# Ultrafast micromachining of Cu and Si at ultra-high repetition rates with pulse bursts


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### Abstract

**We report a novel ultrafast burst mode fiber laser system, which can deliver pulses at ultra-high repetition rates in order to systematically investigate micromachining efficiency on copper and silicon samples.**


## I. INTRODUCTION

The use of pulsed lasers has stimulated a growing interest in micromachining of different materials. Pulsed laser ablation is a well-known technique for micro-processing of materials. The mechanism of laser-material interaction for picosecond and femtosecond regime is quite different as compared to continuous wave and even nanosecond lasers. In ultra-short pulse interaction with material the pulse width is less then electron-lattice thermalization time (which is in the order of few ps for most of the metals). This feature drives the material into an extremely excited state followed by rapid quenching which leads to a material blow of composed of fast ions, atoms, clusters and nano-fragments of the ablated material before sufficient thermal diffusion takes place. This ablation regime brings many advantages for material processing such as reduction of heat affected zone and minimum collateral damage. Efficiency of material processing in ultrafast regime increases dramatically with repetition rate of the pulses, if the conditions are adjusted correctly to avoid excessive plasma and particulate shielding [1]. However, given that there is a minimum pulse energy requirement, continuous operation at high repetition rates can be detrimental due to too much average power leading to heat accumulation. Burst-mode operation of lasers, wherein the amplifier periodically produces a group of pulses avoids this problem. Ultrafast burst-mode lasers are typically limited to several 100 MHz intra-burst repetition rates. Although this is sufficient for most of the materials, metals with high thermal conductivity might require higher repetition rates.

Here, we demonstrate an all-fiber Yb burst mode laser amplifier system in order to systematically investigate the ablation efficiency at very high repetition rates, previously unexplored regime, with an in-burst repetition rate of 1728, 864, 432, 216 and 108 MHz; which is optimized for low burst repetition rate.

## II. MATERIALS AND METHODS

The system is able to produce down to 20-ns long bursts with a total energy of 175 - 210 µJ at a burst repetition rate of 1 kHz, and the individual pulses are compressed down to the sub-picosecond level. The seed signal from a 108 MHz fiber oscillator is converted up to 1728 MHz as multiples of 108 MHz by a multiplier consisting of at five cascaded 50/50 couplers, and then amplified in nine stages (Fig. 1).

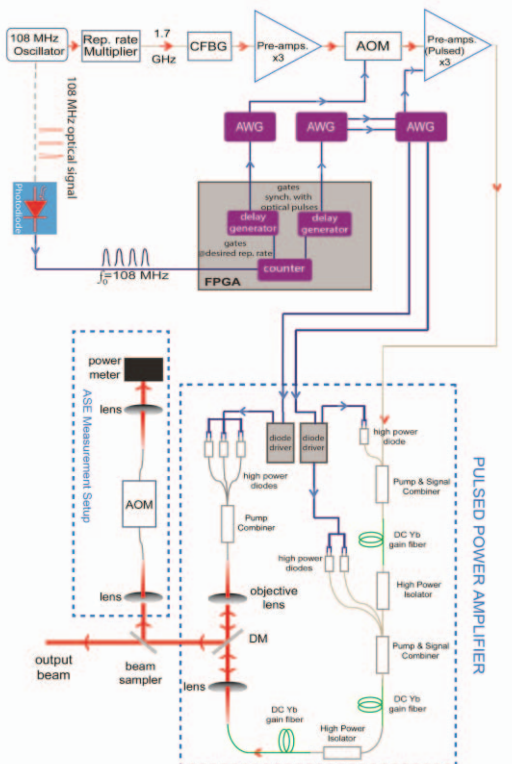


Fig. 1 – Functional diagram of the laser system

The highly cascaded amplification aims to suppress ASE at low repetition rate. Pulsed pumping synchronized with the seed by an FPGA-based electronic system is employed in the six latter amplifier stages. Pump pulses are optimized to obtain the highest

