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Femtosecond laser cutting of glass by controlled fracture propagation

K. Mishchik¹, C. Javaux², O. Dematteo-Caulier¹, S. Skupin¹, B. Chimier¹, G. Duchateau¹, A. Bourgeade³, R. Kling², A. Letan⁴, C. Hönninger⁴, E. Mottay⁴, J. Lopez¹

¹ UNIV BORDEAUX CNRS CEA, CELIA UMR5107, 33405 Talence, France.

² ALPhANOV, Rue Francois Mitterand, 33400 Talence, France.

³ CEA/CESTA, 15 Avenue des Sablières, 33114 Le Barp, France.

⁴ AMPLITUDE SYSTEMES, 11, avenue de Canteranne, Cité de la Photonique, 33600 Pessac, France.

Author e-mail address: choeninger@amplitude-systemes.com

Abstract: We present the use of a compact femtosecond laser with 300-fs pulse duration and pulse energy on the order of 10s of μJ for the cutting of glass by controlled fracture propagation.

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Laser induced controlled fracture propagation [1] has great potential in cutting brittle materials such as glass or sapphire. This method is based on the ability to produce a mechanical stress by the absorption of the laser radiation in the volume of the material. Under specific conditions thermal stresses cause initiation of a top-down through crack which propagates along the laser beam trajectory. The cut parts are released without any mechanical assistance. The cutting sidewalls are smooth and free from any surface defects and debris. However, using CO₂ or YAG lasers, this method has several drawbacks such as poor precision, uncontrolled cutting deviation or low effective cutting speed (few tens of mm/s). There exist techniques to improve cutting quality or proceeding speed [2], however, they could not overcome all the shortcomings of the convenient method at the same time and added extra-cost and complexity to the process. Thus, there is the need to find solutions how to make this technology fast, precise and versatile for different materials.

In this paper we demonstrate that the use of ultrashort pulse laser sources may be advantageous since it allows to overcome several restrictions of the convenient method. We report on the laser cutting of thick soda-lime glass samples using an Yb-doped fiber femtosecond laser (Satsuma, Amplitude Systems, 5W, 1030nm, 300fs). Cutting was achieved at high repetition rate (500 kHz) by focusing the laser beam with a low numerical aperture (NA~0.05) inside the glass sample, which can be translated in three dimensions (Fig. 1a). We have investigated the effect of the experimental parameters, such as numerical aperture, pulse energy, single pulse or burst-mode, and repetition rate on the laser affected zone (LAZ). We demonstrate that in a specific regime an elongated LAZ depicted in Fig. 1b can produce single-pass full cutting of 1mm-thick glass by controlled fracture propagation. The crack follows straight and curve trajectories with a radius down to 1 cm with a federate of 1mm/s. Cutting edge and rim have been characterized using confocal optical and scanning electron microscopies (Fig. 4c-d). We have measured a roughness of the edge to be below 100nm and a path deviation below 10 μm compared to a flat surface, which we attribute to variation of the LAZ diameter along the sample depth.

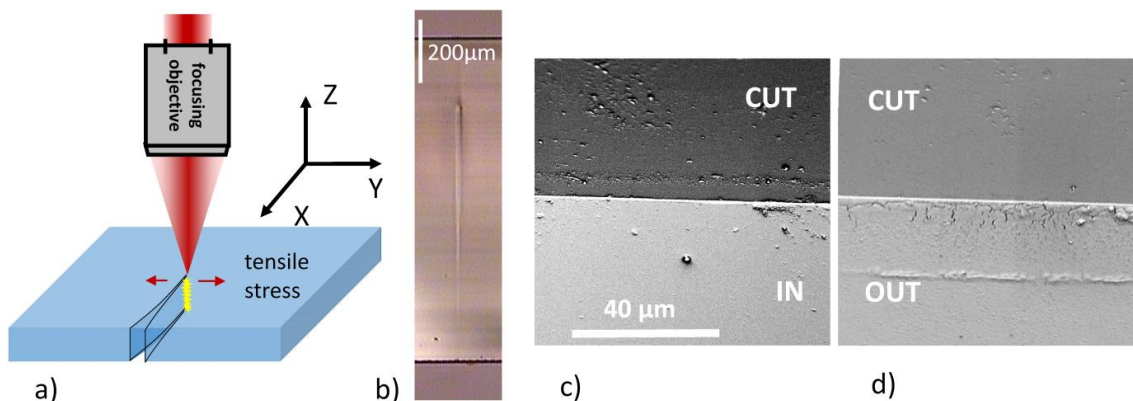


Fig.1. a) Experimental setup. b) Microscopy image of the elongated and narrow LAZ reaching its length of about 800 x 20 μm . SEM images showing cutting sidewall and rim qualities on front (c) and rear surfaces (d). There is no visible chipping.

We also performed theoretical simulations of thermal effects during laser irradiation. The numerical model is based on nonlinear light absorption in the presence of intense optical fields, nonlinear propagation defined by the Kerr-effect, and takes into account influence of free carriers on laser absorption and propagation. Modeling shows that at loose focusing conditions the laser energy is absorbed in a narrow and rather long zone, i.e., a filament is formed. At high repetition rate, the absorbed energy does not dissipate before the subsequent pulse arrives, which results in a local raise of the temperature and generation of high tensile stress in the vicinity of the LAZ. Eventually thermal stress initiates the crack formation along the whole glass depth. The intrinsic property of nonlinear absorption makes this cutting method suitable for wide range of glasses and transparent ceramics, without any need of prior treatment of the samples.

- 1) R. M. Lumley, Controlled separation of brittle materials using a laser, *Am. Ceram. Soc. Bull.* **48**, 850-854 (1968).
- 2) S. Nisar, L. Li, & M. A. Sheikh, Laser glass cutting techniques—A review. *Journal of Laser Applications*, **25** (2013)