MATERIAL-SPECIFIC ABLATION PROFILES SIMPLIFY FAST DRILLING OF FLEX PCB MICROVIAS

Laser drilling of microvias in copper/polyimide/copper (Cu/PI/Cu) laminates is a common yet critical process in flex printed circuit board (fPCB) manufacturing, driven in large part by the popularity explosion in compact mobile electronic devices such as smart phones and watches, wearable devices, and more recently advanced automotive electronics. The specific case of a so-called blind via, in which a top copper foil and underlying polyimide layer are cleanly removed—leaving behind a bottom copper layer with minimal damage—is a benchmarking process for characterizing the suitability of a laser drilling technology. Key challenges include minimal burr in the top copper opening and minimal damage to the exposed bottom copper. Further, high throughputs are required as enormous numbers of vias are required in highly cost-competitive microelectronics manufacturing markets. As via diameters shrink and throughput requirements increase, ultraviolet wavelength diode-pumped solid state (UV DPSS) and/or UV master oscillator power amplifier (MOPA) lasers are increasingly used.

Successful blind via drilling will generally involve a two-step process, with different optimal laser parameters for step 1—top copper layer opening—and step 2—middle polyimide film ablation. This is depicted in Figure 1 for the case of 50 µm diameter via in a 12/25/12 µm Cu/PI/Cu laminate.

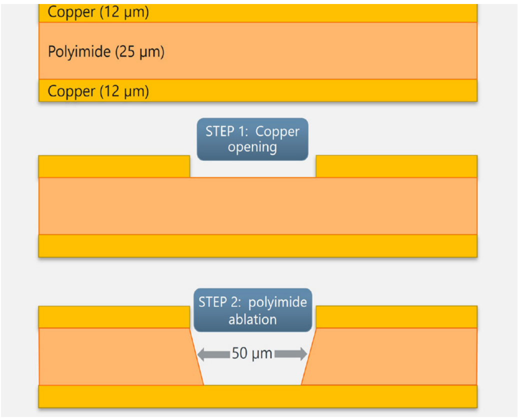

Figure 1. Representation of a 2-step blind via-drilling process in a common fPCB Cu/PI/CU laminate.

Copper and polyimide are among the most well-studied materials in laser material processing due to their high industrial significance. Copper removal requires a relatively high energy density (fluence, in J/cm^2) and is prone to burr formation as molten copper re-solidifies. The high fluence requirement makes it difficult to remove large areas (above a few 10's of µm) with commonly-available laser pulse energies, and the tendency for burr formation presents challenges to downstream processes such as copper plating and laminate stacking.

Polyimide, on the other hand, strongly absorbs UV wavelengths, undergoing a photochemical ablation ("photoablation") process that results in high-quality features with minimal heat-affected zone (HAZ). While there is an optimal fluence for achieving best quality, it is a thermally resilient polymer. Hence a range of fluence levels can be used, resulting in gentle to very strong ablation while still avoiding melting, carbonization, or other heat effects. At the same time, highest ablation efficiency generally occurs at low to moderate fluence levels where, unfortunately, the ablation rate (depth-per-pulse) also tends to be on the low side. Clearly, optimal laser drilling of Cu/PI/Cu laminates could benefit from a laser source that operates with high average power at a wide range of pulse repetition frequencies (PRFs) – allowing for both high and low pulse energies – and with the ability to quickly program both.

This possibility is a reality with the MKS Spectra-Physics® Talon® Ace™ UV100 laser, offering 100 W of UV power at a wide range of pulse energies and PRFs, including 500 µJ at 200 kHz, 100 µJ at 1 MHz, and a continuum of points in between. Pulse width is selectable, ranging from <2 ns to >50 ns, and the powerful TimeShift™ programmable pulse technology is built-in, enabling temporal pulse shaping and tailored burst output.

The Talon Ace was tested for a 2-step drilling process in a 12/25/12 µm Cu/PI/Cu fPCB laminate using a 2-axis galvo scanner/f-theta objective system. The focusing condition was basic Gaussian beam, with no flattop-style or other shaping optics. A standard f=330 mm objective was used to target an approximate via diameter of 50 µm, and the laser's temporal pulse output was optimized for each of the two steps required to form a complete microvia. Microscope images and 3D optical surface profile renderings of select features for step 1 (copper opening) are shown in Figure 2 (a, b, c).

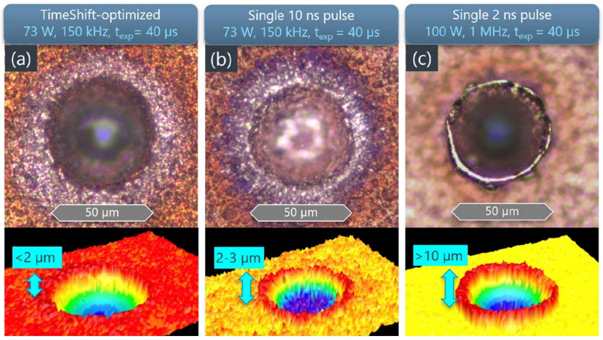

Figure 2. Step 1 copper opening with (a) TimeShift-optimized output, (b) single 10 ns pulse output, and (c) single 2 ns output, each with an exposure time of 40 µs.

