# Special Section Guest Editorial: High Power Laser Ablation II

**Claude R. Phipps[a] and Vitaly Gruzdev[b]**
[a]Photonic Associates, LLC, Santa Fe, New Mexico, United States
[b]University of New Mexico, Department of Physics and Astronomy, Albuquerque, New Mexico, United States

The Special Section on High Power Laser Ablation II considers the field of laser ablation as a broad range of research from studies of 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 combined with precise control over laser power or pulse energy delivers the smallest dimensions and the best accuracy of machined features that are not attainable for any traditional micromachining by mechanical instruments. This makes laser ablation an imperative tool for precise and accurate micro- and nano-machining. 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 nano-machining 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., energy industry, 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. With the first meeting held in April 1998, this line of conferences organized by Dr. Claude R. Phipps celebrated its 20th anniversary in 2018. Because of the COVID pandemic, the 21st HPLA conference was held in virtual format from April 13 through April 15, 2021. It brought together some 200 researchers from the US, Europe, Asia, and Australia to deliver presentations on the fundamental effects and mechanisms of laser-matter interactions, ultrafast laser ablation, simulations and theory of laser ablation, high-power lasers, space propulsion by ablation, biomedical applications, laser-driven fusion, micromachining, surface modification, and removal of space debris by ablation. The next meeting will be in person April 17-20, 2023, at the hotel La Fonda in Santa Fe, New Mexico.

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 to those fields. Stimulated by multiple requests from conference participants and success of the previous special section on High Power Laser Ablation, organizers of the HPLA conference have decided to work on another special section of *Optical Engineering* on High Power Laser Ablation. As before, the papers published in this second special section address some ablation applications as well as fundamental aspects and mechanisms of that phenomenon.

Among the papers focused on the ablation applications, we feature a brief review paper by Hora et al. focused on novel approaches to drive laser-assisted confinement fusion and use of that process as a new source of green energy. The traditional methods consider the fusion reaction between the nuclei of the two heavy isotopes of hydrogen – deuterium and tritium. Their major bottleneck is the need to heat the fuel to the temperatures of the order of 50 million Kelvin and keep it for some time under extreme pressure conditions produce by laser ablation of a shell of a fuel cell. The novel approach discussed in this paper considers use of non-thermal radiation pressure to initiate the fusion reaction between hydrogen and boron-11 nuclei. Based on extended simulation results, this method is compared to traditional approaches.

Luo et al. consider another application of laser ablation in their paper focused on development of a laser de-icing method for high-voltage composite insulators. Ice deposits on high-voltage lines creates significant threats for safe and reliable supply of electrical energy. De-icing of high-voltage composite insulators is among the major challenges since those pieces can be easily damaged by traditional de-icing methods. The paper proposed a safe and highly efficient method of de-icing based on laser ablation of ice by a mid-infrared laser operated at 1940 nm. That wavelength falls into the absorption band of water and delivers high absorption efficiency. Also, it provides protection of the ceramic isolators since a thin water film produced during thermal ablation of ice is sufficient to almost totally absorb the laser radiation. Details of the proposed method and supporting experimental data are reported in this paper.

Among the papers focused on the fundamental aspects of laser ablation, the paper by Dunlap et al. considers a model of lateral plasma expansion in hafnium films just prior to ablation by nanosecond laser pulses. The expansion of the laser-generated free-carrier plasma at the speed of up to 100 km/s stayed unexplained for some time. The mechanism of that effect was recently attributed to a defect-initiated laser-driven detonation (LDD) wave propagation in the electron-hole sub-system of hafnia. The first version of the LDD model leads to a conclusion that propagation of the LDD wave is supported by electrons and holes, which effective masses are almost 100 times higher than those predicted by band structure. This paper reports substantial improvement of the LDD model by accounting for a change in the effective masses between pre- and post-detonation states. Reasonable agreement between theory and experiments is reported.

Hirtle et al. consider fundamental aspects of controlling laser ablation and report results of modeling of the influence of external *dc* electric field on the energy dissipation at the initial stage of laser ablation of silicon crystals. The model is based on density-dependent two-temperature model applied to simulate laser-induced generation of free electrons and holes followed by relaxation. Two approaches are reported. The first one assumes suppressions of the buildup of internal *dc* electric fields due to charge separation produced by ambipolar diffusion and additional free-carrier currents. The second one treats the free electrons and holes as two separate sub-systems to account for charge separation and shielding of the external *dc* electric field. Comparison with experimental data shows the first approach predicts the parametric scaling of ablation rate similar to that observed in experiments.

Gruzdev and Sergaeva consider simulations of free-carrier generation by few-cycle laser pulses utilizing a novel theoretical model of laser-induced photoionization of non-metal crystals. Their approach incorporates the effects attributed to non-zero spectral bandwidth of the few-cycle laser pulses and possibility of simultaneous absorption of several photons of different energies. This type of electron excitation is totally excluded from the traditional photoionization models, e.g., the Keldysh model since they consider simultaneous absorption of several similar photons. The novel approach predicts higher ionization rates as compared to the Keldysh model and appreciable influence of carrier-envelope phase and pulse shape on the rate of free-carrier generation and nonlinear absorption. Those feature open new capabilities to control rate and yield of ablation by few-cycle laser pulses.

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

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. He is an associate research professor with the Department of Physics and Astronomy, the University of New Mexico in Albuquerque, New Mexico, 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** Claude Phipps earned a BS in 1961, and an MS 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. 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 is author of 140 refereed journal articles, 140 conference presentations and has contributed to or edited three technical books in the field, and one popular science book.