FEMTOSECOND PULSES COMBINE WITH PSO TECHNOLOGY FOR EXCELLENT QUALITY AND HIGH THROUGHPUT

The ability of the ultrashort pulse (USP) lasers—particularly in the femtosecond regime—to cleanly ablate materials with minimal thermal effects and debris formation makes them an ideal source for a wide range of precision applications in areas such as ophthalmic surgery, medical devices and implants, advanced microelectronics, and flat panel displays. Irrespective of the application, there is a strong demand for higher powers, shorter wavelengths, and newer techniques to increase throughput while maintaining the same excellent quality. To address this, MKS Spectra-Physics® introduced the IceFyre® FS UV50 laser, offering 50 W of femtosecond pulse output in an ultraviolet (UV) wavelength at a 1.25 MHz repetition rate.

At these elevated power levels and pulse frequencies, it can be difficult to achieve high throughput while maintaining the low heat-affected zone (HAZ) that femtosecond pulses are known for. To do this, beam scanning speeds should be as high as possible for a given trajectory, with laser pulses spaced evenly on the workpiece to assure processing uniformity. Scanning galvanometer systems are commonly used because of their extremely high acceleration as well as their ability to achieve speeds of tens of meters per second on longer, straighter segments. As shape geometries curve and/or change direction, however, scanning speeds can become much slower.

To maximize throughput with consistent machining quality, a laser source must output pulses at a controlled frequency that changes in proportion to changes in trajectory speed, all the while maintaining constant pulse energy and beam parameters. The ability to emit stable, consistent pulses that are triggered at arbitrary points in time is broadly referred to as pulse-on-demand (POD). This capability is necessary for endeavors such as controlling a laser's pulse frequency to achieve a desired location of those pulses on a moving workpiece (or from a moving beam), a technique commonly referred to as position-synchronized output (PSO). PSO requires both a motion control system to generate electrical trigger pulses at a frequency proportional to the trajectory speed and a laser source that is receptive to such a signal, delivering stable optical pulses in an "on-demand" fashion. Figure 1 illustrates the concept of PSO for the case of a trajectory comprised of lower-speed radiused corners as well as straight line segments at higher speeds.

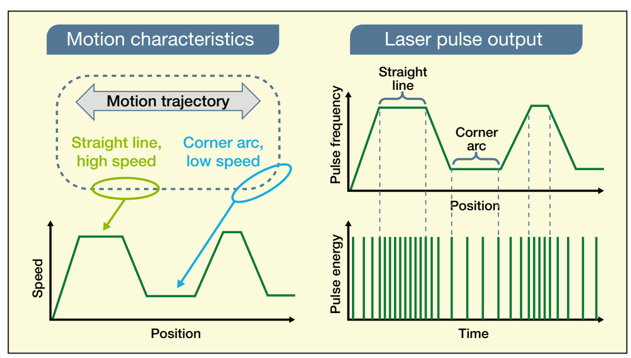

Figure 1. PSO control allows for constant spacing of constant-energy laser pulses on a material throughout a variable-speed trajectory, such as a rounded-corner rectangle.

PSO offers throughput advantages for both multi-axis linear stage motion and high-speed galvo scanner systems. With linear stages, PSO is beneficial because the speed for an entire trajectory is not limited to that of a radiused corner. For galvo processing, benefits arise because the mirrors do not have to be fully accelerated to maximum speed before laser pulses can be triggered.

