Multiscale dynamics and control in ultrafast laser nanostructuring; applications in 3D photonics

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Bypassing diffraction limit in laser material structuring is a key issue for a new range of applications in optics and mechanics requiring optical access to the nanoscale. Enabled by the nonlinearity of interaction, ultrafast lasers show remarkable effectiveness in localizing light on subwavelength scales, building up in many cases on a collective carrier response on surfaces and in the bulk. The 3D capability has a particular interest as ultrafast laser interaction with transparent materials can achieve optical functions by space-design of embedded structural transformations with changes of the dielectric function. Control of laser interaction by beam design can drive selected physical paths and geometries, and we will focus here on structural evolutions and dimensional scales enabled by spatio-temporal beam shaping. Essential for refractive index engineering, laser-induced matter transformation can be significantly influenced by the level of the energy deposition, critically dependent on the pulse temporal envelope. Photoionization can be regulated, leading to unprecedented localization of laser energy. Pulse temporal and spatial design can achieve index structures on scales approaching 100 nm, either in direct focusing or self-organization schemes in model fused silica [1,2]. We follow specific dynamics of electronic relaxation in confinement conditions and point out characteristic times of energy deposition, serving as guidelines for control. Fast electronically-induced structural changes or slow thermodynamic transformations can be discriminated [3]. Concepts of non-diffractive beam excitation can additionally take advantage of this localization and achieve unprecedented high aspect ratio structuring. From the application point of view, the mid-infrared spectral range carries a strong potential in sensing and imaging. Extrapolation of controlled laser-induced structural modification towards mid-infrared materials can achieve strong index contrast on micron and submicron scales. We demonstrate linear and nonlinear 3D optical functions in chalcogenide glasses [4,5] where light transport in mid-infrared can be efficiently achieved with large area modes, and the field distributions can be non-perturbatively accessed.

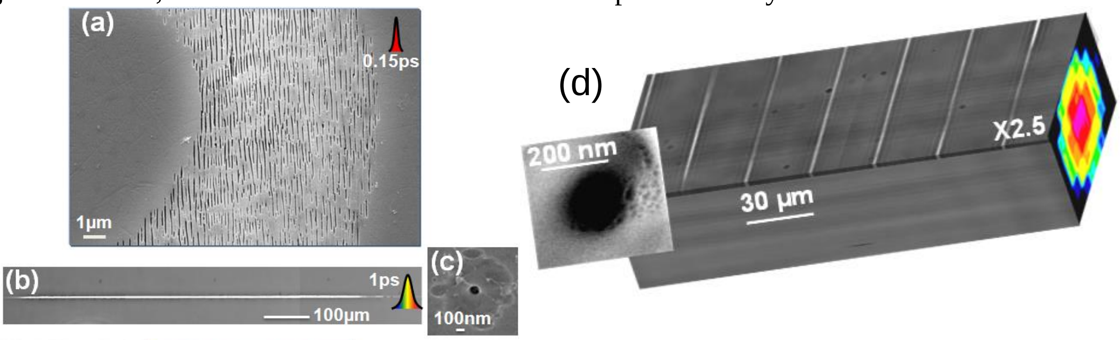

Fig1. (a-c) Examples of bulk nanostructuring in fused silica using self-organization or non-diffractive direct focusing concepts. (d) Embedded photonic device for spectrometry

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