Femtosecond GHz/MHz BiBurst pulses can greatly enhance silicon ablation efficiency

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Scientists working on laser application at the RIKEN Center for Advanced Photonics (RAP) have developed a new technique using GHz bursts of femtosecond laser pulses grouped in MHz envelopes, termed BiBurst mode, for high-efficiency and high-quality ablation of silicon. Published in the International Journal of Extreme Manufacturing (IJEM), the team led by the researchers from the Advanced Laser Processing Research Team employed the BiBurst mode of femtosecond lasers to improve the ablation efficiency and quality as compared with the conventional femtosecond laser processing (single-pulse mode).

The team has demonstrated that the BiBurst mode can ablate silicon at a volume rate 4.5 times faster than the single-pulse mode with better ablation quality when delivering the same amount of total laser energy used in the process. Furthermore, the BiBurst mode achieves the highest ablation efficiency at higher total energy as compared with the GHz laser pulses, providing the capability of deeper drilling with larger volumes. The findings could have great impact both on fundamental research and industrial applications.

The team propose the absorption of the subsequent pulses at the absorption sites (transient incubations) generated by the preceding pulses in the GHz burst pulses as the possible mechanism for the increased ablation efficiency. Further understanding of the laser-matter interactions occurring during the GHz-burst and BiBurst-mode laser ablation would be of great interest for researchers working in the field of laser materials processing.

Meanwhile, laser ablation with femtosecond laser pulses has made high-performance microfabrication possible in terms of precision and quality. Thus, femtosecond lasers are being widely used for commercial applications, including micromachining, trimming, scribining, dicing, and defect repair. Improving throughput is urgently demanded to further accelerate their commercialization and industrial applications. One can imagine that throughput can be easily increased by increasing the intensity and/or repetition rate of laser pulses.

However, higher intensities suffer from plasma shielding, reducing the ablation efficiency and often inducing thermal damage due to the deposition of excessive laser energy. A repetition rate higher than several hundred kHz induces heat accumulation and produces large heat-affected zones, which is not suitable for high precision or high-quality microfabrication.

The findings will overcome these issues and thereby accelerate the adoption of femtosecond lasers for commercial applications. This achievement opens a path for processing of other materials that might show similar laser-matter
interaction behaviors.

Corresponding author Dr. Koji Sugioka says that "GHz/MHz BiBurst mode processing involves various parameters, such as the number, duration, and energy of intra-pulses as well as the time interval of each intra-pulse. Additionally, the different energy distributions of intra-pulses in the bursts (e.g., gradually increased, gradually decreased, or mountain-shaped distribution of intra-pulse energy) should provide different results even for the same burst energy."

"The research on GHz/MHz BiBurst mode processing is still in its infancy, and the accumulation of a massive amount of data with different parameters and materials is necessary. A theoretical approach based on theories in physics is also important; although, the huge amount of processing parameters imposes many challenges."

"Another key factor for commercialization is the development of a high-performance laser system which can easily, flexibly adjust parameters in the GHz/MHz BiBurst. Meanwhile, GHz/MHz BiBurst may offer a new possibility for processing other than ablation. In particular, the capability of gentle heating and melting in a controlled manner will be effective for processing based on thermal reactions, such as microbonding, crystallization, and polishing."

"Applying to the processing specific to femtosecond lasers, including two-photon polymerization, internal optical waveguide writing, and the formation of high spatial frequency laser induced periodic structures (HSFL), could produce distinct features. Thus, I believe that GHz burst mode will open up a new area for femtosecond laser processing."

"However, femtosecond laser interactions with materials are not linear and isolated. There are many complicated phenomena interlinked, including spatially and temporally multiscale and multi-physical processes. It is a very challenging task to tackle mechanisms in the GHz/MHz BiBurst mode processing due to the complexity of the physics and tremendous number of parameters involved."

"Dr. Sugioka's team has made a very good case on how to study this process, elegantly navigated through the jungle of process parameters, and laid a solid foundation on how to further improve the femtosecond laser processing based on the GHz/MHz BiBurst mode."


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Editor-in-Chief Professor Yongfeng Lu commented that "Femtosecond lasers have become essential tools in many areas of advanced manufacturing, such as cellphone production, solar cell fabrication, and manufacturing of advanced electronics."

"Nevertheless, the productivity of laser-based manufacturing is still constrained by the fact that