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Cutting thin glasses with ultrafast lasers

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Abstract

In recent years, the non-linear interaction phenomena of ultrafast laser pulses inside transparent media have attracted many researchers and companies to develop several innovative glass-cutting applications. However, cutting of thin glasses with a thickness of about 50 μm may still be difficult or even impossible. This paper presents a novel cutting strategy that combines back and front side ablation. The bending test results demonstrate that this strategy also improves the breaking strength of the cut chips by about 20 % to above 300 MPa compared to a conventional full cut by front side ablation.

Keywords: ultrafast, laser, patterning, superhydrophobic, superhydrophilic, surfaces;

1. Introduction

In recent years, the non-linear interaction phenomena of ultrafast laser pulses inside transparent media have attracted many researchers and companies to develop several innovative glass-cutting strategies as shown by Kumkar et al. (2014). These processes are typically based on tight focusing several 10 – 100 μm below the surface. In this way, cutting of thin glasses with a thickness of about 50 μm may be difficult or even impossible. Thin glasses are due to their flexibility very attractive for bendable application. Consequently, the challenge for thin glass cutting is to achieve the highest cutting quality in order to maximize the bendability of the cut devices. In this study, a novel cutting strategy that combines back and front side ablation and improves the mechanical stability is presented.

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2. Material & Methods

The cutting experiments were performed on 50 μm thin D263 T glasses from Schott. The laser source was an ultrafast laser Spirit[®] from Spectra-Physics[®] with a pulse duration of 380 fs (FWHM), pulse energies of up to 30 μJ , and maximum average output power of 3 W that was operated at a repetition rate of 100 kHz and a wavelength of 1040 nm. The focusing optic was an f-theta lens with a focal length of 100 mm. The focus radius was determined to be $w_0 \approx 10 \mu\text{m}$ using the method of Liu (1982). A galvanometer scanner was used to scan the laser beam with a speed $v = 1 \text{ m/s}$ across the glass sheets. In this study, the number of scans and the pulse energy were varied. The cutting quality of the sidewalls were investigated using scanning electron microscopy (SEM). The flexibility of the cut chips was measured by performing a 3-point bending test on a zwickiLine material testing machine from Zwick.

3. Results & Discussion

In this study, the influence of the pulse energy and the number of scans on the cutting result was investigated. The results showed that thin glasses were cut at the front side, when the pulse was above 10.8 μJ . Interestingly, the glass sheets were cut at the backside at pulse energies between 7.5 and 10.8 μJ . Here, ablation started at the backside and suddenly jumped to the frontside after a certain number of scans N . A model to explain the underlying laser-matter interaction processes in both regimes is sketched in Fig 1.

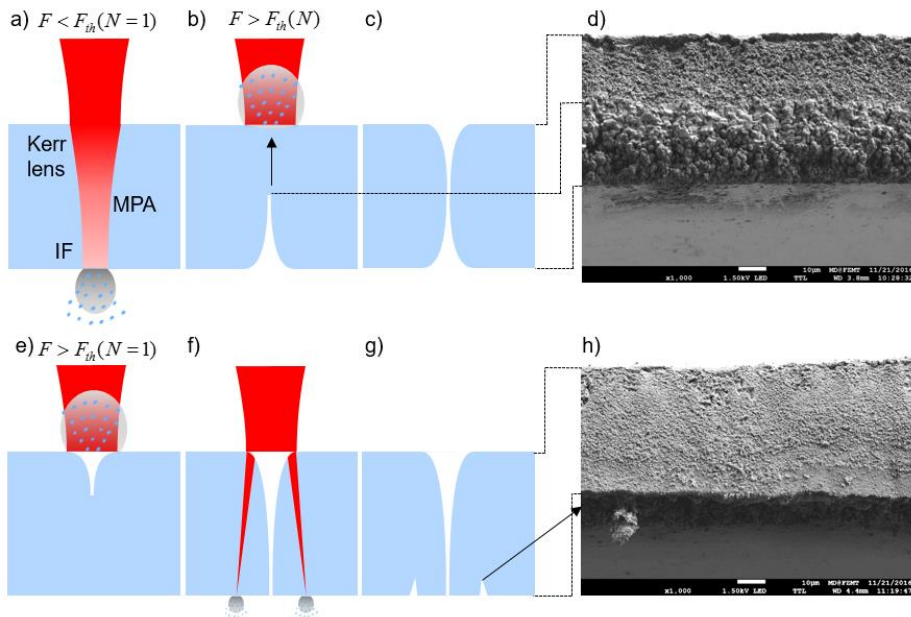


Fig. 1. Laser-matter interaction processes of an ultrashort laser pulse focused on a transparent surface at two different fluencies. a) If glass is irradiated with a fluence below the single-scan ablation threshold $F < F_{th}(N = 1)$, Kerr-lens focusing, multi-photon absorption (MPA), and interference (IF) at the backside control the intensity of the pulse inside the transparent media. In thin glasses, Kerr-lens focusing and IF increase the fluence at the backside above the ablation threshold. b) The multi-scan ablation threshold $F_{th}(N)$ decreases with every scan. When the ablation threshold fluence is reached after a certain number of scans N , ablation jumps from the back to the front side. c) and d) In this way, thin glass can be cut from both side. e) If glass is irradiated with a fluence above the single scan ablation threshold $F > F_{th}(N = 1)$, ablation occurs only at the front side. f) The cut edges act as convex lenses, focus the beam to the backside, and generate parallel scribes (g) and h)).

