Modification of fused silica using femtosecond multiphoton ionization

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Intense, infrared femtosecond laser pulses can ionize any atom. Often the mechanism is well described by field ionization. Technologically, ionizing atomic gases produce the shortest wavelength coherent XUV radiation and the shortest duration optical pulses. The radiation can reach 1000 keV photon energy or it can be concentrated into short pulses with duration as short as 250 attoseconds.

Collective (multielectron) effects and the complex electronic structure can no longer be ignored when femtosecond laser pulses ionize large molecules. However, when collective effects are included, ionization is again well described by field ionization. Technologically, XUV radiations produced by ionizing molecular gases give enough information to image the 3-D structure of the molecule.

Field ionization, modified by local field effects and avalanche ionization, is still active inside transparent materials. Now the material affects the light --- and vica versa. One might guess that it would be difficult to control such processes. However, for very short pulses it is quite the reverse. Depletion becomes so important that the intensity is capped, often with little damage to the material.

Ionization of fused SiO_2 under conditions where depletion dominates can result in a gentle modification to the refractive index. Technologically, waveguides written in the centre of dielectrics becomes feasible. Chemical etching shows that structural changes underlie dielectric modification. Chemical etching produces a relief pattern that can be read with an AFM. Thus we can visualize the modified region with nanometer precision.

AFM studies reveal that, for a wide range of conditions, nano-planes of modified material are formed in SiO_2. Their thickness is <20 nm while their lateral dimensions can be macroscopic. When the focus is scanned with respect to the material, ordered arrays of nanoplanes, separated by $\lambda/(2n)$ are produced. Again the order is on macroscopic scales while the alignment of the planes is controlled by laser polarization.

Ordered nanoplanes will be important in their own right. They also give us a powerful means for studying the build-up and decay (within a single shot, and over many shots) of transient plasmas in SiO_2.

I will emphasize the common aspects of ionization processes in all materials with special emphasis on dielectrics.