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# Feature issue introduction: Progress in Ultrafast Laser Modifications of Materials

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**Abstract:** This feature offers papers related to the first topical meeting, Progress in Ultrafast Laser Modifications of Materials 2013, held in April 2013 at Cargèse, Corsica Island, France, and encompasses advances in science and technology of ultrafast laser modification of materials, from the fundamentals—the interaction of ultrafast non-ablative pulses with dielectrics and other transparent materials, to the applications in various technological fields.

**OCIS codes:** (140.0140) Lasers and laser optics.

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## Introduction

Using recent progress in laser technology and in particular in the field of ultra-fast lasers, we are getting close to accomplish the alchemist dream of transforming materials.

Compact lasers can generate pulses with ultra-high peak powers in the Tera-Watt ranges. These high-power pulses lead to a radically different laser-matter interaction than the one obtained with conventional lasers. Nonlinear processes are observed leading to new and exciting opportunities to tailor the matter in its intimate structure with sub-wavelength spatial resolutions and in the three dimensions.

This new way of processing material has numerous potential applications not only in integrated optics (waveguide writing, novel polarization devices, Bragg gratings, devices for future quantum communications, etc.) but also for optomechanics (sensors, actuators, etc.) and optofluidics (lab-on-a-chips). No other technique holds the same potential to realize 3D multi-functional photonic devices, fabricated in a single step in such a wide range of transparent materials. It exhibits enormous potential in the development of a new generation of powerful components

This field of research is still at its infancy. Numerous aspects of the non-ablative laser-matter interaction (below the ablation regime) have yet to be understood and its full application potential has yet to be unraveled. This approach, using out-of-equilibrium synthesis and processing with laser beams, opens new ways to create functional materials and devices that are difficult whether not possible to achieve with current established techniques. This new field relies on the investigation of laser-material interaction and photo-chemical processes. The understanding of the involved physical phenomena, their associated characteristic times, and the resulting phase or structural modifications is of particular importance.

This feature issue will cover the science and technology of ultrafast laser modification of materials, from the fundamentals – the interaction of ultrafast non-ablative pulses with dielectrics and other transparent materials, to the applications in various technological fields.

This feature includes a total of 14 papers. All are contributed papers. This special issue is one attempt to report some state-of-the-art contributions in four thematic areas: i) Investigation of fundamental phenomena in direct laser writing: volume and surface aspect, ii) Direct laser writing modification in various materials, iii) Process characterization and some aspects of femtosecond laser direct writing, iv) Photonics

### *Investigation of fundamental phenomena in direct laser writing: volume and surface aspect*

There are six contributions in this section

Femtosecond laser has been proved to be a powerful tool to realize periodic structures inside or on the surface of transparent materials. The laser material interaction remains complex and the investigation of the fundamental phenomena is challenging. Zhang et. al [1] present recent research developments on single fs laser beam induced periodic structures. The formation mechanisms and applications of these periodic structures are also discussed. Grunwald et. al [2] explain the formation of surface periodic structure in large-bandgap dielectric and semiconducting transparent materials by multiphoton mechanisms of plasmon excitation. Their theory based on extended Drude-Sipe formalism is applied to predict the ripple periods for selected materials.

Stoian et. al [3] investigate isotropy and anisotropy defects as well as the spatial and temporal dynamics of the electronic excitation and the photo chemistry behavior in femtosecond direct laser writing. Concerning the initial phenomena Buividas et. al [4], explain the bulk and surface modification by avalanche ionization process. In the case of multipulse interaction at high repetition rate, cumulative effect must be taken account. Sun et. al [5] investigates temperature, density of electron reach in this regime with picosecond pulses.

Another singular fundamental aspect concerns the asymmetric writing observed in many experiments: quill effect, nanogratings and so on. Poumellec et. al [6] present a new interpretation based on space-charge built from ponderomotive force and stored in the dielectric inducing an asymmetric stress field.

#### *Direct laser writing modification in various materials*

Fused silica is the paradigm for material modification by direct laser writing. Many groups are investing new materials for extended application. Richter et. al [7] report on the ultrashort pulse laser induced formation of birefringent structures in the volume of different glasses: Borofloat, BK7 and ULE. They demonstrated that birefringence is induced by nanogratings formation. They achieved birefringence in ULE comparable to fused silica, while borosilicate glasses show much less birefringence.

Petit et. al [8] demonstrate how silver containing glass are efficient material for direct laser writing of localized second order nonlinear optical properties.

#### *Process characterization and some application of femtosecond laser direct writing*

Some promising applications of direct laser writing concern the ability to process polymers. Buividas et. al [4] demonstrate the 3D photostructuring of SZ2080 and PDMS polymers without photoinitiators at different focussing conditions. Microlenses and scaffolds were produced as sample structures. This shows a potential to produce optically transparent bio-compatible scaffolds. A. Schaap et. al [9], use a two-step femtosecond laser direct- write technique and wet-etching process to fabricate monolithic glass micromolds with complex three-dimensional surface topologies, and demonstrate the replication of these structures in a soft polymer (polydimethylsiloxane, PDMS).

All these processes need to be characterized and the extraction of the refractive index profile for DLW waveguides represents a difficult task. A. Jesacher et. al [10] propose a quantitative phase microscopy, as a simple approach to gain indirect information about the waveguide. The technique requires no specialist equipment, can be easily performed at any point within a 3D waveguide network and is not computationally expensive.

#### *Photonics*

Direct laser writing is one way to implement devices in integrated photonics. For example, R. He et. al [11] fabricate cladding waveguides in LiNbO<sub>3</sub> crystal by using fs-laser micromachining. The cladding structures support guidance along both n<sub>e</sub> and n<sub>o</sub> polarizations at wavelengths of 0.633 μm, 1.064 μm and 4 μm. The minimum loss was reduced to 0.5 dB/cm after thermal annealing. Juodkazis et. al [12], demonstrate direct laser writing of volume Bragg gratings with diffraction efficiency up to 90% using Gauss-Bessel laser beams in fused silica glass. Hélié et. al [13], present a novel method for assembling endcaps to optical fibers. The method relies on femtosecond laser welding and milling of a glass slide to the polished end of the fiber. The method was applied to both a standard and a microstructured optical fiber [14]. Cheng et. al [14], report on fabrication of a liquid crystal electro-optic modulator in fused silica by three-dimensional femtosecond laser micromachining.

This feature issue, related to the first topical meeting: Progress in Ultrafast Laser Modifications of Materials, is bringing new developments in the fast evolving and promising topic of direct laser writing. We hope it will contribute to expand this field of research by attracting new actors.

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