Introduction: Femtosecond Direct Laser Writing and Structuring of Materials (FDLW) feature

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Abstract: This special issue, "Femtosecond Direct Laser Writing and Structuring of Materials" of *Optical Materials Express*, presents recent advances in the field. The articles presented focus on fabrication processes, related mechanisms, and photo-produced structures, taking into account physical and chemical aspects.

OCIS codes: (140.3390) Laser materials processing; (140.3440) Laser-induced breakdown; (320.7130) Ultrafast processes in condensed matter, including semiconductors; (230.1150) All-optical devices; (160.2750) Glass and other amorphous materials; (320.2250) Femtosecond phenomena.

References and links

1. K. M. Davis, K. Miura, N. Sugimoto, and K. Hirao, "Writing waveguides in glass with a femtosecond laser," Opt. Lett. **21**(21), 1729–1731 (1996).
2. L. Sudrie, M. Franco, B. Prade, and A. Mysyrowicz, "Writing of permanent birefringent microlayers in bulk fused silica with femtosecond laser pulses," Opt. Commun. **171**(4-6), 279–284 (1999).
3. K. Miura, J. Qiu, T. Mitsuyu, and K. Hirao, "Space-selective growth of frequency-conversion crystals in glasses with ultrashort infrared laser pulses," Opt. Lett. **25**(6), 408–410 (2000).

Current advanced femtosecond laser systems offer a myriad of possibilities to modify materials, to implements new optical functionality, or to improve existing materials properties. Femtosecond Direct Laser Writing (FDLW) relies on nonequilibrium synthesis and processing with photon beams, which open up the new ways to create materials and devices that are not currently possible with established techniques. The main advantage remains in the potential to realize 3D multifunctional photonic devices, fabricated in a wide range of transparent materials.

A long-term challenge has been to develop a one-step process to tailor optical components and advanced functionality within the bulk of optical materials. Direct laser writing processes have been observed in the early stage of the lasers and have been investigated and used in parallel. Still, for many years the development for laser writing for 3D structuring of materials has been limited by the use of long laser pulses that provide a very limited useful range between laser structuring and laser damage. The situation has evolved with the appearance of stable femtosecond sources, which offers opportunity for 3D micro- and nano-structuring of materials.

Femtosecond lasers are bringing new insights in term of 3D material architecture. This is primarily thanks to the decoupling of energy deposition during the pulse interaction and the heating of the lattice, which limit the photoinduced structures in the focal volume. During the past decade, laser-material interaction is a field that has been extensively studied. The understanding of the involved physical phenomena and their associated characteristic times are of particular importance for taking advantage of these merging techniques for fabrication of complex optical systems. The repetition rate, irradiance, and dosage, depending on the structure wanted, are parameters that give access to multiple advanced materials processing approach and fabrication. The understanding of the femtosecond laser-material interaction is

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an active area of research to identify the different processes occurring at different time scales and their resulting effects in terms of materials property.

Different material property modifications can be implemented going from linear optical properties (positive or negative index change with isotropic or anisotropic properties) to nonlinear optical properties (second- and third-order optical properties). Physical and chemical modifications can be locally obtained such as mechanical stresses, charge trapping, change of oxydo-reduction state, material stoichiometry, bonds breakage, material reactivity, or phase change (crystallization). No other technique exhibits the same enormous potential in the development of a new generation of powerful components in 3D for micro-optics, telecommunications, optical data storage, imaging, micro-fluidic and biophotonic at the micro- and nano-scale, and many more.

The interest has grown in the past fifteen years since the demonstration of Davis et al. [1] of direct laser writing of optical waveguide in various glasses. Just three years later that a strong birefringence can be imprinted in silica, just by increasing the pulse energy [2] two years after, the same group showed that the slow axis orientation is controlled by the laser polarization. And 11 years after, femtosecond induced controlled non-linear crystal precipitation in glass is demonstrated [3]. One has to mention that before 2005, there have been in OSA and OSA partnered journals or conferences less than ten articles related to femtosecond laser writing published each year. Since 2009, this number is now above 40, giving evidence of this emerging field of research.

This focus issue aims to give to the readers at a moment when different communities are getting involved in the field of femtosecond laser writing the state of the art and an overview of the current research activities. It includes original papers and reviews from leading groups. We hope that the readers will enjoy reading the articles compiled in this special issue, and we therefore encourage our colleagues in this exciting field to submit their work to *Optical Materials Express*.

We also want to express our sincere gratitude to the contributors who accepted our invitation. Finally, this focus issue, Femtosecond Direct Laser Writing and Structuring of Materials, would not have been possible without the efforts of David Hagan (University of Central Florida), Editor-in-Chief of *Optical Materials Express*, and the work of reviewers and the staff coordinating OSA's publications. We want to express our gratitude to all of them.