

OPTIMIZING ABF DRILLING WITH PICOSECOND LASERS

A central challenge in advanced packaging today is routing large numbers of electrical connections through limited areas to connect ever denser integrated circuits with much larger printed circuit boards. The demand for this high interconnect density (HDI) is driven by rapidly expanding, compute-intensive applications such as artificial intelligence (AI), high-performance computing (HPC), and 5G telecommunications. This has motivated a shift towards sequential build-up (SBU) methods based on dielectric materials such as Ajinomoto build-up film (ABF) which allow finer lines and smaller vias at high densities.

Drilling with nanosecond pulsed ultraviolet (UV) lasers is currently the industry standard for forming microvia diameters smaller than 50 μm diameter in ABF. But, as both layer thicknesses and microvia diameters shrink towards the 10–15 μm range, even nanosecond UV lasers begin to look inadequate.

UV picosecond lasers represent a potential solution, but the extent to which they improve speed, quality, and cost depends strongly on the specific process approach used. This work presents results from ABF drilling tests performed with a UV picosecond laser, with emphasis on a “burst-on-the-fly” process technique for a one-shot, one-hole outcome. These results provide insight into how process speed and microvia geometry can be optimized and help define the conditions under which picosecond burst processing is most effectively applied.

Microvia Drilling Challenges and Solutions

It takes numerous pulses from a nanosecond UV laser to drill through a layer of ABF. This has led to the development of two different drilling methods: multi-pass scanning and point-to-point scanning.

In multi-pass scanning, the beam repeatedly follows the same pattern, delivering a single pulse per via location until the set of vias is complete. This enables continuous motion at high speeds but requires accurate retracing over potentially dozens of trajectory repetitions. Small positioning errors between passes can accumulate, distorting via shape.

In point-to-point scanning, the beam is moved to each location and stopped while all required pulses are delivered. This improves placement accuracy but reduces throughput due to repeated acceleration and deceleration cycles.

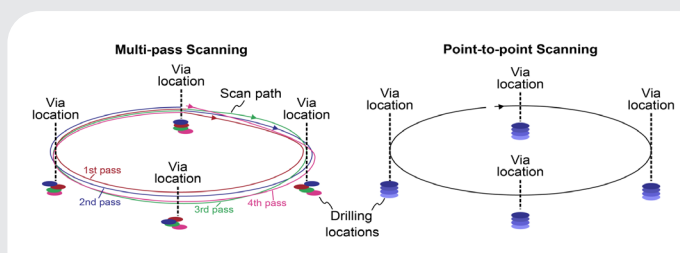


Figure 1. In multi-pass scanning, the beam retraces the same pattern multiple times, delivering a single pulse per pass at each location. This makes the process fast, but sensitive to positioning errors that can distort hole geometry. In point-to-point scanning, the beam traverses the pattern once. It comes to a stop at each location to deliver all the required pulses. This improves accuracy, but the repeated acceleration and deceleration limits throughput.

These limitations become more pronounced at smaller via diameters as positioning error must be further reduced in all motion paths. UV picosecond lasers with burst capability offer an alternative, with reduced thermal impact and decreased reliance on motion system performance

Burst-on-the-fly drilling is a hybrid technique based on picosecond lasers with burst capability. Conceptually, the beam moves continuously while delivering a pulse burst at each location, with sufficient energy to complete the via in a single beam pass. Because the burst duration is rapid relative to beam motion, all sub-pulses are effectively delivered to the same location. Thus, burst-on-the-fly combines the speed of nonstop scanning with the accuracy of point-to-point processing, enabling high-throughput, high-quality microvia formation.

Optimizing Burst-on-the-Fly

Ablation tests on ABF were performed with a MKS Spectra-Physics® IceFyre® UV50. This outputs 50 W (average power) at 355 nm. It delivers pulse widths of about 10 ps and can operate at repetition rates up to 10 MHz. The material used in all testing was 10 μm thick GL102 ABF on copper-clad prepreg and the target via diameter was 15 μm .

Key to this work was the TimeShift™ burst mode capability of the IceFyre laser. TimeShift allows programmable control of the number of sub-pulses in a pulse burst, as well as the temporal spacing and amplitudes of each sub-pulse. Spatially, only simple Gaussian beam focusing was implemented, whereas production-level microvia drilling typically implements beam intensity shaping (flattop, etc.).

The main goal was to establish how ABF ablation varies with total pulse energy, the number of sub-pulses in each burst, and the temporal separation of the sub-pulses, all of which are readily controlled using TimeShift.

