulse laser system. This kind of grating supporting mirror must have three characteristics: high reflectance, broad bandwidth and high damage threshold. The mirrors for broad bandwidth 800nm pulse compression grating were fabricated with optimized parameters by electron beam evaporation using three different kinds of materials (Ta2O5/SiO2/HfO2), 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/cm2 and 2.0J/cm2 (57 degrees, TE mode) at pulse width of 50fs and 120fs, respectively. The corresponding damage mechanisms of the samples at these two cases were explored by detailed characterizing the morphologies of the damage sites with SEM and AFM. The reason of the samples having so high LIDT were also discussed in this paper. The mirrors with three materials provide a solid base for the high laser threshold 800nm pulse compression gratings and may open a new way for broad bandwidth 800nm reflectance coatings used in the ultrashort pulse laser system. The gratings based on the mirrors are in the process of fabricating.

8206-24, Session 4

Enhanced laser-induced damage threshold of antireflective porous glasses

Y. Du, Y. Jin, H. He, L. Yan, F. Kong, H. Guan, Shanghai Institute of Optics and Fine Mechanics (China)

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/cm2, by 10ns 0.532μm pulses of 20 J/cm2 and by 8ns 0.355μm pulses of 12 J/cm2. The treated surfaces with different experiment condition have variational LIDT compared with untreated substrates. Detailed mechanisms for the LIDT enhancement are discussed.

8206-61, Session 10

The transparent ceramics in SICCAS

Y. Pan, Shanghai Institute of Ceramics (China)

No abstract available

8206-62, Session 10

Spin-orbit momentum controlled anisotropic laser ceramics

Y. Sato, J. Akiyama, T. Taira, Institute for Molecular Science (Japan)

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.

8206-63, Session 10

Investigation on the visible and infrared emission properties of Tm: Y_2O_3 transparent ceramic

Q. Yi, S. Zhou, Shanghai Institute of Optics and Fine Mechanics (China)

With the purpose of investigation on the emission properties of Tm3+ ions, a 6 at% Tm3+-doped Y2O3 transparent ceramic was fabricated by sintering at 1800 for 20 hour with a vacuum degree of 1×10-3 Pa. 3 at% ZrO2 was introduced as the sintering aid. The Zr4+ ions can suppress the grain migration and lead to a uniform microstructure. With the using of an optical microscope, the average grain size was measured to be 22 μm. The optical transmittance of the ceramic achieved 76.3 % at 1 μm. Based on the photoluminescence excitation (PLE) spectra at 12 K and 296 K, the room temperature and low temperature PL spectra were investigated under the 361 nm, 485 nm, 683 nm and 795 nm Xe light excitation. The ~453 nm emission band was observed under the excitation at 361 nm and the temperature dependence of emission intensity between 12K and room temperature was investigated. This band consisted of many sharp lines, where the emission intensity at the high energy side decreased with decreasing temperature from RT to 12 K and disappeared below about 100 K. The ~1270 nm emission band was observed under the excitation at 361 nm and 485 nm. The ~1450 nm emission band was observed under all the four excitation wavelengths. The luminescence mechanisms are discussed on the 453nm, 1270 nm and 1450 nm bands.

8206-64, Session 10

Preparation of $Tb_3Al_5O_{12}$ (TAG) transparent ceramics for potential magneto-optical applications in high-power laser systems

S. Zhou, Shanghai Institute of Optics and Fine Mechanics (China)

Magneto-optical materials based on Faraday Effect are fundamental components in high pulse energy and high average power laser systems. To date, the most commonly used Faraday magneto-optical material for high power lasers is the Tb doped glass. Tb doped glass has high Verdet constant and easy large size fabrication. However, in a high power laser system with high repetition operation (≥10 Hz) for the inertial confinement fusion, the application of Tb doped glass would be limited for its low thermal conductivity. On the other hand, during the past two decades, the fast development of transparent ceramics shows that transparent ceramics might be a novel laser material with excellent properties. Typically, transparent ceramic possesses high thermal conductivity close to its single crystalline counterpart. And it is relatively easy to prepare transparent ceramics of large size. Terbium aluminum garnet (Tb3Al5O12, TAG) is an ideal crystalline magneto-optical material in the visible, near infrared region. Another advantage of preparing TAG transparent ceramics is that TAG single crystal is extremely difficult to grow for its incongruent melting nature. Thanks to its cubic garnet structure, TAG transparent ceramics with good optical quality could be made. In this report, Tb3Al5O12 transparent ceramics have been prepared by solid state reaction and vacuum sintering. The optical quality and the microstructure of the samples were investigated. The sample sintered at 1650 possessed relatively good optical transparency from 400 nm to 1600 nm. The Verdet constant measured at 632.8 nm of the quasi-pore-free Tb3Al5O12 transparent ceramic was -172.72 rad T-1 m-1, which was close to the counterpart of Tb3Al5O12 single crystal. The measured thermal conductivity of the sample was 6.5 W m-1 K-1.