On the motion control side, PSO capability is relatively mature for linear stage systems, and it has more recently been extended to galvo scanners. However, the state-of-the-art PSO-compatible laser technology has been somewhat less refined, particularly for femtosecond lasers operating at shorter wavelengths. The MOPA (master oscillator, power amplifier) architecture of traditional ultrafast lasers presents challenges to synchronizing the pulse output for PSO operation. This is due to the pulse-picking nature of the systems, in which a free-running oscillator defines a base frequency from which pulses are selected and amplified. Being tied to this fixed-frequency oscillator inevitably results in timing jitter—a variability in the temporal delay between when a pulse is requested ("triggered") and when it is emitted—which results in spatial locational error ("spatial jitter") of the pulse on the workpiece. Even with advanced techniques, such as shifting the picked pulse from the default to a neighboring pulse to best match a desired position along the trajectory, the result can be unsatisfactory. Essentially, traditional USP laser architecture allows one to have stable pulse energy with limited positional accuracy—or improved pulse placement with reduced pulse energy stability—but not both. Advances in laser technology, however, have largely overcome this problem. Alternative design architectures now allow pulse generation, amplification, and harmonic (wavelength) conversion at arbitrary frequencies, while maintaining good pulse-to-pulse energy stability and beam quality. This is a realization of the POD functionality.

The IceFyre FS UV50 laser is POD-capable, delivering pulses "on demand" with constant energy and beam parameters. To demonstrate the benefits of PSO functionality, MKS applications engineers performed a series of experiments using the laser combined with a high-speed 2-axis galvo scanning system configured for PSO operation.

Figure 2 shows microscope images of one corner of a series of 1 × 1 mm squares processed with a scan speed of 1 m/s, 5 m/s, 10 m/s, and 15 m/s, using (a) conventional free running approach, (b) skywriting technique and (c) PSO method.

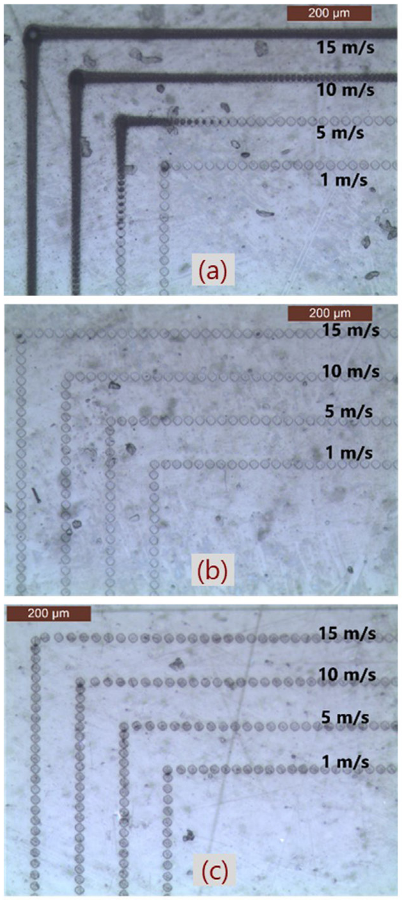

Figure 2. Microscope images showing one corner of a 1 × 1 mm square processed with a UV ultrafast laser with (a) free running, (b) skywriting and (c) PSO techniques.

With the conventional and skywriting approaches, the laser PRF (pulse repetition frequency) was adjusted for each speed to keep a constant pulse spacing of 25 µm. For PSO, the control software was programmed to maintain a pulse spacing of 25 µm and consistent pulse energy on the material throughout the trajectory, regardless of the actual speed.

The results are summarized as follows:

- Figure 2(a): shows that with the free-running approach, the spots are more densely spaced at the corners where the scanner mirrors are accelerating and decelerating. Hence, processing with this technique will result in non-uniform spot spacing and, therefore thermal effects and poor processing quality. For many applications, the corner quality would simply be unacceptable, and the process would have to be executed at a reduced scan speed of ~1 m/s—well below the laser and scanner capabilities.
- Figure 2(b): shows a result generated using the skywriting technique, which is acceptable from a quality standpoint. With skywriting, however, the trajectory segments are preceded and appended by lead-in and lead-out motion segments with the laser gated off until the target speed is attained. Accordingly, this entails additional time to complete the trajectory and therefore reduces throughput, though the uniformity of spot spacing and hence the overall quality goal is achieved.
- Figure 2(c): Finally, with the implementation of PSO, the spot spacing, and constant pulse energy are maintained at all speeds, resulting in excellent quality and highest possible throughput.

