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Laser Damage IV

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The Special Section on Laser Damage IV is the fourth in a series of special sections of *Optical Engineering* focused on laser-induced damage (LID). Previous special sections were published in December 2012, December 2014, and January 2017. The field of LID of optical materials considers processes and effects associated with the high-power, high-energy, and high-intensity laser-material interactions that irreversibly modify the optical properties of the materials, e.g., by increase of scattering or reduction of transmittance. LID has been an issue from the earliest days of the laser and continues to be a major physical effect that limits the output power and energy of pulsed and continuous-wave laser systems. Some 50 years of research in LID of optical materials has resulted in tremendous progress in terms of understanding the underlying mechanisms of damage and orders-of-magnitude improvements of damage resistance of laser optics and laser systems. However, the problem of LID has not been solved. As LID is a fundamental limitation to the advancement of the field, the global laser community remains keenly interested in all topics related to laser damage. The major motivation of the ongoing interest in LID is the development of novel laser systems that probe new ranges of laser parameters, which place even greater demands on their materials, optics, and coatings. Current trends in the field are creating new challenges, such as generation of sub-femtosecond pulses, reduction of laser wavelength towards deep-ultraviolet and x-ray ranges of the spectrum, extension of laser wavelength towards mid-infrared range, and continuous increase of peak power of laser systems above tera-watt level. Also, development and operation of large-scale laser facilities operating in the peta-watt regime, such as the National Ignition Facility and Omega Laser Facilities (USA), ELI Beamlines Facility (European Union), Mega Joule Laser facility (France), SG-III facility (China), and ILE/Osaka University Large-Scale Laser facility (Japan), continuously supports and drives the need for advancement in LID research worldwide.

This fourth special section on Laser Damage is also part of the celebration of the 50th anniversary of the annual SPIE Laser Damage (LD) Symposium, which also known as the Boulder Damage Symposium. The 50th LD meeting was held in September 2018 in Boulder, Colorado, USA, successfully continuing the line of conferences first organized by Arthur Guenther and Alex Glass in 1969. The meeting began as a small topical meeting to rapidly resolve some

“small issues” associated with the failure of optical components in high-power lasers due to damage. Those “small issues” have matured into a significant and expanding international field of research and the subject of the annual LD meeting. Intensive development of high-power lasers and applications in Southeast Asia have motivated the establishment of a Pacific Rim Laser Damage (PLD) conference, first held in 2009 by Shanghai Institute of Optics and Mechanics (China) in cooperation with SPIE. Another indicator of the active growth of research in the field of LID is the fact that the recently published book *Laser-Induced Damage in Optical Materials* edited by Detlev Ristau has received such a strong demand from the international laser-damage community that another edition of the book is under consideration.

The decision to prepare this special section was motivated by the pivotal success of the previous three special sections on laser damage and by the celebration of the 50th anniversary of Laser Damage Symposium. Since the previous three special sections on laser damage in *Optical Engineering*, significant results have been presented at both LD and PLD meetings that deserve publication in a peer-reviewed journal. As is appropriate for the golden anniversary of the LD meeting, this special section contains three review papers looking back over the field. Additionally, there are seven regular papers discussing recent important results.

The review by [Chris Stolz and Raluca Negres](#) is a summary and analysis of ten years of thin-film laser-damage competition annually held as a part of Laser Damage Symposium. Each year, the competition considers specific thin-film samples from multiple manufacturers worldwide tested at pre-announced laser parameters at the same test facility under the same test protocol. Influence of deposition parameters, composition, and treatment procedures on the LID threshold are examined and analyzed. A detailed and extended review paper by [Jinlong Zhang et al.](#) is focused on nodular defects in multilayer optical coatings. Nodular defects are quite common in coatings and are recognized among major initiators of LID. Various aspects of nodular defects, their structure, influence on distortions of laser beams, and their contribution to reduction of LID threshold are examined. The mechanisms of nanosecond fatigue laser damage are the subject of a review by [Frank Wagner et al.](#) The specific fatigue effect under consideration is attributed to reduction of LID threshold of optical materials exposed to multi-pulse laser action at constant fluence (so called S-on-1 measurements) compared to the thresholds of single-pulse LID. Traditional models consider

contribution from accumulation of laser-color centers, however, fabrication-related defects may also contribute to the fatigue effects in the optical materials.

