COPPER MICROMACHINING ENHANCED BY PROGRAMMABLE UV NANOSECOND PULSES

As the demand for smaller, higher-precision products increases – in everything from medical devices to advanced microelectronics – lasers have become ever more indispensable manufacturing tools. Ultrashort pulse (USP) lasers – having pulse widths in the picosecond and femtosecond regime – are increasingly employed for the most demanding microprocessing tasks. This is because they can achieve the highest levels of precision and quality.

However, USP lasers are not a universal solution. In particular, they present some practical limitations in terms of achieving high throughputs at low overall cost. Alternatively, nanosecond (ns) pulsed lasers offer a more mature technology, with generally higher ablation rates, lower cost, better reliability, and easier implementation. While they primarily remove material through thermal ablation – hence limiting their ability to perform highest-precision processing – the use of ultraviolet (UV) wavelengths and shorter, single-digit ns pulse widths can counteract this.

MKS' Spectra-Physics® has developed a ns pulse laser – the Talon® Ace™ UV100 – which delivers 100 W of UV power for high throughput and generates pulse widths as short as 2 ns at high pulse repetition frequencies (PRF) for high-speed precision micromachining. A key feature of the Talon Ace is its innovative TimeShift™ programmable pulse capability, producing pulse widths from 2 to 50 ns and enabling tailored outputs like shaped pulses and pulse bursts. This provides a level of performance that empowers it for applications previously inaccessible to conventional Q-switched ns pulse lasers.

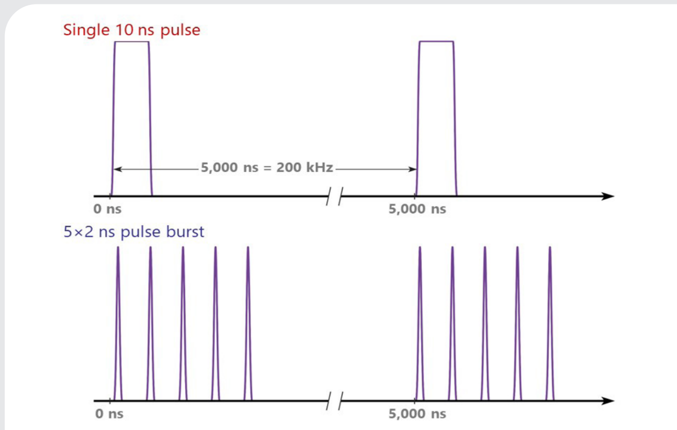

Figure 1. In burst mode, the laser emits a short series of pulses (burst sub-pulses) rather than an individual pulse. Each pulse burst can have nearly the same total energy as a single (longer) pulse at that same repetition rate.

Figure 1 illustrates the Talon Ace's TimeShift burst output capability, showing a 5×2 ns burst compared with a single 10 ns pulse, both at an output pulse (or burst) PRF of 200 kHz. In each case, the sum "laser-on" time is ~10 ns; however, the burst output distributes the energy into a series of sub-pulses, each of which may individually be more optimal for efficient material ablation. Both the separation time between sub-pulses and the energy contained therein are completely programmable, independent of the laser's operating PRF. Further, switching between various TimeShift output profiles is very fast – on the order of 10's of microseconds – making it ideal for on-the-fly changes when processing samples comprised of mixed material types.

Nearly every parameter in TimeShift can be varied, empowering the user to customize the pulse output to match the specific needs of an application. With such great adaptability, it is important to explore how it can improve throughput, efficiency, and quality in micromachining processes.

Experiments were performed to characterize the micromachining capabilities of the Talon Ace in copper plate material (6 mm), using single- and burst-pulse outputs, and comparing with that of a conventional Q-switched, diode-pumped, solid-state laser (Spectra-Physics Talon UV15). A 2-axis scanning galvanometer was used to mill out pockets of material using a multi-pass raster scanning process. The spatial pulse overlap was 60% in both the X and Y directions (scanning and stepping directions) and a 50 kHz PRF was used throughout. The beams were focused with an f=163 mm telecentric f-theta objective and the incident fluence was controlled using an external variable power attenuator.

Ablation rates and efficiencies were determined from the measured depths (and calculated volumes) of the machined features and the overall laser exposure used (power, number of pulses, processing time). Figure 2 shows the volumetric ablation efficiencies versus peak fluence for the different temporal pulse outputs. Ablation efficiency refers to the volume of removed material per unit time normalized to one Watt of average power, and is expressed as mm^3/min/W.

