Summary of Meeting: Excerpts
Brief review on the presented scientific achievements

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Thin Films: This topic was introduced by an invited talk on the role of defects in multilayer mirrors and their production for the NIF presented by Christopher J. Stolz. After a brief outline of the historical development of high power mirrors including the results of material studies, laser conditioning and defect removal, the author concentrated on new methods involving the consecutive deposition of overcoats and ion etching steps for a planarization of optical surfaces. This method is based on the angular dependent etching rate of oxide materials employed for the overcoat and results in a significant reduction of the nodule height in laser mirrors. Defects artificially introduced into a coating structure could be effectively smoothened resulting in an increase of the Laser Induced Damage Threshold (LIDT) to more than 100 J/cm^2 for single pulses of 10 ns duration at the wavelength 1.064 µm.

Defects in coatings were also in the focus of the subsequent contributed presentations clearly demonstrating the increasing importance of this subject in research. For example, Semyon Papernow from the University of Rochester, USA, discussed the effect of nanoscale defects (<100 nm) in HfO_2-coatings on fused silica. These defects were investigated with photothermal heterodyne imaging employing a pump laser operating at a wavelength of 355 nm. A very interesting outcome of the paper was the reduction of absorption by irradiation of the samples with power density of up to 1 MW/cm^2 from a cw-laser at the wavelength 355 nm. This permanent change of up to 70% in absorption was attributed to the depopulation of oxygen vacancy states in the hafnia. In this context the concept and advancements of photothermal microscopy were addressed also by the group of Wolfgang Rudolph (University of New Mexico, USA).

As a further interesting topic, Xinbin Cheng from the Tongji University in China considered the effects of mechanical interface strength in Ta_2O_5/SiO_2-multilayers on the laser damage behavior in the ns-pulse duration regime. He could identify a lower strength level for the interface SiO_2/Ta_2O_5 compared to the interface Ta_2O_5/SiO_2 and interpreted this in the context of his LIDT-tests.

Further interesting work on thin film mixtures and the wavelength dependence of LIDT was presented by research groups from Lithuania (Simonas Kitas, Instiute of Physics, Vilnius University) and France (Mireille Commandre, Institut Fresnel). These contributions summarized and complemented the knowledge recently gained on the damage behavior of oxide mixtures in the fs- and ns-pulse duration regime. In contrast to the past conferences interest in coatings for the ultra-short pulse regime faded slightly whereas coating defects continue to be an area of intensive research activities with focus on mitigation strategies and process optimization as well as on detection techniques and post treatment effects.

Materials and Measurements: The category “Materials and Measurements“ was spearheaded by an invited talk on the on status and future capabilities of the National Ignition Facility presented by Paul J. Wagner (Lawrence Livermore National Lab, USA). He summarized the major achievements of the NIF attained since the first operation of this Megajoule class solid state laser starting with around 1 MJ to the present level of 1.8 MJ. Special attention was paid to the inspection and optimization of the coated optics and to the frequency conversion crystals in the system.

The lifetime of space-borne optics is still a problem of major concern within the community. This was underlined by a talk presented by Wolfgang Riede (Deutsche Zentrum für Luft- und Raumfahrt e.V., Germany) and Denny Wernham (European Space Research and Technology Ctr., Netherlands), who outlined the specific challenges related to the ESA space missions. A clear recommendation was revealed to perform raster scanning in addition to laser damage tests for the qualification of laser optics.

A second talk in this series by Oleg A. Konoplev (Sigma Space Corp., USA) was devoted to assessments of optics for a confidence shot lifetime of 1 trillion at orders of magnitude lower fluence levels compared to the intended lifetime of 3 billion shots of the European AELOS mission projected for the fundamental and first two harmonics of the Nd:YAG-laser. The author presented results of test procedures with 1 million shots and their interpretation before the background of accelerated marathon tests up to 1 trillion shots performed with a high repetition rate laser operated at 600 kHz pulse rate. The measurement and evaluation of threshold values were also subject of vivid discussions within the conference.

