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Water film assisted picosecond laser ablation of glasses

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Abstract

Ultrashort-pulsed lasers have become a promising tool for fast and high-quality processing of glasses. Rear side drilling and crack generation in the bulk of the glass material are the two technologies promising the fastest processing of glasses. However, both suffer when optical glasses coated with laser wavelength matching mirrors are needed to be cut out into smaller-sized optical elements. This paper investigated the laser cutting experiments in SF6 glass plates in ambient air and water assisted conditions. For such task a high pulse repetition rate laser with the pulse duration of 13 ps and the radiation wavelength of 1064 nm was utilised in the experiments. Glass cutting quality and ablation rates were thoroughly investigated. Water-assisted direct glass ablation significantly improved the processing quality and ablation rates compared to the laser cuts performed in ambient air.

Keywords: water-assisted; picosecond; glass; ablation; cutting;

1. Introduction

High average laser power and high pulse repetition rate ultrashort lasers have become a promising tool for fast and high-quality cuts at optimum cost. The highest rates for the laser-based glass cutting are achieved via the rear-side drilling (Gečys et al., 2015), or glass dicing using Bessel beam (Kim et al., 2017 and Dudutis et al., 2018) approaches. However, these approaches cannot be used to cut out elements out of the glass workpieces coated with laser wavelength matching mirrors in advance to the laser cutting. In this case, the laser beam gets effectively reflected and cannot penetrate the glass material. Such small-sized glasses are widely used in compact optical systems and for cost-efficiency purposes.

The direct ablation approach (Eppelt et al., 2017 and Markauskas et al., 2018) does not have the limitation mentioned above. The high intensity focused laser beam can cut through both the glass material and reflective layers easily. Furthermore, direct laser ablation allows high-quality glass processing and cutting of complex shapes. However, the main drawback limiting its wider application in the industry is low cutting rates, especially, in the case of thicker glasses. Studies have shown that the introduced thin water layer onto

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the surface of the workpiece can significantly improve the ablation rate and processing quality of materials, such as metals, semiconductors, and dielectrics (Markauskas et al., 2018).

In this article, a high pulse repetition rate laser was used in the glass ablation and cutting experiments. Experiments were carried out in ambient air and water-assisted conditions. The use of the thin flowing water film on the workpiece surface significantly increased both the processing quality and the glass processing speeds.

2. Experimental setup

Fundamental harmonics of the picosecond laser Atlantic (1064 nm, 13 ps, 0.4-1 MHz, from Ekspla) was used in the glass ablation and cutting experiments. The experimental setup consisted of a laser, a beam expander, and several folding mirrors directing the laser beam to the galvanometer scanner (from ScanLab). The laser beam was focused with an 80 mm focal length telecentric f-theta lens into a minimal diffraction-limited spot size of 28 µm. The laser beam was focused on the top surface of the glass plate. An airbrush was used to form a thin-flowing water-film on the surface of the workpiece by spraying water mist at the inclination angle of 45 degrees. The thickness of the water film was about 200 µm. Experiments were carried out in a 0.4 mm thick SF6 glass sample.

3. Results

Glass cutting experiments were performed in ambient air and water-assisted conditions in a 0.4 mm thick glass plate. Laser pulse repetition rate was varied between 404 and 1 MHz. During the experiments, a constant average laser power of 16 and 42 W was maintained for glass cutting in ambient air and water-assisted conditions, respectively. In the case of the glass cutting in ambient air, the average laser power was reduced to 16 W in order to avoid the fracturing of the workpiece. Applied water layer improved the cooling of the material; thus, the crack formation was not observed even at the maximum investigated laser power of 42 W.

In this experiment, we concentrated on the optimisation of the glass plate cutting rate, which was investigated in terms of the laser pulse repetition rate. Fig. 1 shows the glass cutting rate dependence on the laser pulse repetition rate. Laser scanning speed and the number of laser scans were optimised individually for investigated pulse repetition rate values. Optimised laser scanning speeds are presented in Fig. 1. We found that 520 kHz was the optimal pulse repetition rate value for glass cutting in both the ambient air and water-assisted conditions.

At 520 kHz, the maximal cutting rate of 5 mm/s was achieved while scribing through the thin flowing water layer (2.5 m/s laser scanning speed, and 500 laser scans). The use of the water film improved the glass cutting rate by the factor of 10 compared to the glass cutting in ambient air (0.5 mm/s cutting rate, 3.5 mm/s laser scanning speed, and 7000 laser scans).

