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## High Power Laser Ablation

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The field of laser ablation considers a broad range of research, from the fundamental mechanisms of material removal and surface modification by high-power laser radiation to various applications of that effect. Long-term practical experience shows that lasers can ablate any materials, even those that exhibit superior hardness. Moreover, properly focused laser radiation delivers the smallest dimensions of machined features that are not attainable for any traditional micromachining by mechanical instruments. This makes laser ablation an imperative tool for precise micromachining. Development of novel lasers, e.g., ultrafast laser systems, and emerging novel materials challenge new generations of researchers in this field and stimulate continuous research both in the fundamentals of laser ablation and in various applications.

Although material micro- and nanomachining are the first applications of laser ablation to come to one's mind, the applications are not limited by the machining. Laser ablation has found significant applications in many other fields, e.g., laser-induced breakdown spectroscopy, medicine, nanotechnology, removal of debris in near space, and propulsion of small objects to space. All those and many other areas of laser-ablation research are covered at High Power Laser Ablation (HPLA) conferences held every other year. This line of conferences organized by Dr. Claude R. Phipps celebrated its 20th anniversary in 2018, with the first meeting held in April 1998. The 20th HPLA conference was held from March 26 through March 30, 2018, in Santa Fe, New Mexico, USA. It brought together some 150 researchers from the US, Europe, Asia, and Australia to deliver oral and poster presentations on the fundamental effects of laser-matter interactions, ultrafast laser ablation, simulations and theory of laser ablation, high-power lasers, space propulsion by ablation, biomedical applications, micromachining, surface modification, and removal of space debris by ablation.

The high and stable level of attendance of the HPLA meetings observed over years, broad geographic representation, and the high level of presentations at the HPLA meetings signal continuous interest in those fields. Stimulated by multiple requests from conference participants, organizers of HPLA have considered publishing selected papers of the conference. Success of the HPLA papers previously published in a combined special section on Laser Damage III

(January 2017) encouraged us to make a separate special section on high-power laser ablation.

The papers published in this first Special Section on High Power Laser Ablation are focused on ablation applications rather than on the fundamental aspects of that phenomenon. They can be split into two groups.

The paper by Iouri Pigulevski considers use of laser ablation for propulsion of small space vehicles. Motivated by saturation of the technology of chemical rocket propulsion, this paper analyzes a new access-to-space paradigm based on laser ablation propulsion systems.

Alexander Rubenchik focuses on another field of orbital applications of laser ablation – delivery of high-power laser pulses to the Earth orbit for debris cleaning. Self-focusing is one of the major challenges for developing the surface-bound laser systems for removal of space debris by ablation. A theoretical model reported in this work demonstrates feasibility of almost total suppression of the self-focusing effects by proper use of phase masks and adaptive optics.

Stefan Scharring extends the previous publication of this team appeared in the special section on Laser Damage III (January 2017). 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 the Special Section on Laser Damage III was complete. Laser ablation is frequently considered as a method of creating a recoil to push small orbital debris toward an orbit where Earth atmosphere is dense enough to burn the debris. This paper reports simulations focused on analysis of laser-ablative momentum to determine if it is reliable and safe from the viewpoint of momentum predictability and heat generation. The problem is highly nontrivial bearing in mind random and nonpredictable orientation of the orbital-debris pieces with respect to incident laser beam.

The paper of Carlos Rinaldi is focused on experimental technique for determination of specific impulse produced by laser ablation. Specific impulse is a figure of merit for propulsion of small orbital vehicles by laser ablation. On the other hand, that parameter is of high importance for predicting of trajectories and speeds of the orbital-debris particles to be removed by laser-ablation methods. Therefore, this paper reports an essential contribution to the entire field of orbital applications of laser ablation.

The paper of Somayeh Panahibakhsh reports experimental research from a completely different area of laser-ablation applications – micro- and nanostructuring of glass surfaces by ablation with ultraviolet nanosecond laser pulses. The

nanostructures produced at laser fluence below ablation threshold were extensively characterized using electron microscopy and micro-Raman analysis. The reported nanostructures demonstrate highly ordered morphology and can potentially find applications in photonics and surface science.

Manikandan Esakkimuthu considers another application of laser ablation for surface micro- and nanostructuring. Reporting surface microfabrication by short and ultrashort (femtosecond) laser pulses, this paper is focused on machining of specific surface structures for frequency selection in the terahertz frequency range.

We appreciate the contributions of all of the authors of this special section and are looking forward to the growth of their remarkable contribution to the first Special Section on High Power Laser Ablation in *Optical Engineering*.

The continuing and newly emerging research developments in the field of laser ablation and various applications of laser ablation 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. N. Libenson at the Federal Research Center "S.I. Vavilov State Optical Institute" in St. Petersburg, Russia. From 2003 to 2005 he was with the photo-physics laboratory of Academician of Russian Academy of Sciences Dr. A. M. Bonch-Bruевич at the same institution. He was a visiting researcher at the group of Prof. Dr. D. von der Linde from January

2001 through December 2003. In 2005 he joined the Center for Ultrafast Ultraintense Lasers, Department of Mechanical and Aerospace Engineering, University of Missouri, as an assistant research professor. Since September 2018, he has been an associate research professor with the Department of Physics and Astronomy, the University of New Mexico in Albuquerque, NM, USA. Since 2009, he has been a co-chair of the SPIE Laser Damage Symposium. His current field of research interests includes laser-induced ionization and ultrafast laser-solid interactions.

**Claude R. Phipps** earned a B.S. in 1961 and an M.S. in 1963 at MIT studying AC superconductors. After serving in the U.S. Navy (1963 – 1965), he earned a PhD at Stanford in 1972, specializing in plasma physics under Prof. Oscar Buneman, famous for the theory of the diocotron instability in microwave devices. His thesis on Thomson scattering in a Penning discharge was the first laser-plasma interaction experiment at Stanford. This work measured the electron and ion velocity distributions in Penning discharges using one of the first narrowband ruby lasers built by Ted Maiman's company Korad. He worked in laser development and research at Lawrence Livermore and Los Alamos labs from 1972 until 1995. He was co-leader of the laser effects program at Los Alamos, where he led experimental programs that provided pulsed laser impulse data on surfaces and developed theory to predict this and other data for a wide variety of laser parameters and materials. In 1998, Phipps founded Photonic Associates, LLC (PALLC) in Santa Fe, to develop laser ablation propulsion applications such as the PALLC laser plasma thruster (LPT). In 1998, he initiated the High Power Laser Ablation symposia in Santa Fe, Osaka, and Taos and remains the chair of these internationally attended meetings. He invented the "ORION" concept for clearing space debris with a ground-based laser, and the "L'ADROIT" design for debris clearing and orbit modification using a UV pulsed laser in space. He recently participated in a laser impulse measurement program at École Polytechnique to add data in the 400fs – 80ps regime. He is author of 140 refereed journal articles and 140 conference presentations and has contributed to or edited three technical books in the field and one popular science book.