8206-65, Session 10

The study on light scattering and microstructure in laser transparent ceramics

G. Jin, B. Jiang, Shanghai Institute of Ceramics (China)

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.

8206-66, Session 10

Effect of annealing on luminescence properties of vacuum sintered Ce:YAG transparent ceramic

H. Teng, H. Lin, Q. Yi, S. Zhou, Shanghai Institute of Optics and Fine Mechanics (China)

Transparent ceramics scintillator, such as Ce:YAG, Ce:GYAG, Ce:GYSAG, etc., offer an alternative to single crystals for applications such as gamma ray spectroscopy and radiography. These materials are commonly synthesized using vacuum sintering techniques, while oxygen vacancies trend to form in the crystal lattice during the sintering process, which lead to the variation of valence state of Ce ions and deteriorate the luminescence and scintillation properties of the materials. Here, Y3Al5O12 polycrystalline ceramics with Ce3+ concentration of 0.3at% were fabricated by solid state synthesis, and the ceramic green bodies were vacuum sintered in 1750 for 10h (Figure 1 shows the as-prepared Ce:YAG transparent ceramics). The effects of annealing on the valence state of Ce ions and luminescence properties of Ce:YAG transparent ceramics were investigated. The optimal annealing temperature and atmosphere were obtained. And it was found that the absorption at 370 nm is related to F+ color centers in Ce:YAG lattice, which extend the fluorescence decay time of Ce:YAG. The mechanism of variation behavior of the luminescence properties of Ce:YAG under different annealing conditions was discussed and some details on the luminescence associated with color centers were analyzed.

8206-25, Session 5

Research progress in laser-induced damage of optics for SG laser project

W. Zheng, China Academy of Engineering Physics (China)

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 (3) for square pulse of 3ns. The 48 beams of the SG-III have a right section of 40×40 cm2 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/cm2, 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.

8206-26, Session 5

Laser damage performance of pulse compressor grating

W. Kong, S. Wang, W. Zhang, M. Yun, X. Sun, Qingdao Univ. (China)

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.

8206-27, Session 5

Comparative investigation of laser-induced damage on K9 and fused silica under 1064nm nanosecond laser irradiation

H. Liu, China Academy of Engineering Physics (China)

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.

8206-28, Session 5

Investigation of laser damage mitigation pit induced beam modulation in fused silica

X. Li, Consultant (China)

CO2 laser radiation could efficiently improve optics performance, but mitigation pit induced beam modulation endangers downdream optics. To investigate modulation's variation regularity, it is provided that laser has the shape of flat-top distribution and transmission of laser in linear medium obeys Helmhotz equation. There is no gain and nonlinear effect in fused silica. 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 comparing with mitigation pit on the rear surface, when mitigation pit is on front surface laser damage pit induced beam modulation is more obvious. 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. When adopting a low mitigation laser power, mitigation pit has the appearance of guass distribution. Increasing CO2 laser power or duration time, surface appearance forms a setback type appearance. When laser damage is melted sufficiently, Surface appearance with annular raised region forms could form light spot which makes modulation increases obviously.

8206-29, Session 5

Research for ultra-short pulse ablation of dielectric film mirror

Z. Xiong, Y. Jiang, X. Wang, P. Zhang, F. Wei, X. Li, Shanghai Institute of Optics and Fine Mechanics (China)

In high-power laser system, in order to extend the components' service life and reduce the operation costs, more attentions should be pay at the research for damages ablation at multi-layer optical components and other high load optical components. 240ps, 35ps, 6ps, subpicosecond 1053nm laser pulses has been used to investigate damage ablation and damage resistant experiments at 0° high reflection films. By comparing the damage morphology and damage resistant threshold of the ablation pits at different pulses width, it was superior to use ultra-short pulse to repair multi-layers optical components. It was found that the shorter pulse width has been used, the higher the damage resistant threshold and the lower the laser modulation. Furthermore, the finite-difference time-domain method was used to simulate the electric-field intensification within the large size damage region of multilayer films.

8206-30, Session 5

Incubation effect of laser-induced surface damage of HfO_2/SiO_2 HR coating in the femto-nanosecond region

S. Chen, Y. Zhao, F. Kong, D. Li, H. He, J. Shao, Shanghai Institute of Optics and Fine Mechanics (China)

This paper is devoted to a long-term investigation into the nature of incubation effect of multilayer dielectric HR coatings. Accumulated damage behaviors of HfO2/SiO2 coatings for 800nm, 1053nm, and 1064nm, both fabricated by conventional electron beam evaporation (EBE), were investigated by ultra-short pulse (800nm/~100fs), short pulse (1053nm/~1ps), and long pulse (1064nm/~10ns) lasers, respectively. Incubation effect was found to be a universal phenomenon for HfO2/SiO2 coatings irradiating by the femto-nanosecond lasers. That was, the multiple-pulse damage threshold decreased with the increasing shot number, and this was leveled off when the fluence reached a certain value. 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. Consequently, the nature of incubation effect was analyzed in detail with the accumulation of "electronic trapping states", "structural effects", and both the electronic and structural defects in the different pulse regime, respectively.

