

Special Section Guest Editorial: Laser Damage VI

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This Special Section on Laser Damage, Laser Damage VI, is the sixth in the series of special sections of *Optical Engineering* focused on the diverse aspects of laser-induced damage (LID) of optical materials, surfaces, and components. Previous special sections on laser damage can be found in [vol. 51 \(12\) \(2012\)](#); [vol. 53 \(12\) \(2014\)](#); [vol. 56 \(1\) \(2017\)](#); [vol. 57 \(12\) \(2018\)](#); and [vol. 60 \(3\) \(2021\)](#) of this journal.

The field of LID in optical materials encompasses a broad range of phenomena, processes, and effects associated with the high-power and/or high-energy laser-material interactions that irreversibly modify the optical properties of the materials. Examples of these permanent changes in materials are increased scattering, reduction of transmittance or modification of surface morphology. LID has been a fundamental limitation to the performance of lasers and laser systems starting from the earliest days of the laser epoch. Initially described as a “small” technical problem, in a few years LID became of global interest to the high-power and high-energy laser communities as a major impediment to the increase of output power or energy of lasers and systems. The major strategic aims of research efforts of this field are to properly characterize threshold of LID and identify approaches that increase the LID threshold. 53 years of research on LID of optical materials have delivered a tremendous progress in terms of understanding the fundamental mechanisms of LID and orders-of-magnitude improvements of LID threshold of high-power laser optics. Despite the significant advances made, the problem of LID has not been generally solved for arbitrary laser and material parameters. Moreover, research progress in adjacent areas motivates continued efforts in this field.

As LID is a fundamental limitation to the advancement of high-power and high-energy lasers, the global laser community is keenly interested in all topics related to laser damage. A major driving motivation of the enduring interest in LID is the continued development of novel laser systems. These new systems and sources probe new ranges of laser parameters, demanding novel materials, optics, and coatings. Current trends creating these new challenges include generation of sub-femtosecond pulses (i. e., attosecond, $1 \text{ as} = 10^{-18} \text{ seconds}$), reduction of laser wavelength towards deep-ultraviolet (sub-130-nm) range of the spectrum, extension of wavelength of high-power laser systems towards mid-infrared range (2 to 10 μm), and increase of peak power of laser systems well above terawatt level. The development and operation of large-scale petawatt laser facilities, 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 drives the need for advancement in LID research worldwide. In addition to the interest in LID studies generated by the new systems, the vibrant global market of laser optics drives demands for greater quality and lower prices also drives demands on the laser-damage community.

This special section continues to be inspired by the community associated with the annual Laser Damage Symposium, also known as the Annual Symposium on Optical Materials for High-Power Lasers or Boulder Damage Symposium. The 53rd meeting of the symposium was held online by SPIE in the format of a digital forum in October 2021. Despite the significant impact made on the global research community by the second year of the COVID-19 pandemic, that virtual conference successfully continued the line of the meetings first organized by Arthur Guenther and Alex Glass in 1969. The early conferences were conceived as small topical meetings to rapidly resolve some “small issues” associated with the failure of optical components in

high-power lasers due to damage. Those “small issues” rapidly matured into a significant and expanding international field of research and the subject of the annual meetings. 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 interest in the field is the fact that many SPIE and OSA conferences on high-power lasers now include sessions devoted to LID and related issues. The recent OSA conference on Advanced Solid State Lasers featured extended sessions dedicated to LID in various laser systems.

The decision to prepare this special section was motivated by the strong interest in LID issues worldwide and by the pivotal success of the previous five special sections on laser damage. Since the 5th special section on laser damage in *Optical Engineering*, significant results were reported at both LD and PLD meetings in 2021 that deserve publication in a peer-reviewed journal. Also, participants of the 53^d Laser Damage Symposium demonstrated a significant demand for rapid publication of their manuscripts. This request has motivated the guest editors to undertake an effort to publish this special section within six months. The proposed rapid publication plan has resulted in a smaller total number of submissions to this 6th special section which has five regular papers on the major aspects of LID. Also, there are multiple indications of that the reduced number of submissions as compared to the four pre-COVID special sections is attributed to the general impact of the COVID-19 pandemic on the research community.

Of the five papers published in this special section, three are devoted to LID by femtosecond and sub-picosecond laser pulses, however, they also address LID of thin films and development of a novel apparatus for LID testing. The other two papers are focused on the surface LID and fundamental statistical analysis of LID protocols.

The paper by [Oskouei et al.](#) considers a novel figure of merit to characterize laser-damage behavior of optical coatings in the femtosecond range of pulse durations. It is suggested by analysis of complete spatio-temporal evolution of a femtosecond laser pulse in coatings and can be included into coating specifications for optics design. The traditional approaches to evaluate electric-field enhancement by optical coatings are based on the monochromatic approximation that can deliver significant errors in predictions of field structure for ultrashort pulses. The proposed approach considers actual local peak enhancement of intensity in the field and modification (usually, increase) of pulse width. The paper of [Stehlik et al.](#) compares LID in the HfO₂, SiO₂, and Nb₂O₅ single films deposited by magnetron sputtering against LID in sesquioxide films (Sc₂O₃, Y₂O₃, Lu₂O₃) made by pulsed laser deposition. The LID tests were done by 500-fs laser pulses at 1030 nm at 10 Hz and demonstrated lower LID threshold for polycrystalline films grown on sapphire compared to single-crystal films grown on YAG. The paper of [Kakfa et al.](#) is devoted to a new LID test apparatus and novel protocols to characterize LID of the optics for high-power femtosecond lasers. In contrast to the traditional approaches focused primarily on determining LID threshold by single and multiple laser pulses, this approach considers comprehensive characterization of the performance limitations of ultrafast optics based on three fundamental attributes: initiation of LID, growth of LID sites, and transient (non-damaging) modification of optical parameters. [Urban et al.](#) report on LID behavior of fused silica surface polished by fluid jet polishing as a function of removal depth. The polished surfaces were tested by 351-nm one-ns pulse for both 1-on-1 and R-on-1 testing protocols. Increase of the removal depth from 0.7 μm to 18 μm demonstrated a gradual increase of LID threshold with maximum reached around 5 μm. The paper by [Arenberg](#) is focused on understanding the basic nature of distribution of the the weakest site in an area as a function the size of the area and distribution of damage resistance. The conditions where this weakest site is and is not invariant with area are defined.

The papers collected in this, the sixth special section on laser damage, continue to show the vibrant research done by researchers around the world. The editors hope that the 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 so that they might be read together and considered jointly.

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 Photophysics of Dr. M. Libenson and then with the Photophysics Laboratory of Dr. A. M. Bonch-Bruevich at S. I. Vavilov State Optical Institute (Russia). He was a visiting researcher with 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 with the Department of Physics and Astronomy of the University of New Mexico in Albuquerque, NM. From 2009 through 2022, he was a co-chair of the SPIE Laser Damage Symposium.

Jonathan W. Arenberg is chief mission architect for science and robotic missions at Northrop Grumman Space Systems. He received his BS in physics 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 electro-optical and laser damage standards. In addition to his work in laser engineering and physics, he has contributed to the Chandra X-ray Observatory, Starshade, James Webb Space Telescope, and the Astrophysics 2020 strategic missions studies. He is widely published and holds 15 US and European patents in a wide range of technologies. He is a member of the international program committee for the SPIE Laser Damage Symposium and an SPIE Fellow.