Initial work (Figure 2) established a baseline for the pulse energy and pulse count requirements for complete via drilling (copper underlayer is exposed). Processing was performed with a point-to-point motion trajectory and therefore stationary ablation occurred. The work also explored the effect of high vs. low pulse output frequency. Six different pulse energies (0.4 μJ to 1.1 μJ) were applied with pulse counts of 15, 20, 25, and 30, and at pulse frequencies of 500 kHz (2 μs separation time between pulses) and 2 MHz (500 ns separation time).

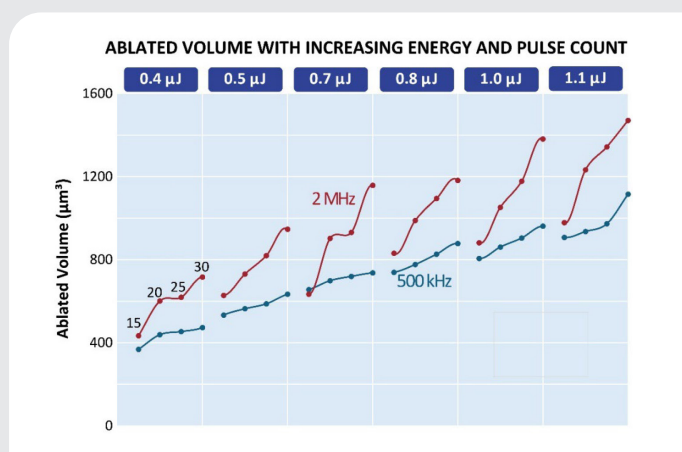


Figure 2. Material removal of ABF as a function of total pulse energy, total pulse count, and pulse frequency. At each pulse energy (shown in the column headers), data is plotted for bursts of 15, 20, 25 and 30 sub-pulses.

As expected, more material was removed using both higher pulse energies and pulse counts. But there was also a strong dependence on the pulses' temporal separation, with the higher 2 MHz frequency enhancing removal rates.

Copper Considerations

Another important factor in via drilling is avoiding damage to the underlying copper. Extensive prior testing of picosecond-pulse copper ablation performed at MKS was referenced for information about this. Figure 3 summarizes those results.

This graph shows that larger sub-pulse counts generally increase copper ablation rate. And, at all sub-pulse

counts, there's a local minimum in copper ablation rate at pulse separations of about 40–50 ns (25–20 MHz). The shorter sub-pulse separation times lead to enhanced copper removal, which is undesirable for a robust ABF microvia drilling process.

delivering a round via with the least taper. Together, these results illustrate the profound impact of burst pulse temporal spacing on ablation quality and underscore the necessity of having a feature like TimeShift that enables full programmability of the laser's pulsed output over time.

Process Optimization

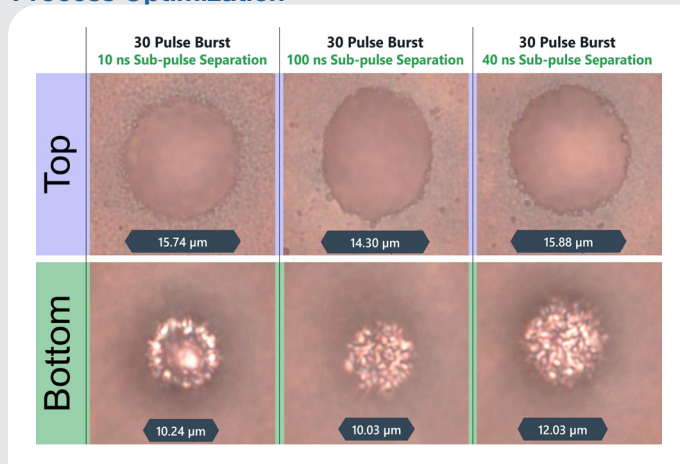


Figure 4. Comparison of three vias drilled with the same pulse energy and sub-pulse count, but with different temporal separations between the sub-pulses. This demonstrates how significantly sub-pulse spacing impacts results.

Obviously, the high pulse frequencies possible with burst mode operation raise throughput by increasing the number of pulses delivered per unit time. But, just as importantly, the short times between sub-pulses also changes the thermal environment at the interaction site.

When sub-pulses are spaced closely enough, heat can accumulate locally, particularly near the copper interface. This “beneficial heating” can enhance material removal. In the case of ABF microvia drilling, it speeds the process and also reduces hole taper. But this effect must be carefully managed to avoid damaging the copper.

