Femtosecond laser pulses with GHz bursts in MHz burst for ablation enhancement circumventing air ionization

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Ultrashort laser pulses are extending in an increasing variety of applications as a high precision microfabrication technique owing to the great confinement of the processing within the irradiated zone. This enables handling a broad extent of materials with little heat diffusion, ensuring precise material ablation. However, ultrashort pulsed lasers face serious challenges for attaining high-throughput material removal. The use of higher laser powers for increasing ablation rates can lead to detrimental effects due to heat accumulation and air ionization. Recently, GHz burst mode laser ablation has been proposed to overcome these limitations thanks to ablation cooling [1]. Bursts of ultrafast laser pulses contribute to material ablation before the residual heat generated by preceding pulses diffuses away from the irradiated region. In addition, reduction of the pulse energy needed for material ablation is also observed. Owing to that, increased ablation efficiencies have been reported [2]. Following this approach, we study the influence of different configurations of the burst mode on ablation of crystalline silicon samples. To this end, multiple bursts (2-5 bursts) at a repetition rate of 64 MHz, each containing various pulses (2-25 pulses) at an ultrafast repetition rate of 5 GHz, were focused onto the sample surface. Results shown in Figure 1 give evidence of the distinct outcomes in ablation among the different burst mode configurations in contrast to single shot ablation. Specifically, the distribution of the total delivered energy in the burst mode allows not to induce air breakdown by the high intensity of single-mode, resulting in better surface smoothness of the ablated area and an increased ablated volume. Thanks to that, the ablated volume increased from 82 μm^3 with a depth of 2.9 μm for single shot ablation to 90 μm^3 with 4.0 μm depth for burst mode (5 bursts with 25 intrapulses) even at the same total accumulated energy.

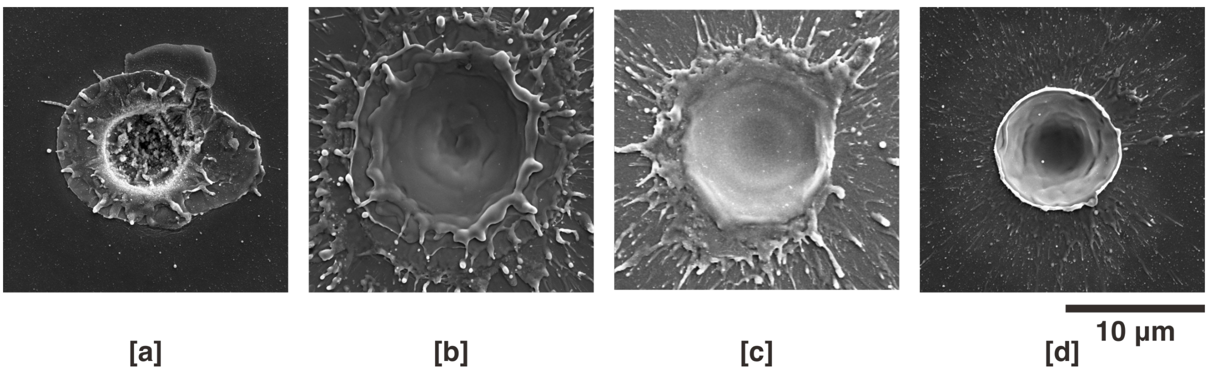

Figure 1 Scanning electron microscope images of the ablated spots on the surface of crystalline silicon samples processed by 1030 nm femtosecond laser pulses in air. Each image corresponds to the following configurations for burst mode: [a] a single shot, [b] 1 burst containing 25 pulses, [c] 2 bursts with 25 pulses per burst, and [d] 5 bursts with 25 pulses per burst. The intraburst repetition rate was 5 GHz while the interburst repetition rate was 64 MHz. Total energy delivered onto the sample was 12.9 μJ for all cases.

[1] C. Kerse et al., Ablation-cooled material removal with ultrafast bursts of pulses, Nature, vol. 537, pp. 84–88, (2016).
[2] G. Bonamis, et al, Systematic study of laser ablation with GHz bursts of femtosecond pulses, Optics Express, 28(19), 27702 (2020).