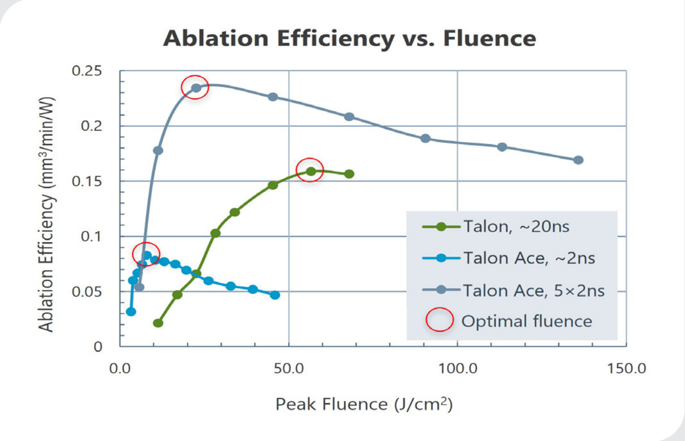

Figure 2. Ablation efficiency data illustrates the importance of pulse width and the benefit of using pulse bursts when processing copper.

For lower fluences, the Talon Ace operating with single 2 ns pulses offered higher ablation efficiency than the conventional Q-switched laser at 20 ns. Interestingly, the fluence level for maximum efficiency with 2 ns pulses (~8 J/cm^2) corresponds to the approximate threshold for 20 ns pulses, where there is virtually no material removal. The situation is reversed when higher fluences are applied, with the longer pulses achieving nearly double the ablation efficiency of the shorter pulses.

Thermal diffusion arguments can explain these results. With longer pulse widths there is more time for heat to spread into the bulk of the copper, which dilutes the absorbed laser energy. Therefore, a higher incident fluence is required to initiate ablation. Once it begins, however, larger incremental volumes are removed. On the other hand, the higher peak power with shorter pulses causes material ablation before significant thermal diffusion occurs. Clearly, the shorter pulse widths offer well-controlled ablation with reduced thermal loading; and with the highest efficiency at a low overall fluence, the reduced energy input to the material should lead to a reduced heat-affected zone (HAZ).

The burst mode output, in this case a 5× burst of 2 ns sub-pulses, provides dramatically higher ablation efficiencies. Comparing the respective peak values, the Talon Ace in burst mode is 2.8× more efficient (0.23 mm^3/min/W) than it is with a single 2 ns pulse (0.08 mm^3/min/W), and is nearly 50% higher than the 20 ns pulses (0.16 mm^3/min/W) of the Talon Q-switched laser. This result of higher burst ablation efficiency is consistent with similar studies using USP lasers (Application Note no. 41), and the reasons behind it are not fully understood.

Quality analysis was conducted using traditional optical microscopy as well as 3D scanning white light interferometry. Figure 3 shows closeup images of the machined copper floors for the three temporal pulse outputs tested, with each being taken at or near the respective optimal fluence condition (peaks of the curves in Figure 2).

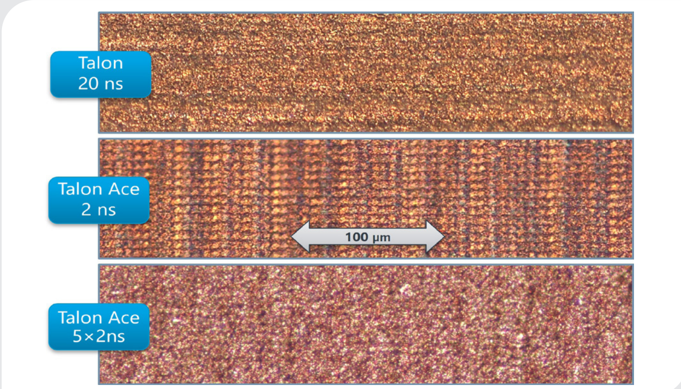

Figure 3. Closeup optical microscope photos showing machined surface quality for 2- and 20-ns single pulse outputs as well as a 5×2ns burst output.

The photographs indicate generally good quality for all conditions. However, the machined surface from the Talon Ace at single pulse (2 ns) output shows individual ablation dots, indicating minimal heat affect (e.g. melting), as otherwise the features would have blended together. In contrast, the individual ablation craters have more clearly blended together for both the Q-switch Talon and the Talon Ace in burst mode, forming what appear to be more uniform, albeit slightly coarse, surfaces overall. This is likely due to some thermal component in the laser/material interaction, such as localized melting, which acts to homogenize the surface topography in-situ.

Next, the edges of the machined features were inspected for burr formation using scanning white light interferometry (Figure 4).

