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Laser Damage III

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Laser damage (LD) of optical materials is attributed to the effects of strong laser-material interactions that violate the normal characteristics of the materials by irreversible modification of their optical properties, e.g., reduction of transmittance or increase of absorbance. Since the advent of lasers, LD continues to limit the output energy and power of pulsed and continuous-wave laser systems. In spite of tremendous research effort and very substantial progress in this area, interest of the international laser community in laser damage issues remains at a very high level. The major motivation of that interest is the development of novel laser systems and continuous expansion of the domain of laser-radiation parameters. Generation of sub-picosecond and sub-femtosecond pulses, reduction of laser wavelength towards deep-ultraviolet and x-ray ranges of the spectrum, and an increase of peak power and output energy of laser systems above TW level create new challenges and put forward novel requirements to optical materials employed in those lasers.

The continuous interest is evident from the high level of attendance and presentations at the annual SPIE Laser Damage Symposium (aka, Boulder Damage Symposium) that has been held in Boulder, Colorado, since 1969. Intensive developments of high-power lasers and applications in Southeast Asia have motivated establishing a partner Pacific Rim Laser Damage conference, first held in 2009 by Shanghai Institute of Optics and Mechanics (China) in cooperation with SPIE. Since the first and the second special sections on laser damage in *Optical Engineering* (December 2012 and December 2014, correspondingly), many significant results have been presented at those two meetings. This special section of *Optical Engineering* is the third one prepared in response to the continuously growing demand from the international laser-damage community. A decision to prepare this special section was partly motivated by the pivotal success of the first and second special sections on laser damage.

The content of this special section slightly deviates from the traditional areas of LD research (i.e., fundamental mechanisms, thin optical films and coatings, mirrors, contamination, defects, surface damage, novel optical materials, and measurement procedures) by introducing two more important topics – laser ablation and applications of laser damage. This modification is motivated by requests from the laser-ablation community whose research interests significantly overlap with those of the laser-damage community. In fact, laser ablation can be considered as a specific type of laser damage with special "positive" applications in multiple fields of material research and manufacturing. The strong relationship between the two areas of laser research is emphasized by the fact that both laser damage and laser ablation consider similar fundamental mechanisms and effects of irreversible material modification by laser radiation. As a natural extension of this scientific connection of the two fields, a cross-promotion agreement was recently established between the SPIE Laser Damage Symposium and the independently operated international conference on High Power Laser Ablation (HPLA). That cross-promotion considers mutual support in submission of manuscripts for publication in relevant special sections of journals. In fact, the cross-promotion almost doubled the number of submissions to this special section. Correspondingly, some papers of this special section were presented at Laser Damage Symposium and Pacific Rim Laser Damage conferences in 2015 and 2016, and others were presented at the HPLA meeting in April 2016. Very few submissions were received in response to the general call for papers by researchers who did not attend any of those three conferences.

In view of the cross promotion between the two communities, the 28 papers selected out of 35 submissions and compiled into this special section represent the entire broad area of high-power laser-material interactions that considers major topics related to laser damage and laser ablation. The fundamental mechanisms of material modification are considered by M. Sun (modeling of ablation-threshold dependence on pulse duration), A. Rämer (simulation of the transient optical parameters of dielectric solids), W. Bauer (visible emission by laser-produced plasma from graphite), J. Han (thermodynamic damage mechanism on Ni/Cr film), and S. Bardy (simulations of laser ablation of aluminum for shock-wave generation).

Various aspects of multilayer coatings for high-power laser applications and laser damage of optical multilayers are addressed in papers by A. Hervy (femtosecond laser-induced damage on coatings for 1-meter class optics), E. S. Field (repair of mirror coatings by ion milling and over-coating), M. Zhu (improvement of LD threshold of anti-reflection coating by plasma ion cleaning), S. Papernov (role of thin-film interfaces in near-ultraviolet absorption and LD threshold), E. S. Field (influence of reduced vacuum pumping on LD threshold of high-reflection coatings), R. A. Negres (LD of intrinsic and

*Now at the DOE Office of Science, Office of Nuclear Physics extrinsic defects in multilayer coatings), J. C. Bellum (analysis of LD tests on broadband high reflecting coatings), E. S. Field (comparison of LD thresholds of broad-bandwidth high reflectors), Y. Xu (response of defects in optical coatings during nanosecond LD and laser ablation), J. C. Bellum (design and LD threshold of a coating for dichroic beam combiner), M. Ďurák (LD threshold tests of ultrafast multilayer coatings for ELI Beamline laser), S. R. Qiu (shape dependence of laser-particle-induced damage on the protective layers of high reflectors), and H. Ma (enhancement of electric field at artificial nodules in broadband high reflectors).

