CMM INTERNATIONAL

COMMERCIAL MICRO MANUFACTURING

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Polycrystalline diamond machining with femtosecond bursts

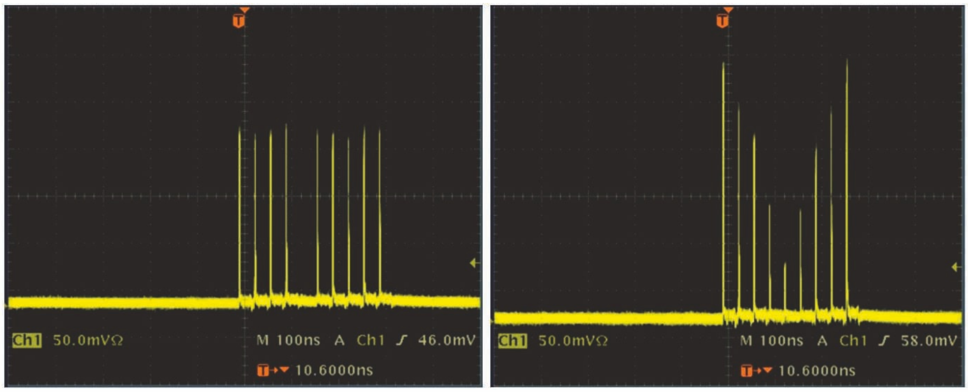
▶ ***Figure 1:*** *The Spectra-Physics Spirit high-energy industrial femtosecond laser.* ▶

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 for 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 electrical discharge machining (EDM).

"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. "

▶ ***Figure 2:*** *(a) Burst pulses from a Spirit 1030-100 laser where the amplitude of the 5th pulse within the burst envelop is set to 0 percent. (b) An example of burst shaping.* ▶



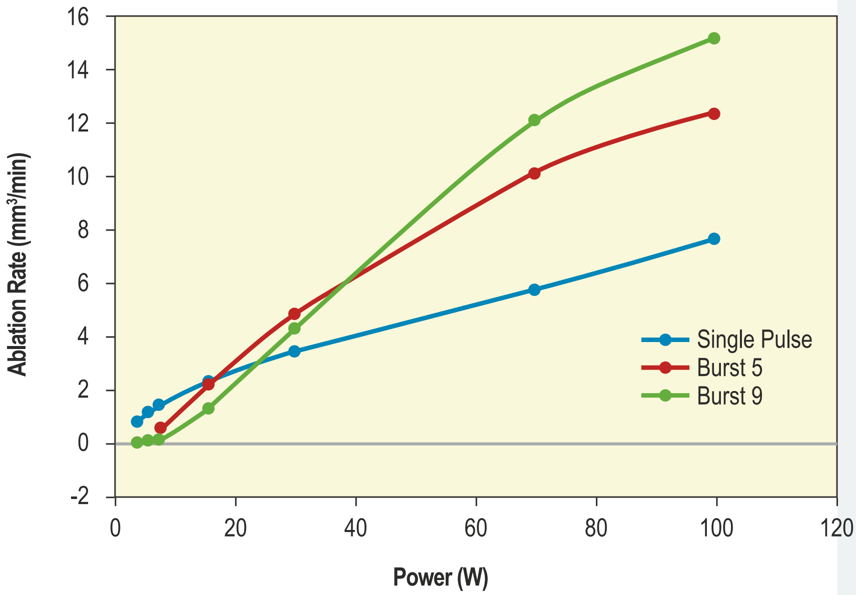
However, the work of Neuenschwander et. al. has shown that there exists an optimal fluence for efficiently removing material and thereby lowering the thermal damage to the surrounding material[1,2]. They have demonstrated that this optimal fluence is ~ e^2 times the threshold fluence, which for most 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 MKS Spectra-Physics Spirit 1030–100 high-power femtosecond laser, which is shown in figure 1, provides a wavelength of 1,030 nm ±5 nm, a power of >100 W, a pulse energy of >100 µJ and a <400 fs pulse duration, with burst mode operation capability. In burst mode operation, each pulse can be split into several pulses, and the burst envelope can be shaped, i.e. the amplitude of each pulse within the burst envelope can be varied. Figure 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 percent, and figure 2(b) shows an example of burst shaping.