Even though the ISO measurement standard for LIDT values, ISO 21254, is virtually accepted by the community still some specific difficulties in the described evaluation are to be considered. For example, the results of a round-robin test dedicated to optics for vacuum applications and an improved data reduction scheme were presented by Lars O. Jensen (Laser Zentrum Hannover e.V. Germany).

In this context the investigations in advanced evaluation techniques for laser damage measurement data by Jonathan W. Arenberg (Northrop Grumman Aerospace Systems, USA) have to be mentioned, which propose approaches on the basis of a maximum likelihood estimation. Furthermore, the group of Wolfgang Rudolph (presented by Luke Emmert) revisited techniques for a time resolved transmission measurement of optical components during the course of laser damage. One of the major experimental findings of this study was the observation that the drop in transmission according to the actual event of damage always appeared prior to the temporal maximum of the pulse.

The session on materials and measurements featured also studies on defects in coatings exemplified by a comprehensive study performed at Research Electro Optics Inc., USA. This work illustrated by a coworker of the company, Sam Richman, was concentrated on detailed defect statistics and their relation to the damage fluence level. The authors indicated, that the major source of defects may be related to the employed ion beam sputtering process and not to the routinely achievable high cleanliness state of the substrate.

Surface contamination was considered within a talk of Douglas S. Hobbs (TelAztec LLC, USA), who showed interesting results of antireflective surfaces produced by etching techniques in comparison to sol gel coatings. LIDT values (355 nm, 10 ns, 250 µm) of up to 27.7 J/cm^2 were achieved for the etched surfaces compared to the range of 31,6 to 35,6 J/cm^2 for sol gel coatings. This study was complemented by a contribution on structured optics by an extended research consortium of several universities from the USA.

As a totally different area interest, Paul J. Phillips (Rutherford Appleton Lab, United Kingdom) reported damage thresholds of ceramic Nd:YAG at cryogenic and room temperatures. The authors tested a set of samples with antireflective coatings deposited by different processes for the wavelengths 940 nm and 1030 nm, respectively. In most cases a significant increase of the measured 1 on 1 LIDT values (1030 nm, 3 ns, top hat profile 250 µm) was observed for cryogenic temperatures. For example, the front surface of one sample revealed an augmentation in threshold value from 31.4 J/cm^2 at 300 K room temperature to 61.1 J/cm^2 at a temperature at 105 K.

Not least, a variety of measurement techniques were considered in further contributions, for example based on photothermal methods like photoacoustic spectroscopy, laser calorimetry, common path interferometry or Hartmann- Shack sensors.

In summary, investigations in an improvement of the ISO standard for LIDT testing, ISO 21254, could be detected as one essential trend of the present conference. The extrapolation and assessment of the lifetime of optical components is persisting to be an unsolved problem and still attracts various research efforts. Furthermore, the economic production and power handling capabilities of structured optics continue to play an important role in the research activities. Finally, the detection and classification of defects was also discussed within the materials and measurement area clearly indicating the significance of this problem.

Surfaces, Mirrors, and Contamination: Sessions on this subject contained several papers on the effect of laser ablated debris and laser induced contamination on the power handling capability of optical surfaces. The session series was opened by an invited talk of James E. Andrew (AWE, United Kingdom), who gave a review on effects of focused high energy lasers beams on a variety of plasma targets.

Helmut Schröder (Deutsche Zentrum für Luft- und Raumfahrt e.V., Germany) presented a talk on contaminations naphtalene and anthracene deposited on coated surfaces during laser irradiation in specially prepared environments to assess the growth effects and laser interaction mechanisms of the contamination layers. The experiments were aimed at a laser damage risk mitigation for optical components employed in ALADIN mission and involved damage tests at 355 nm at a pulse duration of 10 ns. A drastic reduction of the LIDT values to less than 1 J/cm^2 could be observed for contaminated surfaces after a few minutes in an environment containing a partial pressure around 0.3 µbar of the aromatic hydrocarbons.

