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Ultrafast laser micromachining with GHz-bursts

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Abstract

Micromachining with femtosecond lasers operating in the novel GHz-burst regime has recently attracted increasing attention. Indeed, very interesting results have been published on ablation and percussion drilling in this regime. In this contribution, we show our latest results for micromachining of different transparent dielectric materials. We report our latest results on top-down percussion drilling with a Gaussian beam as well as on cutting with a Bessel beam. The dependence on the burst parameters such as burst repetition rate, number of pulses per burst, and burst energy are discussed. The quality and aspect-ratios of the drilled holes will be presented. Concerning cutting with a non-diffractive beam, the surface quality of the cutting planes will be discussed in terms of roughness and straightness.

Keywords: Femtosecond laser processing; GHz-burst regime; Glasses; Drilling; Cutting; Bessel beam

1. Introduction

GHz-burst processing with ultrafast lasers has first been demonstrated by Kerse et al., 2016, for ablation of several materials showing an enhanced ablation efficiency. Since then, the advantages and disadvantages for ablation have been widely studied for different burst parameters (Förster et al., 2021). Indeed, the burst length and number of pulses within the burst have to be carefully chosen in order to profit from a beneficial accumulative regime (Mishchik et al., 2019). Our group recently demonstrated percussion drilling of dielectrics in GHz-burst mode (Balage et al., 2023 and Balage et al. 2023a) where crack-free holes with almost cylindrical shape and smooth inner walls have been obtained. In this contribution, we show some preliminary results on

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a comparison of top-down percussion drilling with a femtosecond laser in either single pulse, MHz-burst or GHz-burst regime. Moreover, we show first results on glass cutting with a Bessel beam in GHz-burst mode. All experiments were carried out using a customized Tangor 100-based laser system from Amplitude. The laser wavelength is 1030 nm, and the pulse duration is 530 fs. The laser source can be operated in single pulse, MHz-burst, or GHz-burst mode.

2. Top-down percussion drilling: comparison of single pulse, MHz-, and GHz-bursts

We first show some results of a comparative study on sodalime applying the three different operating regimes with a Gaussian beam for top-down drilling experiments. The advantage of our study is that we use exactly the same laser source for all different parameters avoiding any need of realignment or beam focusing between the different drillings. Thus, we can apply the same laser fluence but in different temporal shapes. This means that the energy is either in a single pulse, or distributed on several pulses constituting the MHz- or GHz-burst. Figure 1 shows microscope images of the drilled holes after a drilling time of 100 ms at a repetition rate of 1 kHz with an energy of 200 µJ. The energy distribution is specified in the figure caption.

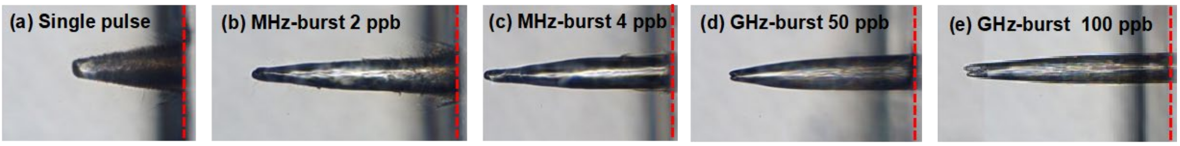

Fig. 1. Microscope images of drilled holes after 100 ms drilling time with an energy of 200 µJ distributed on (a) Single pulses; (b) MHz-bursts with 2 pulses per burst; (c) MHz-bursts with 4 pulses per burst; (d) GHz-bursts with 50 pulses per burst; (e) GHz-bursts with 100 pulses per burst.

We clearly observe a different hole morphology which is by far more tapered in the single pulse regime. The shape in MHz- and GHz-burst mode gives similar hole morphologies, but the hole quality appears to be better in the GHz-burst mode where the inner walls are clearly smoother and no cracks are visible. Moreover, for long drilling times, the holes are much deeper in the GHz-burst mode and feature very high aspect ratios (Balage et al., 2023). A comparative study for different drilling times will be subject of further investigations.

3. Bessel beam cutting with GHz-bursts and comparison with MHz-bursts

This section is dedicated to glass cutting (Nisar et al., 2013). Our approach is to combine the temporal beam shaping of the GHz-burst mode with spatial beam shaping. The Bessel beam shaping (Hermann et. al, 1991) for our cutting experiments was obtained using an axicon (Mishchik et al., 2017). We first formed a primary Bessel beam which was then imaged by a pair of lenses into a secondary Bessel beam with smaller dimensions as depicted in Fig. 2. The dimensions of the secondary Bessel beam result in a length of 1.2 mm and a diameter of around 4 µm (measured). We used samples of 1 mm-thick sodalime glass and 300 µm-thick alkali-free aluminoborosilicate glass (AF32). Thus, the Bessel beam length exceeds the sample thickness, even of the sodalime samples. The cutting process of the glasses was obtained by first creating a line of cracks within the material by the Bessel beam and subsequent singulation by applying a gentle mechanical stress by hand.

