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Single pass cutting of glass substrates >4mm with ultra-short laser pulses

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Abstract

The precise separation of glass is of great importance for various applications, e.g. for the fabrication of displays. The use of ultra-short laser pulses enables localized energy deposition inside the glass sample. The resulting stress fields can be used to define breaking lines enabling glass cutting with high surface quality, no chipping and no need for post-processing. In this presentation, we report on in-situ measurements of the interaction between the laser pulses and the glass. This allows a fundamental understanding of the interaction process, to identify critical processing parameters and to tailor the scribing process. Using adapted laser beam shaping we were able to induce homogeneous modifications and to process glass thicknesses of >4mm in a single pass.

Keywords: Laser marials processing; Glass processing; In-volume modification; Beam shaping; Time-resolved microscopy

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1. Main text

The precise separation of glass is of great importance for various applications, e.g. for the fabrication of displays. The use of ultra-short laser pulses enables localized energy deposition inside the glass sample (Itoh et al., 2006, Gamaly et al., 2006). The resulting stress fields can be used to define breaking lines enabling glass cutting with high processing speed and surface quality, no chipping and no need for post-processing (Kumkar et al., 2014).

In this case, spatio-temporal beam shaping is essential for tailored processing, for example to ensure a homogeneous energy distribution. A typical example for spatial beam manipulation is the use of Bessel beam, which shows promising features, like high-aspect ratio interaction areas and flexile length adjustment (Bhuyan et al., 2014). Here, an elongated interference region can be generated, obtaining higher intensities than a Gaussian beam, and accomplished by several sidelobes (e.g. 17% of the intensity is carried by the first order sidelobe).

In this presentation, we report on in-situ measurements of the interaction between the laser pulses and the glass. This allows a fundamental understanding of the interaction process, to identify critical processing parameters and to tailor the scribing process. For this purpose a pump-probe setup with high spatial and temporal resolution was built.

In the experimental setting (see Fig.1) a single laser pulse at a wavelength of 1026nm and 200fs is emitted from a PHAROS-SP system from Light Conversion. A beam splitter separates the pulse into a pump- and probe beam. The duration of the pump-beam can be varied via a grating stretcher up to 12ps (FWHM). The beam is spatially shaped by a spatial light modulator (SLM, Holoeye, PLUTO) and focused (NA 0.35) into a glass sample where it generates an electron plasma.

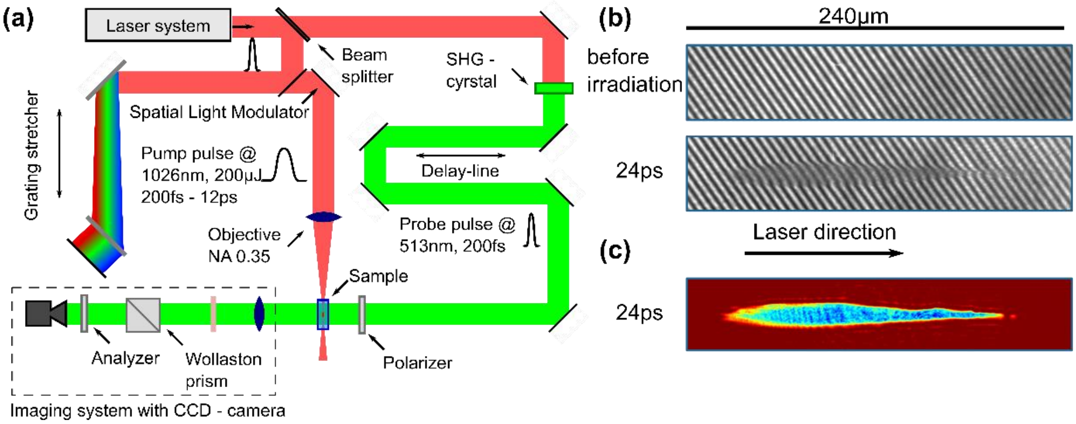

Fig.1. (a) Shadowgraphic and interferometric pump-probe setup with external grating stretcher and spatial light modulator. (b)Interference pattern w/o and w/ plasma interaction and corresponding phase shift. (c) Shadowgrafic image 24ps after arrival of the pump pulse (12ps, FWHM).

The 200fs probe beam is frequency doubled (λ=513nm) and samples the plasma process in time via an adjustable delay line perpendicular to the pump beam. An imaging system with microscope objective and CCD-camera is used to image the interaction area, where the probe beam is partly absorbed and scattered by the laser induced plasma (see Fig. 1c). By integrating an additional polarization element (Wollaston prism) into the microscopic setup a fringe pattern (Fig. 1(b) upper image) can be obtained, which is altered by the modification (again, Fig. 1(b) lower image) (Garnov et al., 2003). This allows to retrieve qualitative information about the plasma generation and subsequent energy transfer to the lattice by measuring the phase change in time (Bergner et. al., 2016).

Here, the pulse duration used is an important parameter to control non-linear effects, like filamentation (Couairon and Mysyrowicz, 2007), and allowing a sufficient electron-phonon interaction (Rethfeld, 2006). By changing the spatial beam characteristics from a Gauss to Bessel-Gauss beam long and thin plasma regions can be generated. Here, we adapted the interaction length to 250µm with the help of the SLM.

Three main regimes can be identified depending on the pulse energy. Slightly above the ionization threshold (≈ 20µJ) a precise thin main maximum of 150µm length can be measured. However, the induced energy is too low for significant material changes on this length scale.

Applying pulse energies above 100µJ results in strong phase changes within the main maximum, extending about the targeted 250µm. However, the first sidelobe already exceeds the ionization threshold, which enlarges the transversal interaction region. Moreover, several filamentation strings can be detected. This leads to a non-uniform intensity distribution, which may lead to processing errors. In contrast, optimal pulse energy (around 70µJ) leads to a slight broadening of the interaction region but shows strong changes in the phase index and leads to sufficient material modifications.

Based on these fundamental results the cutting of glass is investigated. For these experiments the SLM is replaced by an optic with the derived specifications. In this case, the interaction region is extend to 8mm in order to allow the processing of thicker samples. Accordingly, the pulse energy was increased to 1mJ and the sample was translated by a motorized position system.

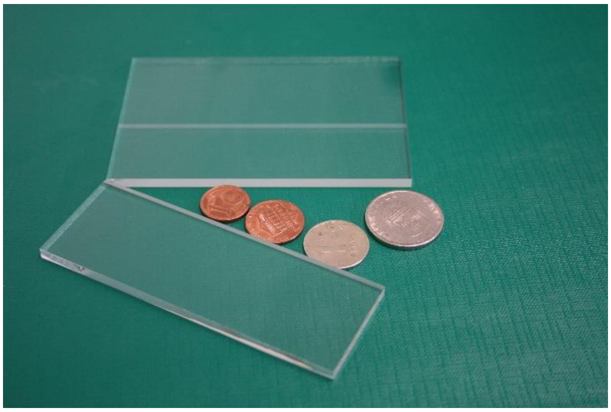

Fig.2. Glass of 4mm thickness w/ internal modifications (upper part) and after separation (lower part). Both breaking lines were processed equally in a single pass treatment.

Using these adapted laser beam characteristics we were able to induce homogeneous modifications and to process glass thicknesses of >4mm in a single pass, exemplary shown in Fig. 2.

In conclusion, we present an in-situ measuring method to analyze the laser induced plasma in transparent material. By changing the spatio-temporal pulse characteristics we obtained an optimal working regime for strong phase and material modifications. Transferring these results to an industrial working station enables the precise processing of glass sample up to 8mm.

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