Revealing New Properties of Light-Matter Interaction Using Ultrashort Light Pulses: From Self-Assembled Nanostructures to Hidden Anisotropy of Light Beam

Peter G. Kazansky and Martynas Beresna
Optoelectronics Research Centre, University of Southampton, SO17 1BJ, United Kingdom
*pgk@orc.soton.ac.uk
Yasuhiko Shimotsuma and Kazuyuki Hirao
Department of Material Chemistry, Graduate School of Engineering, Kyoto University, Kyoto, Japan 615-8510
Yuri P. Svirko
Department of Physics and Mathematics, University of Joensuu, FI-80101, Finland
Selcuk Akturk
Department of Physics, Istanbul Technical University, Maslak 34469 Istanbul, Turkey

Abstract

Interaction of intense ulrashort light pulses with transparent materials reveal new interesting properties and phenomena. Recent demonstrations of 3D nanoripple formation, nonreciprocal photosensitivity, ultrafast laser calligraphy and light blade effect due to hidden anisotropy of ultrafast laser beam are reviewed.

Modification of transparent materials with ultrafast lasers has attracted considerable interest due to a wide range of applications including laser surgery, integrated optics, 3D micro- and nano-structuring [1].Three different types of material modifications can be induced with ultrafast laser irradiation in the bulk of a transparent material, silica glass in particular: an isotropic refractive index change (type 1); a form birefringence associated with self-assembled nanogratings and negative refractive index change (type 2) [2-5]; and a void (type 3). In fused silica the transition from type 1 to type 2 and finally to type 3 modification is observed with an increase of fluence. Recently, a remarkable phenomenon in ultrafast laser processing of transparent materials has been reported manifesting itself as a change in material modification by reversing the writing direction [6]. The phenomenon has been interpreted in terms of anisotropic plasma heating by a tilted front of the ultrashort laser pulse. Moreover a change in structural modification has been demonstrated in glass by controlling the direction of pulse front tilt, achieving a calligraphic style of laser writing which is similar in appearance to that inked with the bygone quill pen [7]. It has also been a common belief that in a homogeneous medium, the photosensitivity and corresponding light-induced material modifications do not change on the reversal of light propagation direction. More recently it have observed that in a non-centrosymmetric medium, modification of the material can be different when light propagates in opposite directions (KaYaSo effect) [8]. Non-reciprocity is produced by magnetic field (Faraday effect) and movement of the medium with respect to the direction of light propagation: parallel (Sagnac effect) or perpendicular (KaYaSo effect). Moreover a new phenomenon of ultrafast light blade, representing itself the first evidence of anisotropic sensitivity due to hidden anisotropy of ultrafasr laser beam has been recently discovered (Fig.1) [9]. We anticipate that the observed phenomena will open up new opportunities in laser material processing and controling of intense light propagation [10,11].

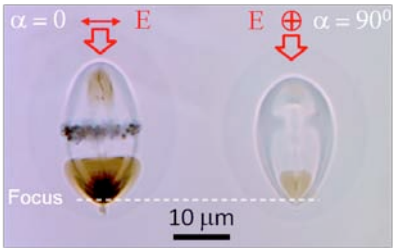

Fig. 1. Images of modified regions in glass along beam propagation direction for writing beam polarised along (left) and perpendicular (right) to the pulse intensity front normal.

References

[1] R. R. Gattas and E. Mazur, "Femtosecond laser micromachining in transparent materials," Nature Photonics **2**, 219-225 (2008).
[2] P.G. Kazansky et al. "Anomalous Anisotropic Light Scattering in Ge-doped silica glass," Phys. Rev Lett.," 82, 2199 (1999)
[3] L. Sudrie, M. Franko, B. Prade, and A. Mysyrowicz, Opt. Commun. "Writing of permanent birefringent microlayers in bulk fused silica with femtosecond laser pulses," **171**, 279 (1999).
[4] Y. Shimotsuma, P. G. Kazansky, J. Qiu and K. Hirao, "Self-organized nanogratings in glass irradiated by ultrashort light pulses," Phys. Rev. Lett. **91**, 247705 (2003).
[5] V. Bhardwaj, E. Simova, P. Rajeev, C. Hnatovsky, R. Taylor, D. Rayner and P. Corkum, "Optically produced arrays of planar nanostructures inside fused silica," Phys. Rev. Lett. **96**, 057404-1 (2006).
[6] P. G. Kazansky et al. "Quill" writing with ultrashort light pulses in transparent materials," Appl. Phys. Lett. **90**, 151120 (2007).
[7] W. Yang et. al. "Ultrashort-pulse laser calligraphy," Appl. Phys. Lett. **93**, 171109 (2008).
[8] W. Yang, P. G. Kazansky and Yu. P. Svirko, "Non-reciprocal ultrafast laser writing," Nature Photonics, **2**, 99-105 (2008).
[9] P. G. Kazansky, Y. Shimotsuma, M. Sakakura, M. Beresna, Yu. Svirko, S. Akturk, J. Qiu, K. Miura and K. Hirao, "Photosensitivity control of isotropic medium by light polarization: Ultrafast light blade", submitted to Nature Photonics (2010).
[10] L. Sudrie, A. Couairon, M. Franco, B. Lamouroux, B. Prade, S. Tzortzakis and A. Mysyrowicz, "Femtosecond laser-induced damage and filamentary propagation in fused silica," *Phys. Rev. Lett.* **89** (18), 186601/1 (2002).
[11] D. G. Papazoglou, I. Zergioti, and S. Tzortzakis, "Plasma strings from ultraviolet laser filaments drive permanent structural modifications in fused silica," *Opt. Lett.* **32** (14), 2055 (2007).