Polycrystalline Diamond Machining with Femtosecond Bursts

MKS | Spectra-Physics®

Industrial use of femtosecond (fs) lasers for micromachining is increasing significantly, and the true potential of fs lasers is becoming evident. Today fs lasers are used for a wide range of applications including cutting and drilling of flat panel display glasses and films, cutting of implantable medical devices, ablation and scribing of solar cells, and surface structuring of various materials. Along with the drive to extremely high-quality processing, high process throughput is increasingly necessary, and as a result, there is a need for high power, shorter duration pulse rate femtosecond lasers with state-of-the art features. Today, fs lasers with output powers of >100 W at repetition rates of up to 10 MHz are available in the market.

When extremely high-quality machining is required, high power fs laser ablation has become a useful alternative to conventional non-laser processes such as milling, grinding and electric discharge machining. However, the work of Neuenschwander et.al., has shown that there exists an optimal fluence for efficiently removing material and thereby lowering the thermal damage to the surrounding material. They have shown that this optimal fluence is ~ e^2 times the threshold fluence, which for most of the materials is ~ 1 J/cm^2. Taking this into account means high energy pulses can be efficiently used only by increasing the spot size and/or splitting the pulses into many pulses of smaller energy (burst pulses) or by increasing the number of spots (for parallel processing).

The Spectra-Physics® Spirit® 1030–100 laser (Fig. 1) delivers pulse energy of >100 μJ and average power of >100 W at wavelength of 1030 nm and <400 fs pulse duration, with burst mode operation capability.

Figure 1
Spectra-Physics® Spirit® high energy industrial femtosecond laser.

In burst mode operation, each pulse can be split into several pulses, and the burst envelop can be shaped i.e., the amplitude of each pulse within the burst envelop can be varied. Fig. 2(a) shows burst pulses from a Spirit 1030-100 laser where the amplitude of the 5th pulse within the burst envelope is set to 0% and Fig. 2(b) shows an example of burst shaping.

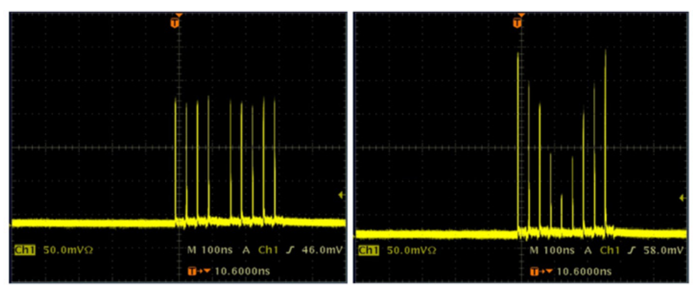

Figure 2
(a) shows burst pulses from a Spirit 1030-100 laser where the amplitude of the 5th pulse within the burst envelop is set to 0% and Fig. 2(b) shows an example of burst shaping.

To investigate the effect of burst mode operation, we characterized the ablation rates and ablation efficiency in polycrystalline diamond (PCD), an ultrahard material, for a range of burst outputs from the Spirit 1030-100 laser. The experiment consisted of pocket milling volumetric regions in PCD, measuring the depth of the milled pockets and determining volume ablation rates and efficiencies. Variables included the number of pulses in the burst envelope and the average power (average pulse energy). The repetition rate was fixed to 1 MHz, and the spot size and scanning speed were kept constant with a pulse-to-pulse overlap of 50%. Fig. 3 shows the resulting dependence of volumetric ablation rate on the average power for single pulse, 5-pulse burst and 9-pulse burst operation. The plot shows that at increasing power levels, burst mode operation results in enhanced ablation rates as would be needed to maintain an optimal fluence. At an average power of 100 W, we observe a 2-fold increase in ablation rate with a 9-pulse burst over that for a single pulse. Normalizing for average power, Fig. 4 shows the ablation efficiency versus average power for single pulse, 5-pulse burst and 9-pulse burst operation. It can be seen that optimal ablation rates can be obtained at high average powers by increasing the number of pulses within the burst envelop. Results of the tests demonstrate the advantage of burst machining for enhancing material removal rates.

