Long and crack-free holes in glass by top-down drilling with femtosecond laser GHz-bursts

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We demonstrate extremely long, crack-free, high-aspect ratio holes in sodalime and fused silica by top-down percussion drilling with a femtosecond laser in GHz-burst mode. By studying different laser parameters, such as burst fluence, number of bursts, or numerical aperture, we were able to optimize our approach in order to obtain aspect ratios of 30 in sodalime and 70 in fused silica. Moreover, the hole quality is excellent, especially in fused silica where the inner walls of the hole are very smooth and quasi cylindrical. In this contribution, we show percussion drilling in two different dielectrics (sodalime and fused silica) with femtosecond laser GHz-bursts and investigate the drilling process by studying the evolution of the hole depth as a function of the number of bursts applied on the sample. The drilling experiments were carried out using an Yb-doped femtosecond laser source (Tangor, Amplitude) delivering 530-fs pulses and up to 100 W average power at 1030 nm that can be used in single-pulse or in GHz-burst mode. The drilling time (and therefore the number of bursts applied) was investigated in the range from 1 ms (1 burst) to 20 s (20 000 bursts). The resulting holes are displayed in Fig. 1a) for drilling times increasing from the left to the right ranging from 2 s to 10 s by steps of 1 s in sodalime for a burst fluence of 172 J/cm².

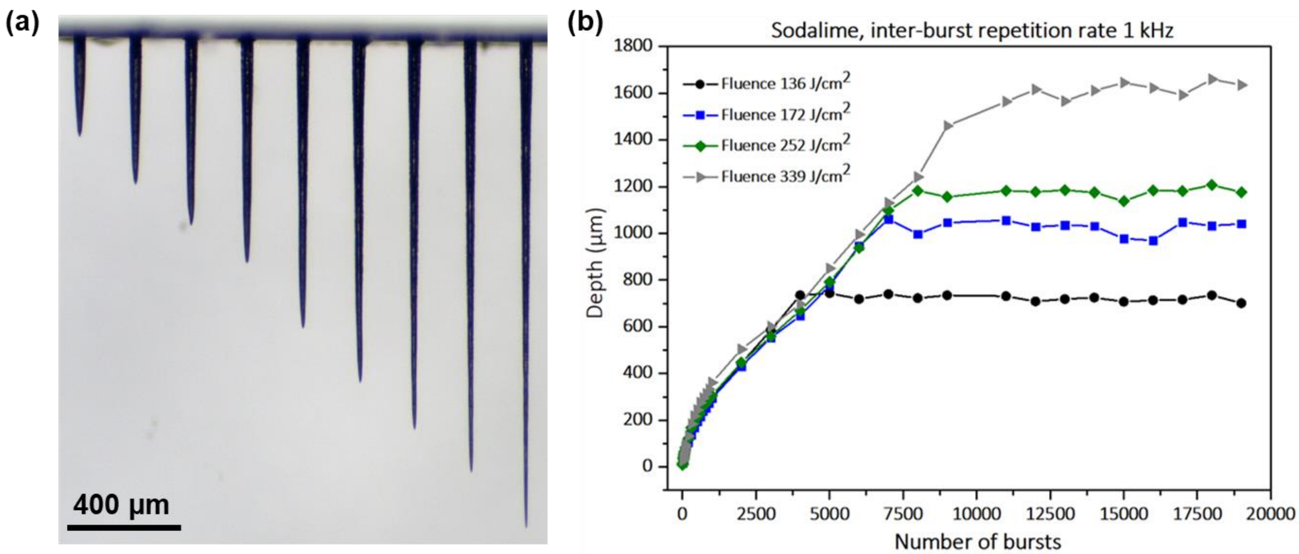

Fig. 1. Microscope images of the holes drilled for drilling times between 2 s and 10 s in sodalime with a burst fluence of 172 J/cm² (a). Evolution of the depth as a function of the number of bursts applied in sodalime for different burst fluences.

Figure 1(a) displays a microscope image of very high-quality holes with smooth inner walls and cylindrical shape. The study of the evolution of the depth as a function of the number of bursts sent to the sample (Figure 1 (b)) led us to discover the different drilling stages that occur during the process. Indeed, with a closer look on the graphs, we can distinguish three linear evolutions of the depth. The very first one, for low burst number, corresponds to the surface ablation. The plume of ablated matter can expand freely and the drilling speed is high. Then, the plume will start to interact with the walls and will become denser resulting in a shielding effect which leads to a lower speed. Then the final stage, the drilling stops for a lack of energy reaching the bottom of the hole. Similar results and comparable depths were obtained in fused silica despite the higher ablation threshold. The latter observation can be explained by the quality of the inner walls, which appear crackled in sodalime, reducing the reflection coefficient leading to higher energy losses towards the tip of the hole.