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## **On the roles of non-linear propagation, scattering, ionization and thermo-mechanical effects in ultra-short laser structuring of glasses**

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Short and ultrashort laser pulses are used for a wide range of micro- and nano-machining applications. Among the most promising ones, the formation of periodic and non-periodic 3D nanostructures inside glasses attract particular attention. These structures can be used for optical memories, as optical components, metamaterials, photonics crystals, for laser-based image inscriptions in security, in counterfeiting fight, as well as in nanofluidics, medicine, etc. Interestingly, ultra-short-laser induced periodic volume nanogratings (VNGs), for instance, are still considered to be the smallest embedded structures ever created by light [1-4].

Previous experimental investigations of the phenomenon revealed numerous interesting features of ultra-short laser processing of dielectric materials [1-3]. In particular, it was found that laser parameters should correspond to a particular window in order to obtain the desired results. In fact, depending on the laser irradiation conditions, different types of permanent material modification could be induced in glasses by ultra-short laser pulses. Single pulse irradiation leads either to smooth modification characterized by positive index change or to void-like rarefaction regions. After multi-pulse laser irradiation, self-organized nanogratings were found at certain laser conditions in fused silica glass and few other glasses.

Many questions concerning the formation mechanisms that explain the required parameter ranges are still open. To better control over the laser-induced processing, resulting modifications are experimentally investigated as a function of laser pulse energy, pulse duration, numerical aperture, laser wavelength, repetition rate, and the number of applied pulses. In addition, numerical model based on Maxwell equations coupled with non-linear ionization equations is developed [4].

Here, in addition, we consider the main photo-thermal processes taking place during ultra-short laser irradiation and thermo-mechanical wave propagation. As a result, spatiotemporal evolutions of temperature, pressure and density are calculated, which accompany the refractive index change over a broad range of timescales from femtoseconds to few microseconds as a function of laser

parameters such as pulse energy, pulse duration, laser wavelength, numerical aperture, number of pulses and repetition rate.

By applying this model, we study the role of the laser experimental conditions and the one of material properties. The physical processes such as pressure wave generation, thermal diffusion and heat accumulation are investigated and the parameter window required for 3D laser treatment is explained.

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