Fig. 2 shows the optical images of the cut edge quality versus pulse repetition rate. Ablation in ambient air at the laser pulse repetition rate of 404 kHz and 520 kHz resulted in low cut edge quality: surface chipping and crack formation were pronounced at the edge of the cut. Increasing laser pulse repetition rate to 653 kHz reduced the average width of the glass chipping from 7.4±2.7 µm to 2.3±0.8 µm. However, thermal accumulation effects became more pronounced at higher pulse repetition rates: the edge of the cut was no longer sharp but melted.

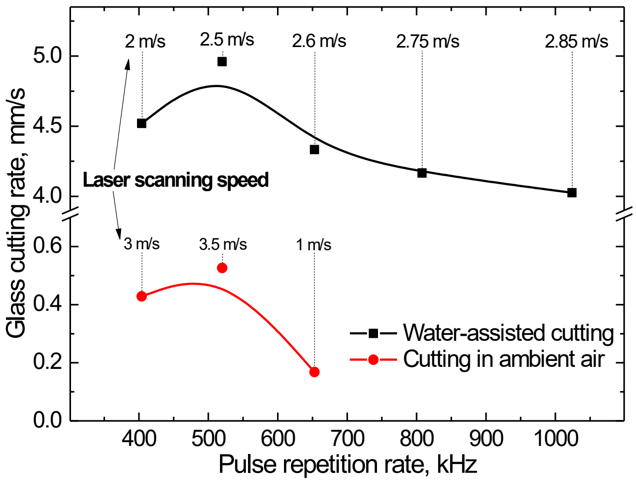

Fig. 1. Relationship between the glass cutting rate and pulse repetition rate in ambient air and water-assisted conditions. Laser scanning speed and number of scans was optimized individually for every investigated laser pulse repetition rate.

On the contrary, glass cutting in water-assisted conditions improved the cut quality. Increasing the laser pulse repetition rate from 404 kHz to 1 MHz did not have any effect on the cut quality and maintained a low surface chipping of 2.6±0.8 µm. In comparison, the rear-side drilling and glass dicing using Bessel beam approaches cannot match the quality of the direct ablation technique. Such techniques result in notably larger surface damage width, usually exceeding 60 µm (Lopez et al., 2015 and Gečys et al., 2015).

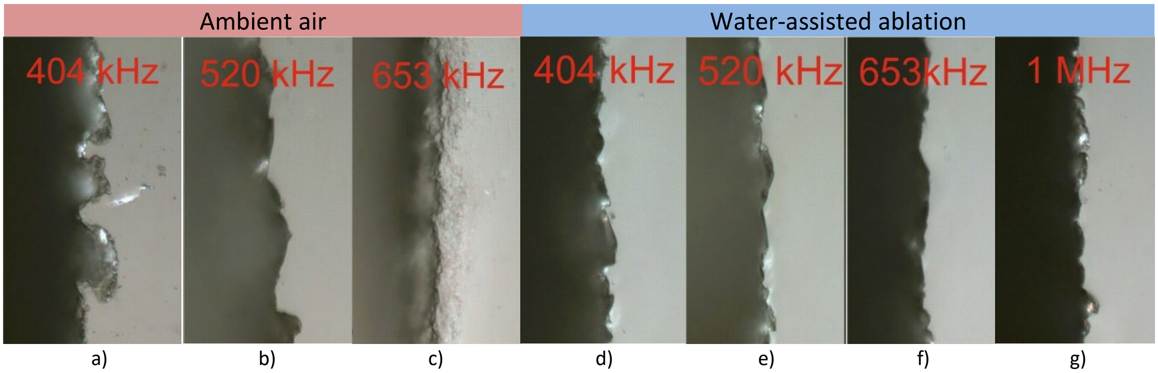

Fig. 2. Optical images of SF6 glass surface damage after glass cutting in air (a-c) and water-assisted conditions (d-g).

4. Conclusions

We have performed 0.4 mm thick SF6 glass cutting experiments with high pulse repetition rate picosecond laser. Experiments were conducted in ambient air and water-assisted conditions. Investigation revealed that the glass cutting rate could be increased from 0.5 to 5 mm/s when the direct material ablation took place through the thin flowing layer of water.

High processing quality remains the main advantage of the direct laser ablation. The average surface edge chipping of 2.6 µm was maintained for all investigated laser pulse repetition rates when the water layer was applied, which was superior to the faster glass cutting techniques, such as rear-side drilling or glass dicing using Bessel beams.

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