Fig 1 a) to c) show the case if the fluence is just below the single-scan ablation threshold $F < F_{th}$ ($N = 1$). Here, the pulses transmit through the front surface. The high intensities inside the glass then lead to Kerr-lens focusing and multi-photon absorption while the pulses propagate through the glass. As the pulses reach the backside, interference with the reflected beam enhances intensity. Both Kerr-lens focusing and interference dominate within the short propagation distance of $50 \mu\text{m}$. Thus, the fluence at the glass backside is increased even above the ablation threshold fluence. In this way, material is ablated selectively from the glass backside as sketched in Fig. 1 a). It should be noted at this point that this selectivity is not related to backside focusing, because the Rayleigh length is about $300 \mu\text{m}$, which is much larger than the glass thickness. In order to explain the switching from back to front side ablation, further phenomena must be taken into account. Every pulse hitting the back and front side decreases the ablation threshold due to incubation, as shown by Rosenfeld et al. (1999). Consequently, as soon as the multi-scan ablation threshold fluence $F_{th}(N)$ is reached at the front side, ablation switches from the back to the front side, as sketched in Fig. 1 b). The results indicated that the fluence can be selected such that $50 \mu\text{m}$ thin glass can be ablated to half the thickness before ablation jumps to the front side, as shown in Fig. 1 c) and d). In this way, thin glass sheets can be cut virtually from both sides.

The laser-matter interaction process of an ultrashort laser pulse focused on the front surface with a fluence above the single-scan ablation threshold $F > F_{th}$ ($N = 1$) is sketched in Fig 1 e) to g). Here, ablation starts immediately at the front side, as sketched in Fig. 1 e). The Gaussian beam profile leads thereby to the formation of curved edges at the front side. Sun et al. (2013) calculated that refraction of the laser beam at the curved crater edges, which act as convex lenses, induces two long spikes next to the scribe. In thin glass, the beam could be focused even to the backside of the glass and cause ablation, as sketched in Fig. 1 f). This model could explain the formation of the two trenches parallel to the cut at the glass backside (Fig. 1 g)).

The SEM images in Fig. 1 d) and g) reveal that the first strategy causes less damage to both front and backside. In order to quantify the cutting quality, $4 \times 4 \text{ mm}^2$ small chips were cut using the two strategies and the front and backside breaking strength was measured as sketched in Fig. 2 a) and b), respectively. The bending test results in Fig. 2 c) demonstrate that the both side ablation strategy improves the breaking strength of the cut chips by about 20 % to above 300 MPa compared to the conventional full cut by front side ablation. Interestingly, the backside strength was higher in both cases. Future studies should focus on optimizing the front side strength.

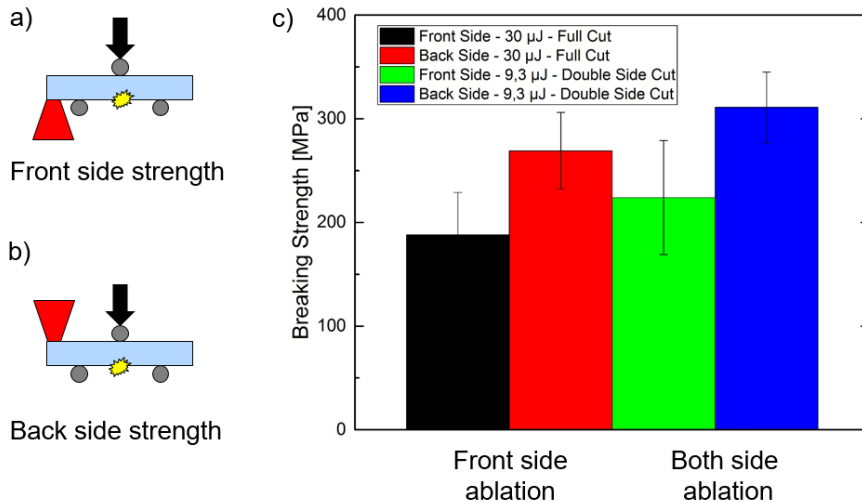


Fig. 2. Comparison of the a) front side and b) back side breaking strength achieved using front and both side ablation c).

4. Conclusion

The aim of this study was to optimize the cutting quality of thin 50 μm glasses using ultrafast lasers. The results showed that thin glasses can be cut either by front side or by a combination of back and front side ablation. SEM investigations revealed that the latter strategy causes less damage to both front and backside. The bending test results demonstrate that this strategy also improves the breaking strength of the cut chips by about 20 % to above 300 MPa compared to a conventional full cut by front side ablation. These findings suggest that ultrafast lasers could be also an interesting tool to cut thin flexible devices on glass substrates.

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