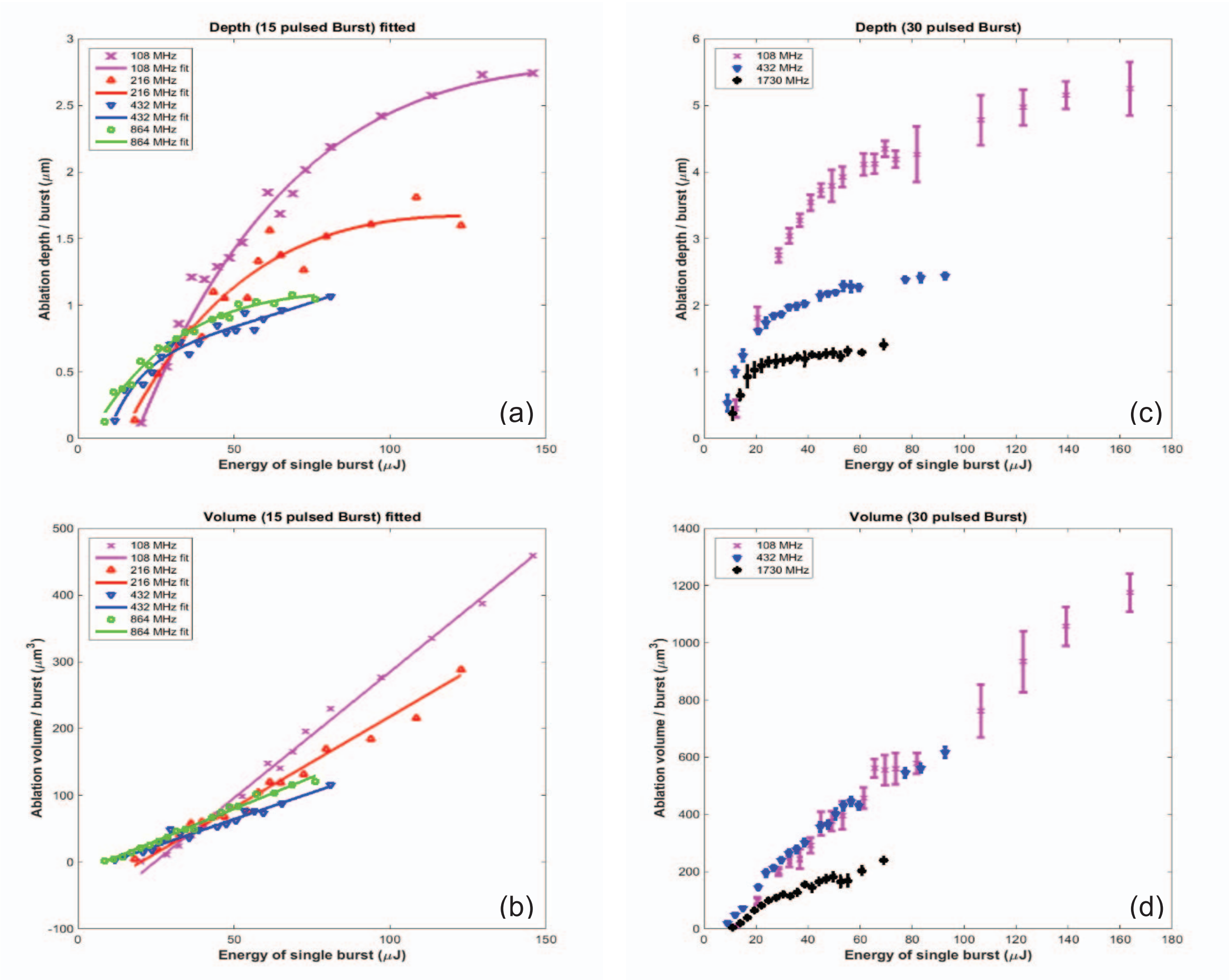


Fig. 2 – Ablation volume and depth vs. burst energy for several in-burst repetition rates. (a) Ablation depth/burst for copper. (b) Ablation volume/burst for copper. (c) Ablation depth/burst for silicon. (d) Ablation volume/burst for silicon

signal-to-ASE ratio, while ASE is monitored closely at the output of the system. At 1 kHz burst repetition rate the ASE ratio for 30 pulsed burst operation is between 25% and 10% for 1728 MHz and 108 MHz respectively. The amplified bursts contain about 15 - 35 pulses of 5 µJ average and 8 µJ maximum individual energy. Previously, we have observed significant increases of efficiency with in-burst rates of 100 and 500 MHz compared to the uniform repetition rate [2].

## III. RESULTS

Fig.2 shows ablation depth and volume per burst energy (bursts constituting ~15 pulses for copper and ~30 pulses for silicon) for different pulse repetition rates inside a burst. Ablation volume and depth seem to increase below 35 µJ/burst (~2 µJ/pulse) as repetition rate increases, for copper samples. However, as repetition rate increases, the volume and depth of ablation decreases for silicon samples.

## IV. CONCLUSION

In conclusion, we built a custom burst mode fiber laser system, which is optimized for material processing at ultra-high repetition rates. In addition, we present, to our knowledge, the first investigation of this unexplored regime. We will continue our investigations on the mechanism of ablation in this regime.


## V. ACKNOWLEDGMENT

Can Kerse acknowledges full Ph.D. scholarship from TÜBITAK BIDEB 2211.


## VI. REFERENCES


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