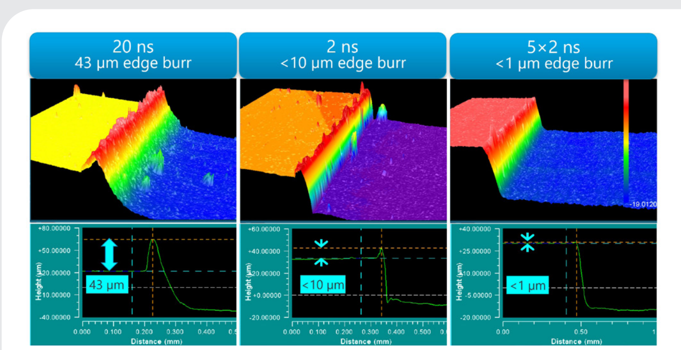

Figure 4. Optical surface profilometry reveals decreasing edge burr when going from 20 to 2 ns pulse widths, and further reduction with a 5×2 ns burst output.

In terms of edge burr, the Talon Ace operating in burst mode yields substantially better results than either of the others (<1 µm average edge burr). It should be noted that none of the processes were optimized for reduced edge burr in this example, therefore improvement is likely possible for all cases. Yet after optimization the Talon Ace with burst output would still be expected to yield the smallest edge burr.

The benefits of using the Talon Ace's TimeShift capability for processing copper has been demonstrated in a challenging industrial application – blind via hole drilling in a 12/25/12 µm copper/polyimide/copper material stack (Application Note no. 69). In the critical first step of a multi-step process, the laser was used to drill a 50 µm opening in the top copper layer using a simplified percussion process, rather than trepanning it. Percussion drilling is inherently faster and lower cost (no moving parts, etc.) but it is challenging to achieve both larger diameters and high quality. Figure 5 contains summary graphics and data, comparing results from a 10×2 ns burst process with those from two different single-pulse outputs (10 ns and 2 ns).

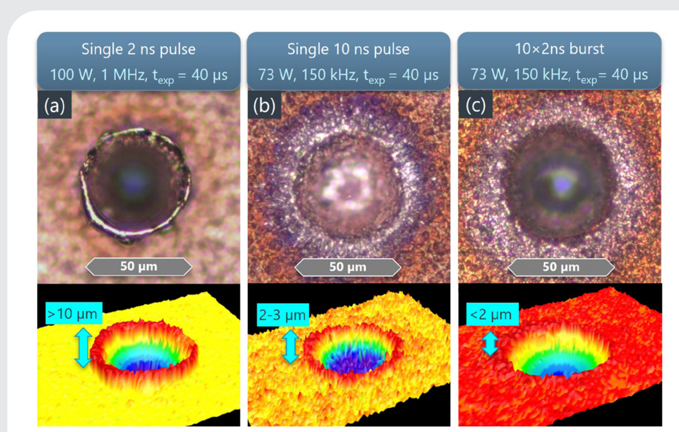

Figure 5. : For equal or lower average power, a 10×2 ns burst offers superior results for flex PCB top copper via opening compared to single 10 ns and 2 ns pulses.

For a drilling time of just 40 µs, single pulses of 10 ns and 2 ns durations were unsuccessful in achieving an acceptable level of quality and throughput.

However, with a 10×2 ns burst, a clean through hole with measurably superior quality is formed in the same amount of time. The low burr height (<2 μm) is important for downstream processes such as copper plating and stacking of multiple flex PCB laminates.

When discussing pulse widths lasers are often grouped as ns vs. USP, but the results presented here imply a more refined distinction. We find that shorter, single-digit ns pulses can have very different processing results compared to 10's of ns. It is also clear that ns pulses in a burst regime can have great processing advantages, as is often seen with USP lasers, which can also lead to significant economic benefit. With TimeShift pulse tailoring capability in both ns and USP regimes, MKS' Spectra-Physics lasers are well-suited to address the most challenging and complex industrial laser processing applications while simultaneously providing a strong value proposition.

PRODUCT

The Talon® Ace™ Laser

Talon Ace UV100 is a powerful pulsed nanosecond laser, delivering an industry-leading >100 W UV power with compelling cost-performance in a small form factor. The new laser delivers unprecedented flexibility, including TimeShift programmable pulse capability and a wide pulse repetition-rate range, to enable micromachining process optimization. Talon Ace UV100 is ideal for high-speed and high-quality manufacturing in micromachining of advanced electronics packaging, PC boards, photovoltaics, ceramics, semiconductors, and other materials and components.

	Talon Ace UV100
Wavelength	343 nm
Power	>100 W
Pulse Energy	>500 μJ
Repetition Rate	0–5.0 MHz
TimeShift Programmable Pulse Capability	Yes
Pulse Width, FWHM (TimeShift programmable)	<2 to >50 ns
Waveform Switching Time	<20 μs
Pulse-to-Pulse Energy Stability	<3%, 1σ

www.spectra-physics.com

Application Note_72_01/10/25