8206-31, Session 5

Novel subwavelength microstructures for antireflection application

Y. Xin, China Academy of Engineering Physics (China)

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. The development of AR SWSs for use in high-energy laser applications is presented. Data from scanning electron microscope (SEM) analysis, reflection measurements, and LIDT testing, is shown for high performance AR SWSs fabricated in fused silica. Results of LIDT testing at wavelengths 1064nm confirm the initial result that AR SWSs can operate at pulsed laser power levels at least higher than fused silica untreated. The environmental durability of SWSs was investigated with promising initial results reported.

8206-67, Session 11

Er-doped fiber lasers operating at pulse duration from ps to ns

S. Wada, RIKEN (Japan)

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.

8206-68, Session 12

Composite YAG/Nd:YAG transparent ceramics for high-power lasers

J. Li, W. Liu, B. Jiang, X. Ba, Y. Shen, G. Jin, Y. Pan, X. Feng, J. Guo, Shanghai Institute of Ceramics (China)

Since Ikesue et al. first fabricated transparent Nd:YAG ceramics of sufficient quality for solid-state lasers with reasonable efficiency, they have attracted much attention because the optical quality has been improved greatly and highly efficient laser oscillations can be obtained whose efficiencies are comparable or superior to those of Nd:YAG single crystals. Compared with laser single crystal, one of the prominent advantages of laser ceramics is ease of achieving composite structure. According to the manufacturing process of ceramics, multi-layer ceramic laser materials can be fabricated together, whereas this is impossible with the single crystal growth method. 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 commercialα-Al2O3, Y2O3 and Nd2O3 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.

8206-69, Session 12

Selection of different sintering aids and morphology modification of the Y_2O_3 powders for Yb^{3+}:$Y_3Al_5O_{12}$ transparent ceramics

H. Lin, Shanghai Institute of Optics and Fine Mechanics (China)

Sintering aids and the morphology of the raw material powders are two important factors for obtaining transparent ceramics with fine quality.

In this work, La2O3, ZrO2, and MgO were adopted to prepare Yb3+:Y3Al5O12 transparent ceramics (the obtained samples were named SL, SZ and SM correspondingly). All of the samples were sintered at 1700 for 20 h with a base pressure of 1×10-3 Pa. The average grain size of SL was about 30 μm, which was the largest among the three samples. La2O3 enhanced the grain boundary mobility (GBM) so fast that pores tended to be enclosed in the grains. While for SZ, the grain boundaries were too obscure to distinguish. Plenty of pores were observed, which may be caused by the strong suppression effect of ZrO2 on the GBM. It is found that MgO has a positive effect that the grain boundaries move moderately so that pores could be eliminated well and meantime the grains would not get too large.

Calcination combined with ball milling was adopted to improve the morphology of the commercial available Y2O3 powders. Meantime, urea precipitation was used to prepare Y2O3 powders with good morphology. Comparison of the transparent ceramic samples from the Y2O3 powders with different preparing methods was also performed.

Laser performance of the Yb3+:Y3Al5O12 transparent ceramics has also been investigated.

8206-70, Session 13

Study on the weak absorption in KTP crystals

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Potassium titanyl phosphate (KTP) is usually utilized in all-solid-state laser as a good nonlinear optical crystal. Knowledge of variations in the weak absorption of different types of KTP crystals is important for the application. In this study, the flux-grown KTP crystals with titanium from TiO2, TiCl4 and Ti(OC4H9)4, respectively, and the hydrothermal-grown KTP crystal have been investigated. The weak absorption coefficients of the KTP crystals have been measured at 1064nm and 532nm by Photothermal common-path interferometer. The weak absorption coefficients of four samples are 100ppm cm-1, 800ppm cm-1, 45ppm cm-1, 20ppm cm-1 at 1064nm and 2.6×104ppm cm-1, 1.6×105ppm cm-1, 1.2×104ppm cm-1, 3.0×102ppm cm-1 at 532nm, respectively. The results showed that the weak absorption coefficients of the flux-grown KTP with titanium from Ti(OC4H9)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(OC4H9)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.

