Femtosecond laser-induced material modifications to control stress states in silica: a step toward metastable polymorphic phase generation

Yves Bellouard
Galatea Lab, STI/IMT, Ecole Polytechnique Fédérale de Lausanne (EPFL)
Rue de la Maladière 71b, Case postale 526, CH - 2002 Neuchâtel Switzerland
yves.bellouard@epfl.ch

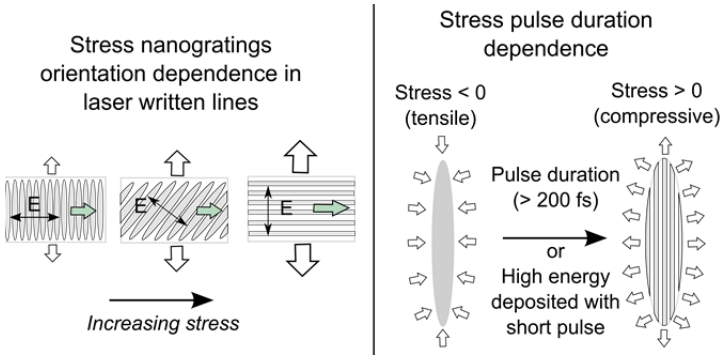
Femtosecond laser exposure of silica in a non-ablative regime induces localized volume changes resulting in a stress-field surrounding laser affected zones. Here, we review these effects and illustrate potential applications of laser-induced controlled stress-state.

Non-ablative femtosecond laser pulses applied on fused silica induce mainly two types of modifications: homogeneous modifications and self-organized nanogratings[1],[2]. Noteworthy, a localized net volume expansion is associated with the occurrence of self-organized nanogratings[3] which orientation affects stress distribution[4]. For shorter pulses (< 200 fs) and low-energy – corresponding to the regime of homogeneous modifications, densification is observed[5].

The laser pulse duration can therefore be used to introduce either tensile or compressive stress, which intensity and direction can be fine-tuned by controlling the pulse energy and the laser polarization.

Laser-induced stress in the material affects the laser exposure process but also has interesting applications. For instance, it can lead to path-dependent machining, but if controlled (see illustration), can also be used to create known stress state[6]. It may also offer a path for high-pressure phase generation in silica.

Controllable bulk-stress state has a high technological potential in the field of integrated microsystems, and more generally, as a possible tool for better understanding the formation of high pressure phases in silica.



Left: Illustration of the effect of self-organized nanogratings orientation in laser-written line on stress intensity. The maximum intensity is found for nanogratings perpendicular to the writing direction. Right: stress-state inversion by switching between continuous modifications to nanogratings.

[1] K. M. Davis, K. Miura, N. Sugimoto, and K. Hirao, Opt. Lett. 21, 1729–1731 (1996).
[2] Y. Shimotsuma, P. G. Kazansky, J. Qiu, and K. Hirao, Phys. Rev. Lett. 91, 247405 (2003).
[3] A. Champion and Y. Bellouard, Opt. Mater. Express 2, 789–798 (2012).
[4] A. Champion, M. Beresna, P. Kazansky, and Y. Bellouard, Opt. Express 21, 24942–24951 (2013).
[5] Y. Bellouard, T. Colomb, C. Depeursinge, M. Dugan, A. A. Said, and P. Bado, Opt. Express 14, 8360–8366 (2006).
[6] B. McMillen and Y. Bellouard, Optics Express 23, 86–100 (2015).