The laser damage performance of optical coatings is an enduring area of interest for the community. This special issue has three regular papers concerned with that area of research. The paper of [Meiping Zhu et al.](#) considers the influence of an overcoat layer and deposition temperature on LID threshold of 532 nm high-reflector produced prepared by electron-beam evaporation. Zhu et al. show that increased deposition temperature improves LID thresholds by stimulating crystallization and better oxidation of the deposited materials. [Wenwen Liu et al.](#)'s report is focused on studies of single- and multi-pulse LID of multilayer coatings produced from $\text{Al}_2\text{O}_3/\text{SiO}_2$ layers for operation at 355 nm. Of specific interest are fatigue effects in this relatively novel type of optical coating. [Cheng Li et al.](#) consider the similarity and difference between two regimes of LID of high-reflective coatings: 7-nanosecond pulses at 355 nm and 30-picosecond pulses at 1064 nm. A substantial similarity of damage morphology is discussed in terms of isolated nanometer-size defects and specific field distribution in the coatings. The LID of random anti-reflective nano-size structures on surface of silica optical windows is examined by [Christopher Wilson et al.](#) These random structures continue to attract interest as a possible alternative to anti-reflection coatings since the coatings constantly demonstrate relatively high damage thresholds.

The other topics of the publications of this special section are contamination, surface LID, and materials characterization. [Christian Muhlig and Simon Bublitz](#) characterized nonlinear optical absorption in nonlinear crystals. Their work showed that defects can contribute to the nonlinear absorption and that contribution can be identified and characterized. Laser-induced contamination of optical components for space-flight missions is the subject of the contribution by [Georges Gebrayel El Reaidy](#). His study reports that the early stages of the contamination in a vacuum chamber

evidences a slight anti-reflection effect. Improvement of threshold of surface LID of KDP crystals by combining single-point diamond turning, magneto-rheological finishing, and ion-beam figuring is reported by Feng Shi. Substantial improvement of surface quality and surface-defect inhibition result in two-fold increase of LID threshold of the KDP surfaces.

The editors hope that the reviews, and continuing and newly emerging research developments in the field of laser-induced damage and optical materials for high-power lasers represented by these papers will be of benefit to the readers of *Optical Engineering* and researchers from multiple related areas. The editors also feel there is value in bringing together these papers in this special section, much like the annual gathering of LID experts annually in Boulder.

Vitaly E. Gruzdev received an MS in optical systems and devices from the Institute of Fine Mechanics and Optics (ITMO University) in St. Petersburg, Russia, in 1994, and a PhD from the Federal Research Center "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 high-intensity laser-solid interactions and laser damage in transparent solids. He was with the Laboratory of Surface Photo-physics of Dr. M. Libenson and then with the Photophysics Laboratory of Dr. A. M. Bonch-Bruевич at S. I. Vavilov State Optical Institute (Russia). He was a visiting researcher at the group of Prof. Dr. D. von der Linde from January 2001 to December 2003. In November 2005 he joined the Center for Ultrafast Ultraintense Lasers at the College of Engineering, University of Missouri. Since September 2018, he has been a research associate professor (LAT) with the Department of Physics and Astronomy of the University of New Mexico. Since 2009, he has been a co-chair of the SPIE Laser Damage Symposium.

Jonathan W. Arenberg received his BS in physics in 1983 and an MS and PhD in engineering, all from the University of California, Los Angeles. He has been an active and contributing member of the LID community since 1986. His major research interests center around measurement methods and standards. He is on the US national and ISO committees drafting standards. He is the international program committee for the SPIE Laser Damage Symposium and an SPIE Fellow.