8206-71, Session 13

Structural and spectral investigations on heavily Er^{3+}-doped $ATaO_4$(A=Sc,Y,Gd,Lu) polycrystalline powders

P. Zhou, Q. Zhang, D. Sun, S. Yin, Anhui Institute of Optics and Fine Mechanics (China)

30at% Er:ATaO4(A=Sc,Y,Gd,Lu) polycrystalline powders were synthesized by the solid-state method. Their structures were determined by Retvield refinement to X-ray powder diffraction. The optical spectroscopy of the trivalent erbium ions in monoclinic ATaO4(A=Sc,Y,Gd,Lu) polycrystalline powders was studied by absorption and emission measurements at room temperature. Under the excitation of 980 nm light, the green photoluminescence of 2H11/2,4S3/2→4I15/2 and the 1.5μm infrared 4I13/2→4I15/2 emissions were observed. The decay times of Er3+ from the multiplets 2H11/2,4S3/2, and 4I13/2 were studied at room temperature. The decay curve from the multiplets 2H11/2 and 4S3/2, exhibits a non-exponential behavior, which maybe due to cross-relaxation process. The 808nm laser-excited luminescence spectra around 2.8μm(4I11/2→4I13/2) has also been studied.

8206-72, Session 13

Studies on the spectroscopic properties of Nd/Na-codoped CaF_2 single crystal

Q. Wang, Shanghai Institute of Ceramics (China)

High optical quality Nd/Na co-doped CaF2 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 1.25×10-20cm2 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 CaF2 crystal. All the results showed that Nd/Na co-doped CaF2 crystal would be a promising gain media in solid-state lasers.

8206-32, Session 6

Progresses of damage research in LFEX laser development

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In the activation of LFEX laser (1 ps, 10 kJ) system, we observed a heavy organic oil contamination in the compression chamber. After the evacuation of the compression chamber, all of mirrors and gratings were covered with oil frost, and the damage threshold (DT) 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. The source of contamination was traced, and we found the same contamination detected in other compression chambers. Contamination materials were identified as Paraffin-oil and DBP (Di-Butyl Phthalate). We made several efforts to reduce this contamination, and finally, succeeded to keep DT to original value after the evacuation with silica gel.

During this investigation, we found this kind of contamination is very common even in the DT samples. The plastic container for the DT sample was the source of contamination, and the silica gel was an effective material to reduce the contamination. This fact indicates that the environmental condition for the dielectric-coated optics is very important for high power lasers. We will report details of our research in the presentation.

8206-33, Session 6

Current status of the LULI laser facilities request of appropriate optical components for high-energy ultra-intense lasers

J. Zou, Ecole Polytechnique (France)

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.

8206-90, Session 6

Multiscale study on laser-induced damage in fused silica optics by ns pulses at 355 nm: materials modification and damage structure

X. Ju, C. Li, Univ. of Science and Technology Beijing (China); J. Huang, X. Jiang, China Academy of Engineering Physics (China)

In this talk, the LID scenario was studied multiscalely from microscopic (μm) to macroscopic (mm) in our work. We try our best to provide a different, unique, effective research route to physically study the damage mechanism. The aim of our work is not only to open new avenues for studying LID in optical materials but also to expand the applications of synchrotron-based techniques. The fused silica samples were specially polished on both surfaces. Pulsed Nd-YAG laser was employed at ambient conditions. The wavelength, pulse length were 355 nm and 6.8 ns, respectively. The examined fluence ranged from 0 to 65 J/cm2 and the examined frequency was 1/5/10 Hz. Combined advanced analysis methods of synchrotron XRD, synchrotron XRF, synchrotron X-ray CT, positron annihilation technique, FT-IR, XPS and photo-thermal absorption techniques were employed to analyze the damage mechanism. We report systematic and extensive data about the concentration and spatial distribution variation of surface metal inclusions, structural modifications such as variation of atomic size vacancy defects and variation of bond angle and length of Si-O-Si covalent bond, and the 3-D structure analysis of damage craters after irradiation. The obtained systematic data were used to discuss the role of laser fluence and frequency, the role of metal inclusions, the role of vacancy cluster and the role of structure alteration, and to establish a realistic damage model to acquire a physical insight into UV laser-induced damage process.

Our work provide a panoramic 3-D visualization of damage scenario from micron scale to millimeter scale, which combines the voids, cracks, crater together as a whole of damage. This panoramic visualization invokes scientists to consider the LID as a more complex and multiscale scenario. We hope that our work will motivate the future study of irradiation damage, which can extend our understanding of the LID behaviour of optical materials and provide more methods for damage mitigation.

8206-34, Session 6

Multi-shot 1064 nm laser-induced damage of glass substrate

O. Sheng, S. Chen, Z. Liu, Chengdu Fine Optical Engineering Research Ctr. (China)

The properties of multi-shot laser-induced damage to glass substrate (fused silica and K9 glass) are investigated. The source is a Nd:Yag laser with the following characteristics: wavelength-1064 nm, pulse duration-5 ns and repetition rate-5 Hz. During the test, the beam is focused on the sample surface, and beam diameter is about 670 μm at 1/e. S-on-1 test procedure is used to determine the optics laser damage threshold. An in situ observation of irradiated area, by means of a long distance microscope and a CCD camera, is applied to diagnose whether laser damage occurred. After testing, Nomarski microscope is employed to observe the laser-induced damage morphology. 50 mm diameter, 5 mm thick test samples are manufactured by two different polishing processes. Parts of the test samples are MRF polished. Polishing induced contamination and subsurface damage (SSD), which are produced during grinding and polishing processes, are the widely admitted damage initiators. In this sample preparation procedure, MRF polishing process is able to minimize the SSD, and acid etching is utilized to decrease

the concentration of polishing contamination as a post processing. The test results suggest that: 1. Laser induced damage threshold is strongly correlated with SSD. 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.