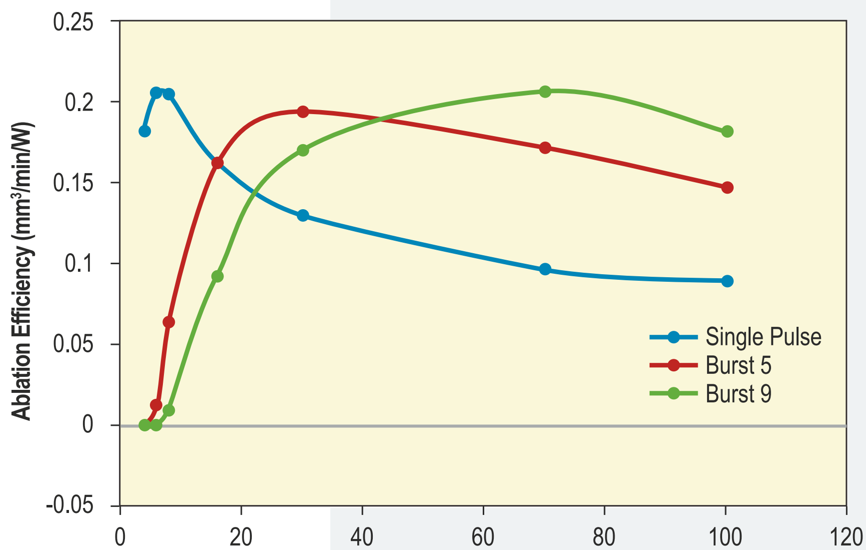
To investigate the effect of burst mode operation, MKS characterised the ablation rates and ablation efficiency in polycrystalline diamond (PCD), an ultrahard material, for a range of burst outputs from the Spirit 1030-100 laser. The experiment consisted

"The experiment consisted of pocket milling volumetric regions in PCD, measuring the depth of the milled pockets and determining volume ablation rates and efficiencies."

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 percent.



▶ ***Figure 3:*** *Volumetric ablation rate in polycrystalline diamond (PCD) versus average power for single pulse, five-pulse burst and nine-pulse burst operation.* ▶



▶ ***Figure 4:*** *Ablation efficiency in PCD versus average power for single pulse, five-pulse burst and nine-pulse burst operation.* ▶

Figure 3 shows the resulting dependence of volumetric ablation rate on the average power for single pulse, five-pulse burst and nine-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, a two-fold increase in ablation rate with a nine-pulse burst over that for a single pulse is observed. Figure 4 shows the normalised ablation efficiency versus average power for single pulse, five-pulse burst and nine-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 envelope. Results of the tests demonstrate the advantage of burst machining for enhancing material removal rate.

In summary, the Spectra-Physics Spirit 1030-100 laser has the ability to tailor pulse intensity in the time domain, and this approach has been proven to enable two-fold enhancement of material removal rates in PCD. ●

References

[1]Kramer, T., Zhang, Y., Remund, S. Jaeggi, B., Michalowski, A., Grad, L. and Neuenschwander, B. (2017). *Increasing the specific removal rate for ultra short pulsed laser-micromachining by using pulse bursts.* Journal of Laser Micro/Nanoengineering, volume 12, issue 2, pp.107–114.

Available at: https://bit.ly/3nBIF3c

[2]Beat Neuenschwander, B., Jaeggi, B., Foerster, D.J., Kramer, T. and Remund, S. (2019). *Influence of the burst mode onto the specific removal rate for metals and semiconductors.* Journal of Laser Applications, volume 31, issue 2, article no. 022203.

	Spirit 1030-140	Spirit 1030-100	Spirit 1030-70	Spirit 515-50
Wavelength	1030 nm ±5 nm			515 nm ±3 nm
Power	>140 W	>100 W	>70 W	>50 W
Pulse energy	>600 µJ	>100 MJ	>70 MJ	>50 MJ
Repetition rates	100 kHz-30 MHz	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	TEM00 (M2 <1.2)			
Beam diameter	2.5 mm ±0.5 mm			
Beam divergence, full angle	<1 mrad			<0.5 mrad
Burst mode	>600 µJ/ burst	>100 µJ/burst, up to 12 sub-pulses		N/A
Pre-pulse contrast ratio	>250:1			
Polarisation	Horizontal			
Cold start time	<30 min.			
Warm start time	<15 min.			

SPIRIT 1030-140, 1030-100, 1030-70 and 515-50 femtosecond lasers are designed for high-precision industrial machining, affording reliable and robust 24/7 operation. They deliver high average powers, high pulse energies and high repetition rates for increased throughput. Customers benefit from exceptionally short pulse duration and excellent beam quality, which enable high-precision machining of complex and challenging parts with literally no heat-affected zone (HAZ).