In summary, the Spectra-Physics Spirit 1030-100 laser features a simple but powerful capability of tailoring pulse intensity in the time domain, and this approach has been proven to enable 2-fold enhancement of material removal rates in PCD.

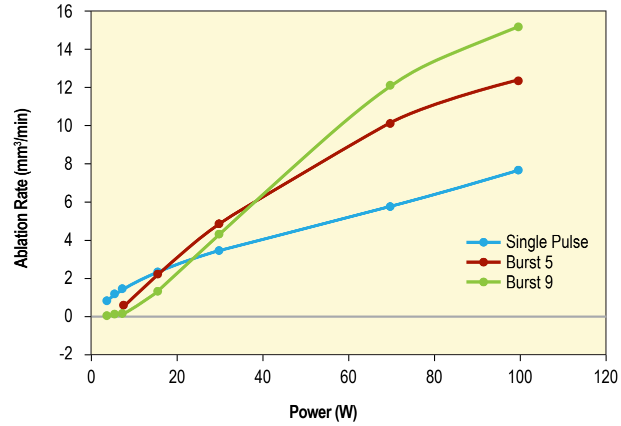

Figure 3
Volumetric ablation rate in PCD vs. average power, for single pulse, 5-pulse burst and 9-pulse burst operation.

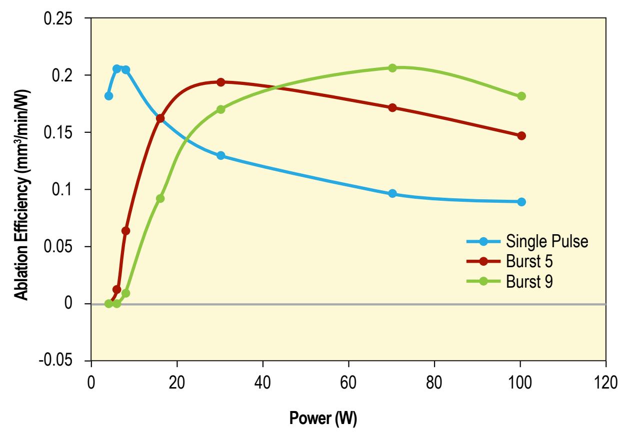

Figure 4
Ablation efficiency in PCD vs. average power for single pulse, 5-pulse burst and 9-pulse burst operation.

PRODUCT: *SPIRIT® 1030-100, 1030-70 AND 515-50*

The Spirit 1030-100, 1030-70 and 515-50 lasers set new standards for femtosecond lasers in high-precision industrial manufacturing. These lasers deliver high average power, high pulse energy, and high repetition rates for increased throughput. Customers benefit from the shortest industrially available pulse duration and superior beam quality that in turn enables machining complex and challenging parts with highest precision and quality with literally no heat affected zone (HAZ) at the highest throughput. Spirit 1030-100, 1030-70 and 515-50 are designed for industrial use and offer reliable and robust 24/7 operation with lowest cost of ownership.

	Spirit 1030-100	Spirit 1030-70	Spirit 515-50
Output Characteristics			
Wavelength	1030 nm ±5 nm		515 nm ±3 nm
Output Power	>100 W	>70 W	>50 W
Pulse Energy	>100 µJ	>70 µJ	>50 µJ
Repetition Rates	1–30 MHz		
Pulse Selection	Single shot to 2 MHz using Integrated Pulse Picker (AOM)		
Pulse Width	<400 fs		
Power Stability	<1% rms over 100 hours		
Pulse-to-Pulse Stability	<2% rms		
Spatial Mode	TEM_{00} (M^2 <1.2)		
Beam Diameter	2.5 mm ±0.5 mm		
Beam Divergence, full angle	<1 mrad		<0.5 mrad
Burst Mode	>100 µJ/burst, up to 12 sub-pulses		N/A
Pre-Pulse Contrast Ratio	>250:1		
Polarization	Horizontal		
Cold Start Time	<30 min.		
Warm Start Time	<15 min.		

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