8206-35, Session 6

Research of damage characteristic of fused silica surface at UV pulse laser

J. Huang, China Academy of Engineering Physics (China)

In ultraviolet (UV) pulse laser, anti-damage capability of fused silica optics is directly depended on the absorptive impurities and scratches in subsurface, which are induced by mechanical polishing. In the research about influence of subsurface defect on anti-damage capability, a series of fused silica surface with various impurities and various structure scratches were created by HF acid solution etching with different depth. ToF-SIMS and scanning probe microprobe reveals that with increasing etching depth, impurity content in the subsurface layer is decreased, the scratches structure becomes more smooth and diameter to depth ration is increased. Damage test with 355 nm pulse laser shows that when subsurface thickness is removed 600nm by HF acid etching, anti-damage capability of fused silica is enhanced and initial damage threshold is raised by 40 percent. Field enhancement caused by change of scratches structure was calculated by FDTD software, and the calculated results are accordant to the damage test results.

8206-73, Session 14

Progress on large-scale LBO crystal growth

Z. Hu, Y. Zhao, Y. Yue, X. Yu, Technical Institute of Physics and Chemistry (China)

Lithium triborate (LiB3O5, LBO) crystal used to be grown by the Top-Seeded Solution Growth method (TSSG). Research on the growth of large-scale LBO crystal has been going on in our group since 2004. The key point of fast growing large-scale and high quality LBO crystals was thus solved with the use of this new solute transport technique as well as a new flux system. The largest LBO single crystal reported in the world with the size of 160×150×77mm3 and the weight of 1988g was successfully grown in four months. To evaluate the quality of the large LBO crystal, the transmittance, optical homogeneity, and laser-induced surface damage threshold were measured. In the near future, LBO crystal will play an active role in the progress of large-aperture, high-energy, high-power laser techniques.

8206-74, Session 14

Fluoride crystals: exotic materials for optoelectronic applications

M. Tonelli, Univ. di Pisa (Italy)

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 LiYF4, LiLuF4, BaY2F8 and LiGdF4 doped with rare earth ions (Ho3+, Tm3+, Pr3+ and Yb3+) to develop solid state laser in the near infrared (1 !m and 2 micron) and visible wavelength region. We have also studied the spectroscopic properties and developed high-efficiency tunable lasers in cw and pulsed operation regime. We studied the fluoride crystals doped with Tm3+ and we obtained 70% slope efficiency and 300 nm wavelength tunability. Moreover we studied samples doped with Ho3+ in cw and pulsed regime. We have also investigated and compared laser emission in the visible region of three different crystals (YLF, LiLuF and LiGdF) doped with Pr3+ for RGB application. Also we studied YLF crystal doped with Yb3+and showed for the first time the development of solid state crycooler at 155 K temperature.

8206-75, Session 14

Czochralski growth and optical investigations of Er^{3+}:$GdTaO_4$ crystal

H. Yang, Q. Zhang, D. Sun, S. Yin, Anhui Institute of Optics and Fine Mechanics (China)

Highly doped Er3+:GdTaO4 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 Er3+:GdTaO4 were calculated. The near-infrared and mid-infrared fluorescence properties were also discussed. Er3+:GdTaO4 may be regarded as a potential solid-state laser host material compared with other Er3+-doped crystals.

8206-76, Session 14

Optical and lasing properties of disordered Nd: $SrLaGa_3O_7$ crystal

Y. Zhang, H. Zhang, H. Yu, S. Sun, J. Wang, Shandong Univ. (China)

A disordered Nd:SrLaGa3O7 (Nd:SLGM) laser crystal was grown by the Czochralski method. It was found that the thermal conductivity increases with increasing temperature, indicating glasslike behavior. Thermal conductivity values along the a- and c-axes were found to be 1.95 and 1.70 W m–1 K–1, respectively near 30°C, neither of which are as high as the previously reported value of 11 W m-1 K-1. The polarization absorption and emission spectra were measured. 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. The Nd-doped crystal was investigated for their lasing properties in the free-running generation. 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: SrLaGa3O7 as the gain medium and a laser-diode (LD) as the pump source. The LD pumped passively Q-switched experiments will be performed in the future.