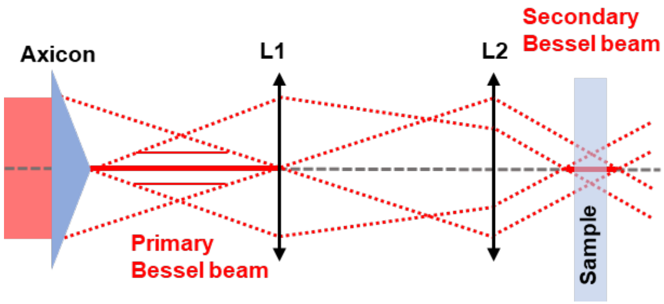

Fig. 2. Schematic drawing of the Bessel beam formation by an axicon into a primary Bessel beam with subsequent imaging into a secondary Bessel beam with smaller dimensions.

In order to quantify the quality of the cutting process, we measured the surface roughness Sa of the cutting planes with a confocal profilometer. Figure 3 shows the resulting surface roughness Sa as a function of the pitch of the consecutive Bessel beams with a total burst energy of 200 µJ in the Bessel beam in GHz-burst mode with 50 pulses per burst and, in comparison, obtained in MHz-burst mode with 4 pulses per burst for both materials. The results for sodalime correspond to the green triangles (GHz-bursts) and green dots (MHz-bursts), whereas the black triangles (GHz-bursts) and black dots (MHz-bursts) are the corresponding results for AF32, respectively. The green curve is a guide to the eye.

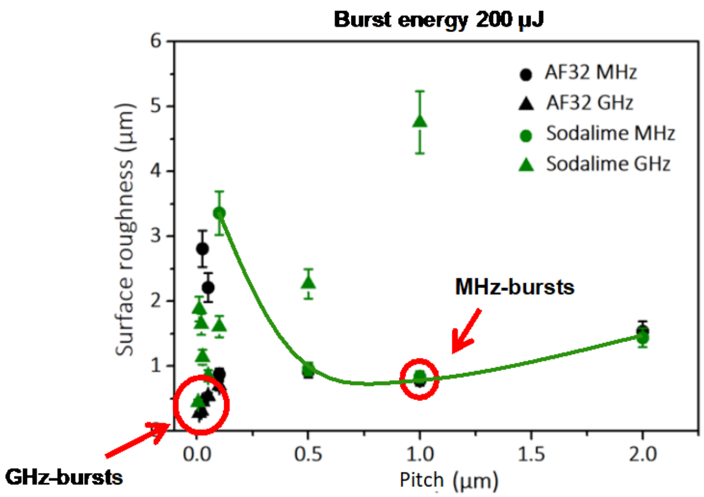

Fig. 3. Surface quality Sa as a function of the pitch in sodalime (green symbols) and AF32 (black symbols) for GHz-bursts of 50 pulses per burst (triangles) and MHz-bursts of 4 pulses per burst (dots) at 200 µJ burst energy for both regimes.

Obviously, there is an optimum pitch leading to best results of surface quality in terms of roughness. The corresponding profilometer images of the smoothest cutting planes (best results) as indicated by the red circles in Fig. 3 are shown below in Fig. 4. The corresponding pitches are 0.05 µm in GHz-burst mode and 1 µm in MHz-burst mode, respectively, for both materials.

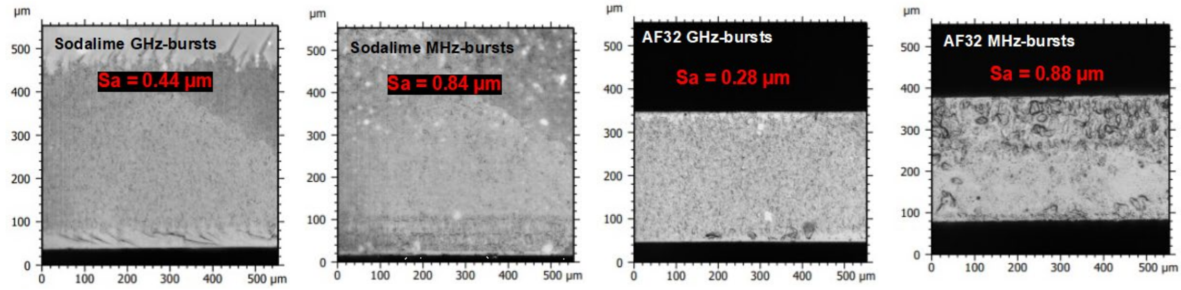

Fig. 4. Profilometer images of the cutting planes with an energy of 200 µJ in GHz-burst mode with 50 pulses per burst and in MHz-burst mode with 4 pulses per burst. The pitches are 0.05 µm in GHz-burst mode and 1 µm in MHz-burst mode, respectively. Laser comes from the bottom.

This preliminary study shows that for comparable parameters, the quality of the resulting cutting planes is better featuring a lower surface roughness Sa in GHz-burst mode than the ones obtained in MHz-burst mode for both materials. A thorough study of the best parameters in the respective burst regimes and for the determination of possible processing windows is subject of future work.

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