The subfield of novel optical materials and material characterization is represented by the papers devoted to direct absorption measurements in thin rods and optical fibers (C. Mühlig), detailed characterization of nonlinear-optical and LD properties of glucuronic acid y-lactone (R. K. Saripalli), and testing of piezochromic coatings for detection of laser-induced shock waves and impacts (F. Gehring). LD measurements and procedures are considered in the paper by G. T. Phillips (mass removal of graphite by laser-induced oxidation).

Papers by Z. Jiao (mitigation of beam-sampling grating) and T. Doualle (CO_2 processing of fused silica for LD mitigation) are from the subfield of surface-damage mitigation.

Papers by S. Demos (morphology of the particles ejected during nanosecond-laser damage) and C. Shen (particle ejection following LD of rear surface on NaCl window) are devoted to surface effects of LD.

Finally, papers by S. Scharring (laser-based removal of space debris of irregular shape) and R.-A. Lorbeer (minimization of thrust noise in long-term laser ablation of propellant material) are devoted to applications of laser damage. It is worth noting that the paper by S. Scharring, "Laser-based removal of space debris of irregular shape" was recognized among the top downloaded papers of the journal even before this special section was complete. In summary, the researchers of the HPLA community have contributed 8 high-quality papers to this special section on laser damage. We are looking forward to growth of their remarkable contribution to another special section of *Optical Engineering*.

The continuing and newly emerging research developments in the field of laser damage, laser ablation, and optical materials for high-power lasers represented by these papers will be very beneficial for readers of *Optical Engineering* and researchers from multiple related areas.

Vitaly E. Gruzdev received an MS in optical systems and devices from the Institute of Fine Mechanics and Optics in St. Petersburg, Russia, in 1994, and a PhD from S. I. Vavilov State Optical Institute in St. Petersburg, Russia, in 2000 in the field of optics. Since 1994 he has been doing research in the field of fundamental mechanisms and effects of laser damage in transparent solids. He progressed from laboratory fellow to senior scientist at the Laboratory of Surface Photo-physics headed by Dr. M. Libenson at S.I.Vavilov State Optical Institute. From 2003 to 2005 he was with the photo-physics laboratory of Academician of Russian Academy of Sciences Dr. A. M. Bonch-Bruevich at the same institution. He was a visiting researcher at the group of Prof. Dr. D. von der Linde from January 2001 to December 2003. In 2005 he joined the Center for Ultrafast Ultraintense Lasers of the College of Engineering, University of Missouri. Currently, he is a research assistant professor with the Department of Mechanical and Aerospace Engineering of the University of Missouri. Since 2009, he is a co-chair of the SPIE Laser Damage Symposium. His current field of research interests includes laser-induced ionization and ultrafast laser-solid interactions.

Michelle Shinn received her physics degrees at Oklahoma State University. After receiving her PhD, she joined Lawrence Livermore National Lab in 1984, working in the Laser (Y) Division until 1990, when she left to join the faculty at Bryn Mawr College as an associate professor of physics. In 1995, she started at Jefferson Lab as a staff scientist. From 1996–1999, she led the design, procurement, and installation activities for the IR Demo free-electron laser (FEL) optical cavity, transport and diagnostics, and from 1999 to 2006 performed the same duties on the Upgrade FEL, which is still the world's highest power tunable ultrafast laser. For her work at Jefferson Lab and earlier work on the use of lasers in society, in 2012 she was elected a Fellow of the American Physical Society. In August of 2013 she started a one-year assignment at the DOE Office of Nuclear Physics Facilities and Project Management Division, and joined the Office in January 2016. She is the Program Manager for Industrial Concepts, responsible for the NP Small Business Innovative Research program and is working to strengthen ties with industry in order to foster the development of commercial applications from nuclear physics research.