8206-77, Session 14

Preparation, crystal structure, spectra and energy levels of the trivalent ytterbium ion-doped into rare earth stannates

K. Ning, Anhui Institute of Optics and Fine Mechanics (China) and Graduate Univ. of Chinese Academy of Sciences (China);

Q. Zhang, Anhui Institute of Optics and Fine Mechanics (China)

Yb3+-doped Rare Earth Stannates Ln2Sn2O7(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 Yb3+ in Ln2Sn2O7(Ln=Y, Gd) were assigned and the crystal field parameters were fitted to energy splitting of Yb3+-doped Ln2Sn2O7 (Ln=Y, Gd).

8206-36, Session 7

Long pulsed laser-induced damage in optical materials

Z. Shen, X. Wang, B. Wang, X. Ni, J. Lu, Nanjing Univ. of Science & Technology (China)

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/cm2 and 4.8 J/cm2 for 1 ms and 10 ns pulsed laser irradiation, which are in good agreement with those expected from the thermal damage model. Furthermore, the surface damage morphologies of single crystal silicon induced by 2 ms pulse width laser were inspected by optical microscope (OM). The damage morphology formed by 2ms laser irradiation is evident in deep crater. Three types of craters are formed at different laser energy densities. The wavelike circular ripples, with the spacing of 15±5 μm, surround the rim of the crater as a consequence of the movement of molten silicon and the surface tension. Three types of cracks were generated: cleavage crack, radial crack and circumferential crack. Moreover, the experiment result shows that the radial crack initiates from the laser spot and the circumferential crack is located outside the laser spot. It is confirmed that the radial crack is influenced mainly by the hoop stress and the circumferential crack grow along the circumferential direction under the action of radial stress. Both the crack initiation position and the extension direction are consistent with our finite element method (FEM) calculation based on the thermo-elastic-plastic theory.

The damage morphologies in optical films induced by long pulsed laser were observed to start in isolated spots, and the damage threshold decreases to a minimum value when the laser spot size increases, which enlighten the inducement of the defects and impurities originated in the films. In addition, a cone-shaped cavity was observed in the substrate. The damage morphologies of anti-reflection (AR) and high-reflection (HR) coatings are different. For the AR film, both the film surface and substrate surface are damaged while the middle of is undamaged. As the laser energy density increases, the damage extended inward from the two surfaces. For the HR film, the damage initiates from the film layers and is located at isolated spots. As the laser energy density increases, the isolated spots gradually connect to a whole and the damage extends to the substrate but not the rear surface.

8206-37, Session 7

Mechanical polishing to improve uniformity of beam sampling grating and its effects on laser-induced damage

H. Rao, Z. Liu, Y. Liu, S. Fu, Univ. of Science and Technology of China (China)

As an important optical element, beam sampling grating (BSG) is used in the terminal of inertial confinement fusion (ICF) drivers. It can provide a very slight sampling beam for the precision diagnosing of laser energy and wavefront distortion. However, in practice, its non-uniform diffraction efficiency seriously influences the accurate signal of sampling beam, and finally affects diagnostic ability.

BSG is usually fabricated by holographic ion beam etched (IBE) process. In this paper, a mechanical polishing processing technology was used to improve uniformity of the diffraction efficiency of BSG after IBE. The effect of this technology on the laser-induced damage threshold (LIDT) of BSG will also be studied. In the processing, cerium oxide (CeO2) was used to polish the local areas of grating where exhibit higher diffraction efficiency with the purpose of changing the depth of grating grooves and duty cycle, and then they have similar efficiency with the surrounding areas. By iteration of the above process, we finally achieve the improved uniformity of diffraction efficiency of the whole area of a 430 × 430 mm2 BSG. The uniformity of the diffraction efficiency was characterized by RMS; the smaller the RMS, the better uniformity. The RMS of diffraction efficiency of BSG after mechanical polishing shows great reduction down to 5.3% as compared with that of the as-polished RMS of 11.3%. The effects of this processing on laser damage threshold will be characterized by the measuring the LIDT for the laser radiations of 355nm.

8206-38, Session 7

Multiple-defect coupling effect of nanosecond-pulsed laser-induced damage in optical materials

Z. Yu, H. Qi, Y. Zhao, H. He, Shanghai Institute of Optics and Fine Mechanics (China)

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.

8206-39, Session 7

Analysis of subsurface damage during fabrication process and its removal

K. Xiao, L. Bao, W. Wang, J. Zhu, Shanghai Institute of Optics and Fine Mechanics (China)

Subsurface damage (SSD) in optical components is known to play an important role in restricting the high flux operation in high power laser systems. 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 order to obtain expectant optical components, we need to obtain the distribution and character of fractures in the subsurface region introduced during fabrication process, and therefore investigate the positions and depths of the SSDs in the processed optical components accurately and remove them ultimately. In this study, we made several groups of samples of fused silica with different surface roughness, and manage to detect the positions and depths of the SSDs via Total Internal Reflectance Microscopy (TIRM). The lateral distribution of the SSDs is obtained. The surface etched in fluoride solution exposing subsurface damage is observed in Scanning Electron Microscope (SEM). The TIRM detection results agree with the SEM observation well. The character of fractures in the subsurface region is discussed, and the results indicate that the character varies along with different

materials. 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.

