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Anisotropic nanostructures directly written by fs pulses in wide-bandgap materials

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The use of lasers to directly pattern optoelectronic devices primarily utilizes direct irradiation by UV light. We present here an alternative route using multi-photon absorption within a spherical focus in 3D space, thus allowing complex embedded structures to be directly written. In wide-bandgap materials such as chalcogenide, fluoride and silica glasses, our observations suggest free electrons are produced within the focus of a high-power infrared ultrashort pulse. The anisotropic interaction of this plasma with the incident pulse produces micron-sized DBR gratings of a 150nm pitch.

An amplified Ti:S laser with 250kHz repetition rate, 150fs pulse duration, and wavelength tuned from 800-850nm, is used to write embedded diffraction gratings and arrays of dots. The laser beam is focussed with a 50x objective into transparent polished samples, with pulse energies ranging from 0.1-1.1μJ (Fig.1a). During the writing process broadband sub-bandgap UV light is emitted from a micron-sized spot at the sample focus. The written structures are permanent, typically with large refractive index changes on the order of $\Delta n = +0.01$ depending on the material.

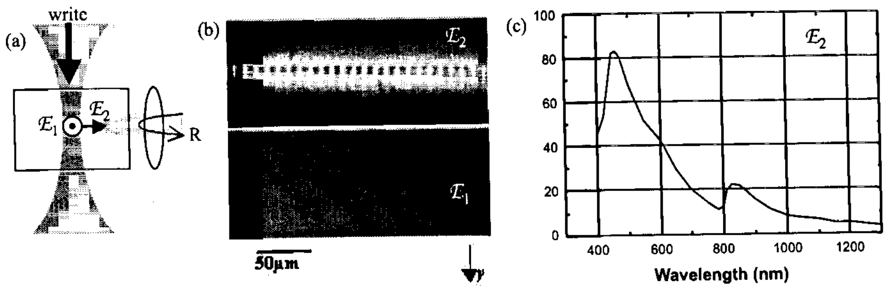

Figure 1: (a) Geometry of writing and reflectivity measurement of photonic dots, with different writing polarizations $E_{1,2}$. Multi-photon absorption modifies the material only at the the sample focus. (b) Reflection images of the same structure written with different polarizations. The images switch if viewed from the orthogonal direction (out of the page). (c) Reflection spectrum of directly-written dots.

Reflection from these devices can be clearly observed above a threshold of 0.5μJ per pulse, indicating that the phenomenon is fluence-dependent.[2] Individual small structures such as photonic dots can be clearly seen from the side (Fig.1b upper). However this is the case only if the writing laser's linear polarization is along the direction from which reflection is observed (E_2 in Fig.1a). When either the direction from which reflection is viewed, or the writing polarization is changed to E_1, the strong reflection disappears, (Fig.1b lower). We have also confirmed this phenomenon for lines and gratings, and demonstrate it appears only after a larger pulse threshold.[3]

The reflection, of order 2% per photonic dot, appears strongly blue which is confirmed by the reflection spectrum (Fig.1c). To explain the specifically-directed blue reflection requires the presence of an anisotropic microstructure. Modelling indicates the photonic dot is built from a refractive index grating oriented with planes perpendicular to the writing beam field direction, and spacing 150nm. We suggest that the electron plasma produced by the intense local laser field is accelarated by the *ac* optical field creating counter-propagating plasmons along the E-field direction which interfere. Regions of high-electron density modify the material by breaking bonds locally, creating the observed nanostructure.

Similar laser induced periodic structural modification has been observed on the surface of materials but never before in the bulk. We speculate that the origin of the anisotropic reflection is also the primary cause of other unexplained anisotropic phenomena reported in similar experiments.

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[2] E. Bricci, J.D. Mills, P.G. Kanzansky and J.J. Baumberg, to be published in Optics Lett. (2002).
[3] J.D. Mills, E. Bricci, P.G. Kanzansky and J.J. Baumberg, Appl. Phys. Lett. **81**, 196 (2002).