Ultrafast laser pulses create periodic planar nanocracks in glass

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The structures produced may be useful for a variety of applications, including lab-on-a-chip devices and optical storage of information.

Femtosecond laser pulses with focused intensity above the ionization threshold initially deposit energy homogeneously in fused silica. After many exposures this homogeneity can vanish, producing beautifully arrayed nanometer-thick planar cracks throughout the focal volume. These are oriented perpendicular to the laser polarization and have a periodicity approximately half that of the laser wavelength in the medium. These nanocracks have the largest aspect ratios (length-to-thickness $\sim 10^4$) of any nanostructures created in a pure material using light, and can be placed and replaced inside glass with unprecedented control. This allows them to be used in a variety of biophotonic and data storage applications as well as in the study of material fatigue.

The planar nanocracks result from the continued irradiation and an inherent shot-to-shot memory in the material. The precursors of the nanocracks are randomly distributed, transient nanoplasmas produced by ionization. The laser’s electric field drives the growth, elongation and flattening of the nanoplasmas into nanoplanes and eventually nanocracks oriented perpendicular to the electric vector. The self-imposed periodicity of the nanocracks arises from the allowed field distribution inside the irradiated volume filled with evolving plasma nanoplanes.

To produce nanocracks in fused silica, we use tightly focused femtosecond laser light at a wavelength of 800nm. After irradiation, we polish the samples and weakly etch them in hydrofluoric acid. This allows us to use a scanning electron microscope (SEM) to reveal their morphology, as illustrated in Figure 1. Although the irradiated regions are only few microns wide, we have demonstrated that nanocracks arrayed in consecutive passes can be stitched seamlessly into large bulk or surface nanopatterned areas.

Figure 1. Top: Self-assembly of periodic nanocracks in continuous writing. Bottom: Scanning electron microscopy (SEM) images of nanostructures with polarization $E$ parallel (right) and perpendicular (left) to the writing direction $S$. $k$: Laser light direction.

Figure 2. Optical images of microchannels created with polarization $E$ perpendicular (top) and parallel (bottom) to the writing direction $S$.继续在下一页
We used selective chemical etching of the nanostructures to produce microchannels in fused silica. By controlling the orientation of the nanocracks, we can also control the etch rates.  

As shown in Figure 2, channels with nanocracks aligned along the writing direction (top) etch nearly 100 times faster than those aligned perpendicularly (bottom).

We also use polarization control to create porous capillaries in glass. Figure 3 shows an SEM image of some nanopores and the decay of a fluorescence signal from a Rhodamine 6G dye solution in the capillaries as evidence of nanofiltration of the dye molecules.

Figure 4 presents SEM images of written (top) and rewritten (bottom) data voxels. High-contrast reading of the voxels in polarized light is based upon their inherent form birefringence and is performed with a low-intensity incoherent light source. We demonstrated 1,000 rewrites with little degradation in data readability. The voxels survive temperatures up to 1100°C, which makes fused silica glass a near ideal medium for ultra-durable, rewritable optical data storage.

We are only just beginning to understand these nanocracks in glass, which are remarkable self-assembled nanostructures. Many more exciting applications will emerge in the years to come.

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References