8206-40, Session 7

The influence of laser plasma effects on the characteristics of silicon surface damage

J. Han, W. Fan, Sichuan Univ. (China); L. Yang, Chengdu Fine Optical Engineering Research Ctr. (China); G. Feng, X. Gao, Y. Liu, L. Bao, Y. Huang, Sichuan Univ. (China)

Silicon is the basic material for electro photonic detectors, so the studies of the laser induced damage of silicon are of great significance in laser detecting and military applications. 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. The ionized SiOx or SiNx vapor exited in laser plasma. The color of silicon surface was changed by covering a mixed layer of SiOx and SiNx thin film.

8206-41, Session 7

Laser cleaning effect observed by laser calorimeter

H. Liu, Chengdu Fine Optical Engineering Research Ctr. (China)

Absorption was found to decrease if the sample was irradiated by laser. Laser Calorimeter was utilized to detect the weak absorption and the tiny variance of absorption. HfO2 film was chosen to be considered, since the absorption of HfO2 film decreased obviously during our experiments. HfO2 film was deposited on fused silica substrate (JGS1), by electron-beam evaporation. Samples were observed under microscope, and no defect was found at the center, where laser conditioning would occur.

With the laser power of 12 W, a sample was measured absorption at 1064 nm laser for 20 times. The same experiment was carried out to the 532 nm laser and 355 nm laser, while the power of 532 nm laser was 9 W and the power of 355 nm laser was 0.8W. All of the laser power is far below the damage threshold. Results showed that absorption decreases regularly at all wavelength lasers.

The data were carefully treated and fitted. It indicates that the absorption decreases according to exponential function, while the decreasing rate was fastest at 355 nm laser and lowest at 1064 nm laser.

After 24 hours, the samples were measured again, and no increased absorption was detected. And then, the sample irradiated by 1064 nm laser already was measured again at 355 nm laser, while the 355 nm irradiated sample was measured at 1064 nm laser.

3 cleaning methods were also introduced, that is, wiping with alcohol, cleaning with ultrasonic, and cleaning with dry ice.

The results revealed that laser conditioning was far beyond a cleaning process. A theoretical model was presumed.

8206-42, Session 7

Laser-induced damage on 355 nm silica optics due to Fresnel diffraction on surface contamination particles

X. Miao, China Academy of Engineering Physics (China)

The surface contaminations are well known to lower the laser induced damage threshold (LIDT) and shorten the lifetime of optics. Damage phenomena caused by contamination particles emphasize the need to consider optical system interaction in which imperfections on one optic can cause significant damage to both upstream and downstream optical components. Light intensity modulations caused by opaque obstacles on silica lenses in high power lasers often enhance the potential for laser induced damage. To study this effect, particles with different sizes were sputter deposited on the input surface and irradiated with a 6.8 ns laser beam at 355nm. The damage morphology and sizes are characterized by Nomarski optical microscopy. The results show that a clean silica surface damages at fluences above 12 J/cm2. but a surface contaminated with particles can damage below 7 J/cm2, the LIDT descend exponential with the sizes of the contamination particles. The relation between the depth of the compressed silica and the fluences is linear to the same size contamination, about a good approximation. The experiments are modeled by calculating the light intensity distribution behind an obscuration by using of fresnel diffraction theory. The comparison between calculated light intensity distribution and the output surface damage pattern show good agreement. The predictions provide the basis for optical cleanliness specifications on the ICF to reduce the likelihood of optical damage.

8206-43, Session 7

Study of dust-pollution-induced laser damage on fused silica surface

X. Zhou, J. Huang, China Academy of Engineering Physics (China)

Dust caused by laser-induced damage in optical component in vacuum environment at the ICF facility was collected with fused silica flat optics. The transmission change of the dust polluted optics was observed and analyzed. The damage probability of the dust polluted optics was tested by s-on-1 method using pulsed Nd-YAG solid laser. Results showed that dust polluted sol-gel anti-reflection film coated fused silica optics exhibited lower transmission and higher damage probability than the naked fused silica flat optics. Besides, the dust particle on the input surface will cause severer damage than on the output surface. Electromagnetic field modulating induced by dust particles on surface of fused silica optics was simulated using the FDTD theory. Simulation results suggested that dust particles on the input surface introduced higher light field enhancement than on the output surface.

8206-44, Session 7

Study on mechanisms of HF solution improving damage properties of fused silica subsurface cracks

F. Wang, China Academy of Engineering Physics (China)

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.

8206-45, Session 7

Research of removing polishing powders from BK_7 substrates by ultrasonic cleaning method

T. Ding, X. Chen, Z. Shen, B. Ma, J. Zhang, H. Jiao, Z. Wang, Tongji Univ. (China)

The cleaning process of optical substrates plays an important role during the manufacture of high-power laser coatings, and the polishing powders are the major contaminations on the substrates which would much reduce the laser induced damage threshold of the optics. Therefore how to effectively remove the polishing powders is a significant subject.