With IceFyre and its TimeShift capability, the ability to independently control sub-pulse timing and amplitude provides significant process flexibility. In this work, only the burst sub-pulse separation time was optimized. Yet one could easily imagine additional optimizations,

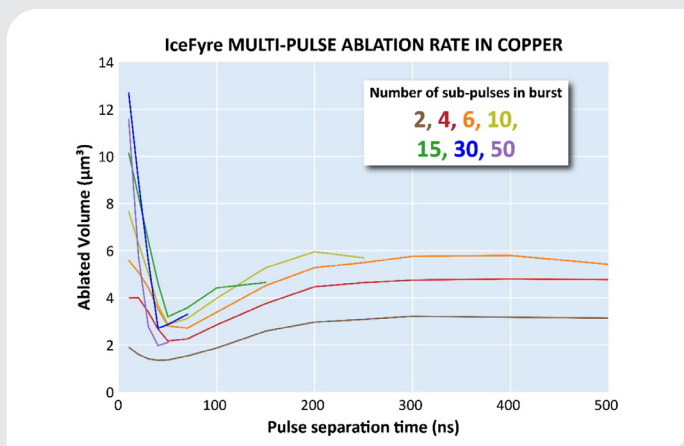


Figure 3. Copper ablation rates for a fixed pulse energy as a function of the number of sub-pulses in the burst and their temporal separation.

The series of photos in Figure 4 show how copper ablation factors into ABF drilling. It shows both the tops and bottoms (exposed copper surfaces) of three different vias all drilled with the same total pulse energy and sub-pulse count (30) and at a nonstop scanning speed of 4 m/s. The only difference between them is the temporal separation between sub-pulses.

The leftmost photos show a hole with a substantial amount of taper, plus significant damage to the copper. In the middle set of photos, a much larger separation between sub-pulses (100 ns instead of 10 ns) has moved processing out of the strong copper processing regime, thus eliminating the copper damage. However, hole taper is not improved and, most critically, the longer temporal duration of the burst has caused noticeable elongation of the via.

The rightmost images represent the optimal process window. An intermediate sub-pulse spacing of 40 ns prevents copper damage while simultaneously

such as variable separation time and sub-pulse energy all within the same burst, for addressing more sensitive and complex material configurations.

Nevertheless, the results presented here clearly demonstrate the potential of programmable burst

technology to optimize the balance between efficient ABF removal and reduced copper damage, thus improving processing speed, via quality, and overall cost per via for ABF drilling in advanced packaging architectures.

PRODUCT

IceFyre Industrial Picosecond Lasers

The IceFyre UV50 is the highest performing UV ps laser on the market, providing >50 W of UV output power at 1.25 MHz (>40 μ J) with 100's μ J pulse energies in burst mode, and pulsewidths of 10 ps. It sets new standards in power and repetition rates from single shot to 10 MHz. The IceFyre UV30 offers >30 W of typical UV output power with pulse energy >60 μ J (greater pulse energies in burst mode) and delivers exceptional performance from single shot to 3 MHz. The IceFyre IR50 provides >50 W of IR output power at 400 kHz single pulse and delivers exceptional performance from single shot to 10 MHz.

The IceFyre laser's unique design combines fiber laser flexibility with an exclusive power amplifier capability to enable TimeShift ps programmable burst-mode technology for the highest versatility in the industry. A standard set of waveforms is provided with each laser; an optional TimeShift ps GUI is available for creating custom waveforms. The laser design enables true pulse-on-demand (POD) and position synchronized output (PSO) triggering with the lowest timing jitter in its class for high quality processing at high scan speeds, e.g. when using a polygon scanner.

	IceFyre UV50	IceFyre UV30	IceFyre GR50	IceFyre IR50
Wavelength	355 nm		532 nm	1064 nm
Power	>50 W @ 1250 kHz	>30 W typical @ 500 kHz >25 W @ 800 kHz >20 W typical @ 1 MHz	>50 W @ 500 kHz	>50 W @ 400 kHz
Maximum Pulse Energy, typical (greater pulse energy per burst possible with TimeShift ps)	>40 μJ @ 1250 kHz	>60 μJ typical @ 500 kHz >31 μJ @ 800 kHz >20 μJ typical @ 1 MHz	>100 μJ @ 500 kHz	>200 μJ @ 200 kHz
Repetition Rate Range	Single shot to 10 MHz			
Pulse Width, FWHM	<12 ps (10 ps typical)		<15 ps (13 typical)	
TimeShift ps	yes			
Pulse-to-Pulse Energy Stability	<2.0%, 1 σ			<1.5%, 1 σ
Power Stability (after warm-up	<1%, 1 σ, over 8 hours			