

High-irradiance effects in femosecond laser fabrication

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Abstract: Laser micro-fabrication and micro-structuring of materials is usually carried out at the conditions close to the dielectric breakdown. Interplay between multi-photon and avalanche generation of electrons and thermal relaxation become critically important at those conditions in photo-polymerization, waveguide writing in glasses and for creation of new materials at the focal region. Relevant mechanisms of structuring are reviewed and discussed.

1. Introduction

Femtosecond laser pulses are the most precise tool to modify materials on the surface and in the bulk (volumetric recording). Over the last decade, demonstrations of unique capabilities of ultra-short laser pulses in fields as different as optical memory, photonic crystals, micro-optical and mechanical structures, bio-scaffolds, and sensing were demonstrated. Predictions made in 2005 [1] on versatility of fs-laser as material modifying tool is now clearly demonstrated: photo-polymerization of micro-optical elements in variety of polymers which are photo-sensitized or not, creation of active waveguides for laser emission in phosphate glasses, formation of micro-/nano-fluidic channels and bio-friendly scaffolds without photo-initiators are all making strong progress over last years. Another prediction [1], that fs-laser structuring will enter nanotechnology space by being able to confine modification within 100 nm cross sections in all three-dimensions (3D) is now becoming an enabling technology for the high-resolution 3D structuring of glasses, photo-polymers and crystals.

In this presentation we will present specific applications of nano-/micro-structuring of (i) surfaces (ii) 3D photo-polymerization without photo-initiator for high precision micro-optical elements, and (iii) creation of new materials in the focal volume by micro-explosion using fs-laser pulses.

1. Surface structuring by ripples

High melting temperature substrates such as sapphire Al_2O_3 , SiC, or diamond are promising materials for nano-texturing by laser ablation since melting is minimized due to controlled heat dissipation at low repetition rate (< 0.2 MHz); the period of self-organized ripple patterns is small due to high refractive index, n , (period $\Lambda = \lambda/(2n)$ where λ is the wavelength of laser irradiation). Ripples made on such substrates by strongly focused (spot size 1-4 micrometers) fs-laser pulses can form carpets of arbitrary size (sub-millimeters) and shape only limited by the time required to cover the area.

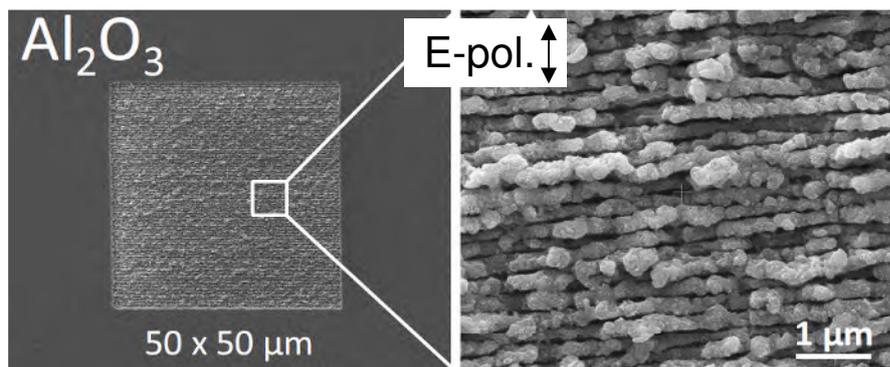


Fig. 1. Ripples on sapphire made by ablation with 800 nm/150 fs laser pulses [2].

2. Photo-polymerization

High fidelity and quality micro-optical elements required for polarization optics can be made on a micro-scale using direct laser writing technique. One example is a precisely fabricated spiral plate for 100% efficient conversion of a circularly polarized plane wave into an optical vortex of a well-defined charge, l , defined by a step height of the spiral plate.

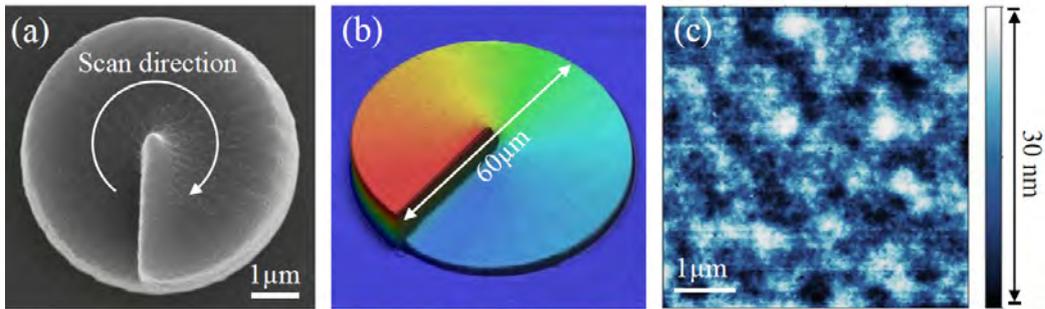


Fig. 2. Micro-optical element: spiral plate polymerized by 800 nm/ 150 fs (a) and 1030 nm/280 fs (b) laser pulses [3]. Surface roughness (c) of polymerized surface was below 30 nm; photo-polymer SZ2080.

3. New high pressure and temperature phases of materials

Micro-explosions made by tightly focused single laser pulses can generate high pressure and temperature conditions in a multiply-ionised breakdown plasma which drives compression wave. Femtosecond laser pulses have unique ability to deliver such high- p, T conditions at record fast rates. Since a single pulse energy driving explosion is in hundreds of nano-Joules, the shock wave pressure propagating from the central core is quickly dissipated and thermal quenching occurs also very fast. This captures unusual material phases which might be useful in applications as well as can provide fundamental insights in light-matter interaction and high density materials.

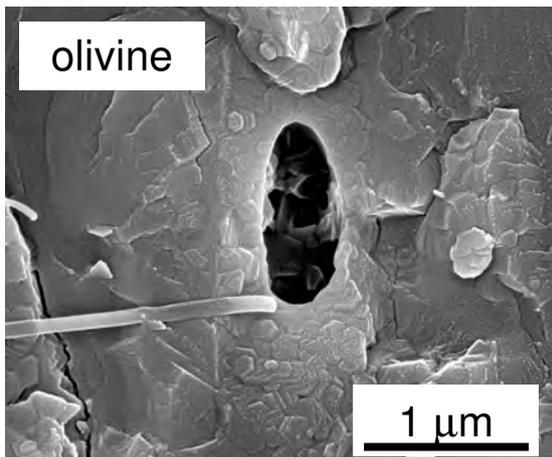


Fig. 3. Olivine crystal structured by micro-explosion triggered with a single 800 nm/150 fs laser pulses [4]. Breaking of the sample for SEM observation reveals the void formation, re-crystallization and plastic deformation – a nano-ribbon.

Creation of new materials with unusual properties will always be one of the drivers of modern technology. Dielectric breakdown leads to breaking of chemical bonds and can lead to formation of new phases and stoichiometry changes. Recently generation of molecular oxygen in GeO_2 glass and densification of silica [5], super-dense phase of body centered cubic bcc-Al in sapphire [6] were demonstrated. Control of material structure at nanoscale would lead to possibility to control of electric and thermal conductivity and is promising for thermo-electrical converters. Direct write of 3D patterns with different electrical and thermal conductivity is a future target.

References

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