High-quality engraving of metal is an application that USP lasers are well known for. However, PSO capability is required if one wishes to achieve best quality and throughput with today's high-power laser sources. To demonstrate this, 1 × 1 mm^2 squares were engraved in stainless steel with a galvo scanner operating at 7.5 m/s and using the three processing techniques described above (free running, skywriting, and PSO). The parameters were adjusted to have both a spot-tospot and cross-hatch line overlap of 50%. Analysis of the laser-milled features was performed with 3D confocal microscopy and the results are shown in Figure 3.

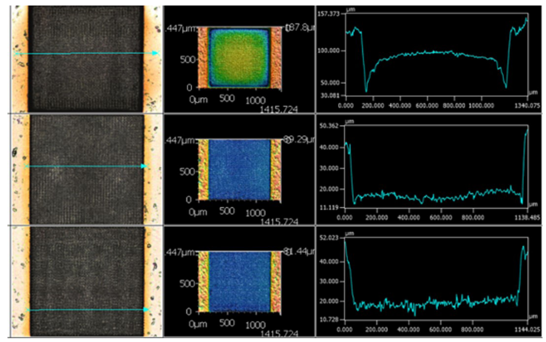

Figure 3. 3D confocal imagery and analysis of stainless steel engraving when using free running (top), skywriting (middle), and PSO (bottom) techniques.

With a conventional free-running technique, the edges of the pattern are overly engraved due to the high overlap during the repeated acceleration and deceleration phases of the scanner motion. The results with skywriting and speed-dependent trigger techniques show similar quality. However, the processing speed with PSO is significantly faster (>40%) than with skywriting, demonstrating a clear advantage with the technique.

Higher laser power naturally leads to higher processing throughputs, but the supporting equipment must be up to the task. With high-speed galvo scanners and precision motion stages, the capabilities are in place for precise spatiotemporal synchronization of laser pulses with the trajectories used to process a workpiece. The excellent machining quality made possible by the UV wavelength and femtosecond pulse width of the IceFyre FS UV50 laser can also be achieved with maximum throughput when combined with advanced PSO pulse control technology.

PRODUCT

Product: IceFyre FS UV50 and IR200 Lasers

IceFyre FS UV50 is the highest-performing UV femtosecond laser on the market, providing >50 W of UV output power, >50 µJ pulse energy, and pulse widths of 200 W) and high pulse energy (>200 µJ) with a wide repetition-rate range from a single shot to 50 MHz in the infrared. High average power (>200 W) and high pulse energy (>200 µJ) combined with high repetition rates up to 50 MHz push femtosecond micromachining applications to the highest levels of throughput at the lowest cost-of-ownership.

The IceFyre FS platform delivers exceptional versatility for optimal process performance. It offers flexible burstmode operation with adjustable repetition rates, pulseon-demand (POD) and position-synchronized output (PSO) triggering, and TimeShift™ programmable pulse capability for flexible burst-mode operation.

Building on MKS' deep experience and technology, the patent-pending IceFyre FS lasers pass extensive environmental qualification testing to ensure high reliability and a low cost-of-ownership. Fully automated and computer controlled, the laser exhibits exceptional stability in power, beam parameters, and beam pointing during 24/7 operation to deliver high precision and reproducibility for demanding applications.

	IceFyre FS UV50	IceFyre FS IR200
Wavelength	343 ±2 nm	1030 ±6 nm
Power	>50 W @ 1 MHz and 1.25 MHz	>200 W @ 1-50 MHz
Maximum Pulse Energy	>50 µJ @ 1 MHz	>200 µJ @ 1 MHz
Repetition Rate Range	Single shot to 3 MHz	Single shot to 50 MHz
Pulse Width, FWHM	<500 fs	
Pulse-to-Pulse Energy Stability	<2% rms	
Power Stability (after warm-up)	<1% rms over 8 hours	
Spatial Mode	TEM_{00} (M^2 <1.3)	
Polarization	>100:1, vertical	
Beam Diameter at Exit	5.0 mm ±0.5 mm	
Beam Divergence, full angle	<0.20 mrad	<1.0 mrad

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