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. Our research are helpful to find the best cleaning methods which have much cleaning efficiency and lower induced damage to the surface of BK7 substrates.

8206-46, Session 7

Reduction of the 355-nm laser-induced damage initiators by removing the subsurface defects in fused silica

M. Yang, H. Qi, Y. Zhao, S. Liu, K. Yi, Shanghai Institute of Optics and Fine Mechanics (China)

The surface laser-induced damage threshold (LIDT) was improved more than 2.2-fold by removing the subsurface defects(SSD)in fused silica. Two HF etching techniques and magneticrheological finishing were used to reduce the SSD. The residual subsurface cracks were revealed by HF etching and characterized by optical microscope. The effect of the SSD removal on laser damage resistance was characterized by measuring the LIDT at 355nm. The results show that the crack number density of the final treated sample decreased from 1000 to <10 cm-2, and the surface-LIDT enhanced from 13.2 to 30 J/cm2 compared with the un-treated sample.Through the connection between the enhancement of surface damage resistance and subsurface defects removal in fused silica, two kinds of initiators are distinguished: absorbing impurities and subsurface cracks.

8206-78, Session 15

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

R. Moncorge, ENSICAEN (France)

No abstract available

8206-79, Session 15

Preparation and laser characterization of Cr^{2+}: ZnSe mid-infrared laser crystals

Y. Dong, H. Zhang, W. Chen, Y. Xu, Y. Li, Y. Leng, Shanghai Institute of Optics and Fine Mechanics (China)

Cr2+: 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 Cr2+: ZnSe single crystals were characterized. Using a widely tunable Tm:YAP laser as pumping sources, its laser performance was demonstrated.

8206-80, Session 15

Study on the properties of the DKDP crystal with different deuterium content

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KH2PO4 (KDP) and its deuterated analogue KDxH2-xPO4 (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.

8206-81, Session 15

Effecting of Na and K codoped on Yb: PbF_2 laser crystal

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Lead fluoride crystals doped with YbF3, NaF- and KF-codoped were grown using the vertical Bridgman method. The transparent, high quality crystals have been obtained using a special procedure.

Influence of the codoping with Na+ and K+ ions on the distribution coefficients, X-ray photoelectron spectrometry, absorption spectra, photoluminescence spectra and fluorescence lifetimes of the Yb ions has been studied.

8206-82, Session 15

Energy levels fitting and crystal-field calculations of Nd^{3+} doped in GYSGG crystal

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The single crystal Nd0.03Gd0.93Y2.04Sc2Ga3O12 (Nd3+: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 Nd3+ in 7.6K and 114 levels of Nd3+ in 300K were assigned. Finally, the fitting results of free-ions and crystal-field parameters are compared with those already reported for Nd3+:GSGG and Nd3+:YSAG. The results indicated that the free-ions parameters are similar to that of the Nd3+ in GYSGG, GSGG and YSAG crystal, and the crystal-field interaction of GSGG and YSAG is stronger than GYSGG.

8206-83, Session 15

Generation and mechanism discussion of multiwavelength garnet crystal lasers

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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.

8206-84, Session 15

Study on the fourth harmonic frequency generation of DKDP crystal

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DKDP crystal was conventionally grown from 93~94%-deuterated solution of high pure materials and two crystal(one is an angle-tuned type- phase-matched, the other is a temperature-tuned 90° phase-matched) was required to get high-efficiency high power uv generation at 266nm.

The crystals were installed inside copper heater,which temperature was regulated in the range 40°C~80°C and kept constant with accuracy~0.1°C. The experiment shows the subnanosecond pulses could obviously improve the efficiency of quadrupling.The efficiency is improved to 1.8 times that before used with an average uv power of several wattes. The results shows that there are some changes about the efficiency of quadrupling in material after changes about efficiency after on, further research is being planed.

8206-85, Session 15

Laser damage threshold and nonlinear optical properties of large aperature elements of YCOB crystal

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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.

8206-86, Session 15

Study of the laser-induced damage in DKDP crystals

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In this paper, by using the traditional temperature-reduction method, KD2PO4 (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.

8206-87, Session 15

Spectroscopic properties of Yb-doped $Ca_{1-x}Sr_xF_2$ laser crystals by gamma-rays irradiation

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In this paper, the spectroscopic properties of Yb:Ca0.5Sr0.5F2, Yb, Na:Ca0.5Sr0.5F2 disordered crystals and Yb:CaF2, Yb, Na:CaF2 single crystals were studied after γ-rays irradiation. These crystals were grown by the Bridgman technique. Colour centres and Yb2+ 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 Yb3+ as charge compensators can suppress the deoxidization of Yb3+ to Yb2+. The spectroscopic properties of these crystals were also studied after heating samples.