The Talon Ace's TimeShift-optimized result in Figure 2a represents a tailored burst output, fully progammable that yielded exceptional edge quality (<2 µm burr) and clean copper removal, punching through to the underlying polyimide with a mere 40 µs exposure time—just seven pulse bursts at the 150 kHz PRF. There is minimal debris and oxidation around edge of the opening, indicating low overall heating and hence efficient use of the available pulse energy. When applying the exact same power, PRF, and exposure time with a single 10 ns pulse (Figure 2b), the result is incomplete copper removal, a taller burr, and notably more debris and oxidation. These remarkably different results that were generated with otherwise identical laser parameters proves the value of TimeShift pulse tailoring for process optimization. Lastly, Figure 2c shows the result when the shortest available pulse width of 2 ns is applied. Although the copper is removed, it is done so with a reduced diameter and unacceptably large edge burr of >10 µm.

With optimized parameters for step 1 defined, the remaining step 2 (polyimide removal) is relatively straightforward due to foreknowledge that (A) pulse tailoring is not required to achieve good quality and (B) low fluence and hence low pulse energy is optimal for best quality. As such, the Talon Ace was operated at the maximum PRF that maintains an output of 100 W average power (1 MHz and 2 ns pulse width). A fully-drilled blind microvia, processed with unique TimeShift pulse output profiles for steps 1 and 2, is shown in Figure 3.

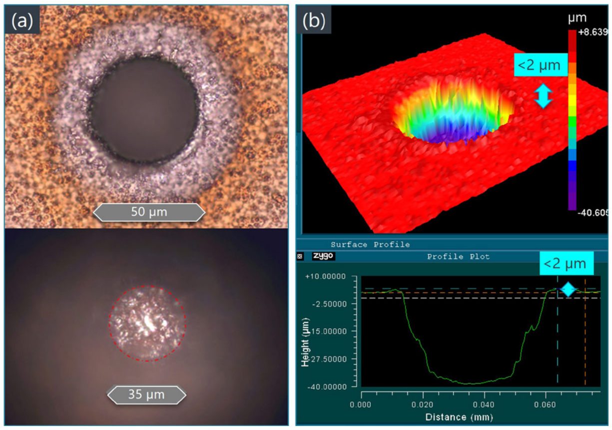

Figure 3. Optical microscope (a) and optical surface profiler (b) images of a ~50 µm diameter microvia drilled by the Talon Ace UV100 using 2-step process.

The top copper opening (Figure 3a, top) exhibits the same or slightly improved quality compared to the step 1-only result, and the exposed bottom copper layer (Figure 3a, bottom) is of similarly excellent quality. It is worth noting here that the short pulse, low energy output used in step 2 is also favorable to leaving the bottom copper layer intact with minimal damage, which allows for additional tolerance and some amount of over-processing to assure full polyimide removal. The optical profiler imagery confirms the minimal burr (Figure 3b, top) and only very slight removal of the bottom copper layer at the center of the focused Gaussian beam (Figure 3b, bottom).

The time required for polyimide removal was determined as 45 µs, which is 45 pulses at 1 MHz. The overall laser processing time—steps 1 and 2 combined—is 40 + 45 = 85 µs, equating to >11,700 vias per second. This is a theoretical, laser-only figure, which does not include the time required to move between via locations. It is the laser-capable throughput when drilling an entire pattern of vias first with step 1 parameters and then once again with the step 2 parameters, with a single switch of laser output in-between. Switching between pulse outputs is also very fast with the Talon Ace UV100—in the regime of 10's of microseconds—and therefore drilling each single via to completeness before moving to the next one is feasible, with very high throughputs approaching 10,000 vias/s.

Blind via drilling in Cu/PI/Cu fPCB laminates can be challenging due to the disparity in preferred laser parameters for ablating copper and polyimide. While UV DPSS lasers are well-entrenched for this task, they are often accompanied by costly and complex beam shaping and scanning equipment. With the Talon Ace UV100 and TimeShift pulse programming technology, a new regime is revealed for shaping pulse energy in the time domain, enabling rapid and precise material-specific process customization.

Product-application performance takeaways:

- The high average power and high-quality Gaussian beam of the Talon Ace UV100 enables high-speed microvia processing for flex PCB manufacturing using a percussion-only process.
- TimeShift programmable pulse capability enables tailoring the Talon Ace's output to match the ideal pulse energy and temporal intensity profile for each material in a layered stack.
- Process challenges that were overcome using TimeShift techniques include copper edge burring, back surface copper damage, and relatively low ablation rate of polyimide.
- The Talon Ace's unique ability to quickly change the temporal pulse output profile in 10s of microseconds, may reduce or eliminate the need for costly and complex beam shaping and scanning equipment.

PRODUCT

The Talon® Ace™ Laser

Talon Ace UV100 is a powerful new 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)3	<2 to >50 ns
Waveform Switching Time	< 20 μs
Pulse-to-Pulse Energy Stability	<3%, 1σ

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