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Femtosecond laser processing with GHz long burst and second harmonic generation

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Abstract

Femtosecond pulses with bursts of GHz repetition rate can significantly improve the ablation efficiency of femtosecond lasers. Freely adjustable bursts involve thermal and non-thermal ablation mechanisms. The long GHz bursts can remove very efficiently heated matter, with non-thermal ablation leading to a high-quality material processing. We report an experimental study on crystalline silicon line scribing with GHz burst regime of femtosecond pulses at 515 nm. The number of pulses per bursts varied from 50 ppb to 200 ppb. A second harmonic generation module was placed at the output of a 100 W femtosecond GHz laser to generate up to 50W of second harmonic (SHG,515nm) at 200 kHz. The results show the highest ablation efficiency obtained on silicon with fs pulses (more than 10 mm^3/min/W), and the crucial role of the pulse overlap.

Keywords: femtosecond laser processing, GHz bursts, second harmonic generation

Recent studies have demonstrated the ability of femtosecond pulses GHz bursts to perform high quality micromachining, while the ablation efficiency is significantly improved compared to MHz repetition rate bursts. In this work, thanks to the high flexibility in the number of pulses and using a new set of parameters available, the laser allows a wide range of process optimization.

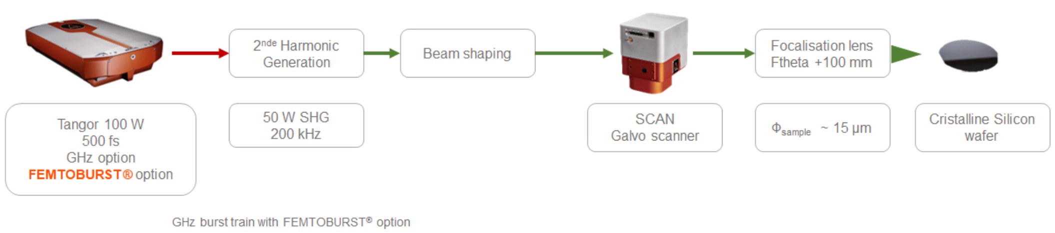

Fig. 1. Schematic representation of the laser system used for GHz ablation at 515 nm.

With the GHz oscillator used, delivering adjustable bursts from tens to thousands of femtosecond pulses with sub-nanosecond period for burst pulses and a total burst duration of tens of nanoseconds to millisecond, the specific GHz interaction mechanisms, very different from standard MHz repetition rate, are studied. In case of long GHz burst, an efficient thermal ablation occurs after a heating phase. Since the individual pulse energy is lower than the ablation threshold, the first individual pulses participate to heat the material up to an efficient thermal ablation of heated material. Then the following pulses can remove very efficiently the remaining heated matter, with non-thermal ablation leading to high-quality material processing.

This experimental study reports single burst ablation results on crystalline silicon. The intra-burst repetition rate was fixed at 1.28 GHz, and the number of pulses per burst (ppb) were set to 50 ppb, 100 ppb and 200 ppb. A second harmonic generation (SHG, 515 nm) of a 100 W femtosecond GHz laser is used (Tangor 100W) to generate up to 50 W of SHG at 200 kHz. The results show ablation efficiencies never achieved before in femtosecond ablation, passing from a maximum efficiency of 2.5 mm^3/min/W obtained with a 1030 nm wavelength, to more than 10 mm^3/min/W obtained with a 515 nm wavelength (see Fig. 2). The consequence of this increase in ablation efficiency is a better machining quality as also shown in the figure below. As already highlighted in our previous results, one of the keys to optimizing process parameters is the use of pulses overlap near 40%, rather than 70%, usually used in single pulse femtosecond cutting.

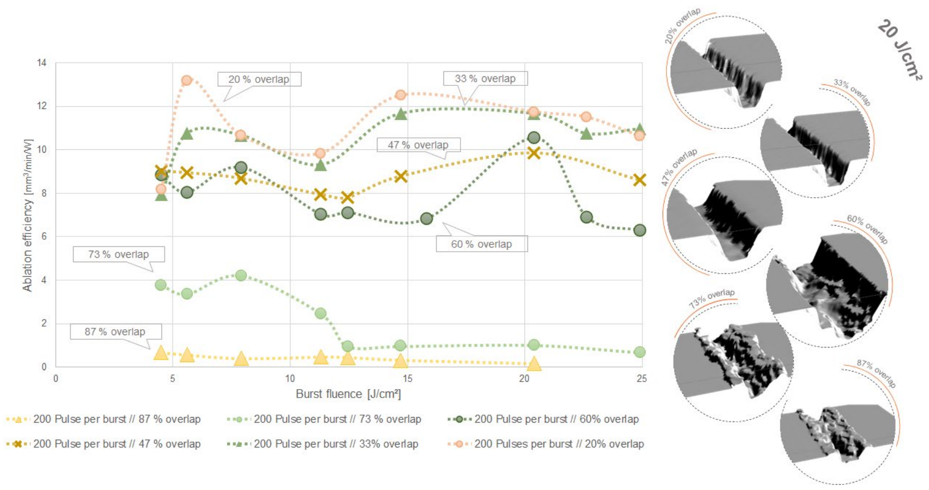

Fig. 2. Line scribing obtained with 515 nm GHz bursts on silicon. The effect of the pulse overlap is shown both on the ablation efficiency and on the scribing quality.

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