Self-organized form birefringence in glass irradiated by intense ultrashort light pulses

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Abstract: Correlation between anisotropic reflection and birefringence in glass irradiated with femtosecond pulses is observed. Direct evidence of self-induced nanogratings and form birefringence is obtained.

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The use of a femtosecond laser light to directly write structures deep within transparent media has recently attracted much attention due to its capability for writing in three-dimensions. New phenomena of light scattering and Cherenkov third-harmonic generation peaking in the plane of polarization during direct writing with ultrashort light pulses in glass have been reported [1]. An amplified Ti: sapphire laser operating at 850 nm, 150 fs pulse duration was used in the experiments. These observations were unexpected because the scattering of polarized light in the plane of light polarization in isotropic medium such as glass is always weaker compared to the orthogonal plane, since a dipole does not radiate in the direction of its axis. The phenomena were interpreted in terms of angular distribution of photoelectrons and sub-wavelength anisotropic index inhomogenities. Other experiments demonstrated uniaxial birefringence of structures in fused silica written by femtosecond light pulses [2]. The index change for light polarized along the direction of polarization of writing beam was much stronger than for the orthogonal polarization. The origin of this anisotropic phenomenon remained a mystery until recently. More recently we observed a further anisotropic property in silica after being irradiated by a femtosecond laser – strong reflection from the modified region *occurring only along the direction of polarization of the writing laser [3]*. This can arise from a self-organized periodic sub-wavelength (~ 150 nm) refractive index modulation, which is also responsible for the anisotropic scattering phenomena reported in the experiments on direct writing with ultrashort pulses in glass. We speculate this arose from a mechanism associated with the creation of a hot electron plasma by multiphoton absorption of incident light. Anisotropic index inhomogeneities are then induced by electrons moving along the direction of light polarization. Self-organized nanostructures are in turn produced by a pattern of interference between the incident laser radiation and a plasmon-polariton wave generated within the sample. Positive feedback leads to exponential growth of the periodic nanostructures in the plane of light polarization, which become frozen within the material. However microscopic mechanism of this effect is still not fully understood. Experiments were carried out to clarify the relationship between the phenomenon of anisotropic reflection and the birefringence induced by femtosecond irradiation. Irradiated glass samples were positioned between cross polarizers and it was observed that the onset of birefringence occured at a writing-fluence level ~0.5 μJ/pulse, equal to that found in the case of anisotropic reflection (Fig.1).

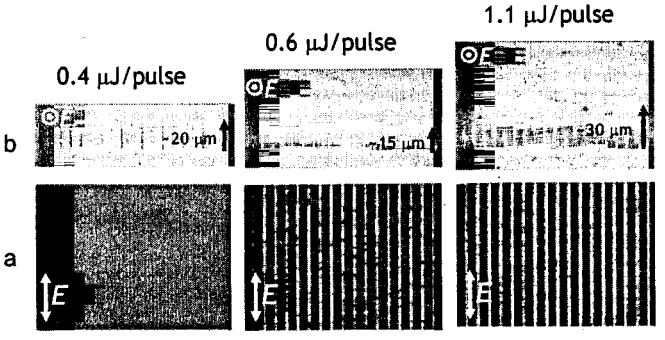

Fig. 1. Images of embedded diffraction gratings in cross polarizers (a) and side-views of the gratings, demonstrating strong anisotropic reflection (b).

Experiments were carried out in different glass samples and sapphire listed in Table1. The red shift of the reflection spectrum in sol-gel silica and Ge-doped silica indicates smaller period of self-induced grating structures. The reason for this shift is currently under investigation.

Samples	Birefringent?	Reflection?
Soda-lime glass	No	No
Nanocrystal glass	No	No
BK7	No	No
Sapphire	Yes	Yes, weak
Ge-doped silica	Yes	Yes, redish/blue
Fused silica	Yes	Yes, blue
Sol-gel silica	Yes	Yes, red

Table 1

We also fabricated embedded birefringent Fresnel zone plates and observed strong stress-related birefringence of the glass surrounding embedded structures (Fig. 2).

Fig. 2. Side view of Fresnel zone plate in cross polarizers Diameter is 1 mm.

We are succeed in direct imaging of self-induced nanogratings. The femtosecond-laser-induced birefringence is therefore likely to be caused by these laterally-oriented small-period grating structures. Birefringence of this nature is well known as 'form' birefringence. The phenomenon reported in this paper represents an unusual type of birefringence – self-organized form birefringence, which should be useful in many monolithic photonic devices.

References

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