Further studies in this area were illustrated by a group from the Osaka University (Hidetoshi Murakami, Osaka University, Japan) and other Japanese research centers. This group concentrated on oil contaminations found in the LFEX Laser system at the Osaka University and reported on a decrease of LIDT values by a factor ½ during 120 hours of operation under a specially prepared atmosphere of N_2 with toluene.

Another remarkable topic of the sessions was the removal of scratches and defects from optical surfaces. Among contributions discussing laser based method, outstanding achievements at the NIF were presented by James A. Folta (Lawrence Livermore National Lab, USA). He introduced the specially established high volume facility for recycling of large NIF optics with laser damage sites. The defect mitigation is achieved on the basis of a CO_2-laser irradiation scheme with dynamic beam diameter and adapted spot sizes controlled by an online imaging system. The facility enables a repair rate of up to 98% and processed already more than 2500 pieces of large scale optics for the NIF.

The effects and removal of pre-existing defects and subsurface damage of fused silica were also discussed in several contributions including laser based and magneto-rheological fluid finishing techniques for repair. Within the framework of the development of an ignition facility in China, the influence of scratches with different width on fused silica and plastic surfaces on laser damage thresholds was addressed by a contribution from the Tongji University. The scratches were indented by a diamond tip with different loads in mirror coatings of HfO_2/SiO_2 and laser damage tested under different angles of incidence.

Besides a variety of specific application oriented research activities, clear tendencies towards a deeper understanding of laser induced contamination effects are of continuous importance within the community. Also, the repair of optical surfaces, scratch removal and advanced cleaning techniques are in the focus of present research activities.

Fundamental Mechanisms: The topic was introduced by a comprehensive survey on the present knowledge on laser damage in dielectric films prepared by Wolfgang Rudolph. He summarized some major aspects of the role of material properties and defects in damage mechanisms induced by ultra-short up to long laser pulses. Theoretical models on the basis of electron photon interaction schemes could be principally confirmed by many experiments in the fs-pulse regime and indicate a predominance of material properties in laser damage mechanisms. However, for longer pulses, the role of intrinsic mechanisms fades, and thermal effects gain of importance for longer pulse durations in the nanosecond region. In this context, especially defects in the coatings have to be considered as a major origin of damage at fluence values far below the expected intrinsic threshold values of dielectric materials. As a consequence, detailed investigations in the different types of defects appearing in dielectric coatings are an essential prerequisite for further progresses in the power handling capability of coatings for longer pulse durations. The authors presented advanced approaches for analyzing defects in coatings including for example photothermal microscopy techniques, time resolved damage studies, and third harmonic microscopy.

Besides several articles dedicated to bulk damage in KTP, borosilicate glass, and fused silica presented by authors from the Lawrence Livermore National Lab, USA, and a consortium of French research groups, a comprehensive study on the dynamics of ultra-short pulse damage was published by groups from Lithuania (Vilnius University) and France (Institut Fresnel).

The work presented by Nerijus Siaulys (Vilnius University) was concentrated on digital holographic pump probe experiments to resolve the different interaction phases of ultra-short pulse laser radiation with Ta_2O_5 single layers. By tuning the time delay between pump and probe beam, the electron gas generation and plasma dynamics could be recorded, and typical time constants were identified. For example, the highest electron density in the conduction band could be assigned to a time interval of 200 fs, and temperature rises due to lattice heating were observed approximately 1.4 ps after the maximum of the pump pulse (1,030 nm, 300 fs) had passed the sample. The experimental data were found in accordance with theoretical models describing the damage dynamics. This contribution indicates a trend towards studies in detailed models for damage dynamics in thin films and bulk optical material which was also by other publications within the conference.

As a further apparent research topic of high interest in the field of fundamental mechanisms again defects in dielectric materials could be identified reflecting one of the general aspects addressed by many talks and posters.