SYSTEM-IN-PACKAGE (SiP) MATERIALS CUTTING WITH GREEN PICOSECOND LASERS

System in package (SiP) is a chip packaging approach for further increasing the density of computing power. With semiconductor feature shrink slowing, the industry has turned toward the gap that exists between semiconductor processing dimensions (nanometers-micrometers) and printed circuit board (PCB) dimensions (micrometers-millimeters), a space spanning roughly three orders of magnitude. Such a large dimensional mismatch affords various approaches for further miniaturization. Functionally, SiP achieves performance gains by integrating historically discrete and isolated components such as memory, logic, radio frequency (RF) chips, etc., into a single package (often referred to as heterogenous integration) on a shared printed circuit board (PCB) substrate with the requisite inter-connections designed in. SiP technology has become common in mobile consumer electronics such as smart phones, wearables e.g. watches, earpods and many other devices.

For singulation of SiP devices, lasers in the ns pulse width regime at UV and green wavelengths may be suitable. However, there are challenges if excess heating cannot be tolerated, especially as these devices become even more condensed. This leads to an interest in processing with shorter pulse durations for reduced heat affected zone (HAZ). Such may be the case if there are encapsulations that use a heat-sensitive bonding media, such as solder or adhesive, that may fail under excess thermal loading. Furthermore, processing with ultrashort pulse (USP) lasers may be desired due to the presence of copper traces embedded within the SiP laminate which can become excessively hot, resulting in the potential for layer delamination. With these considerations in mind, experiments were conducted to optimize cutting processes for SiP related materials using a high-power green picosecond laser, the MKS Spectra-Physics IceFyre® GR50.

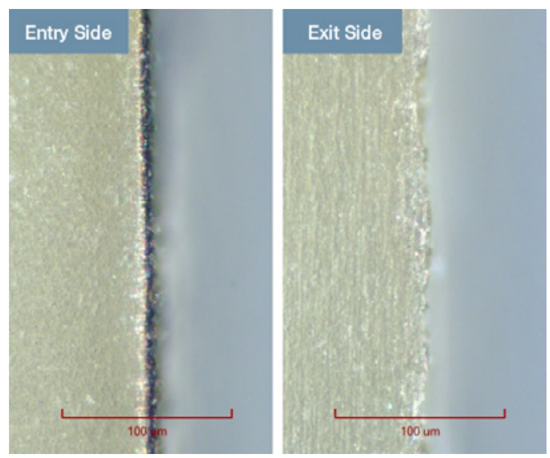

Figure 1. Entry (left) and exit side view of 200 µm thick FR4 board cut with green picosecond pulses.

A primary component of SiP boards is thin (or "ultrathin") glass reinforced epoxy laminate material (FR4), typically 100–250 µm thick. Laser cutting of FR4 is challenging due to its inhomogeneous constitution of glass fibers and epoxy resin with their differing optical and thermal properties. When processing thicker FR4 with lasers, care must be generally taken to avoid excessive heating and melting, which can result in undesirable carbonization. With thinner FR4, and when using picosecond pulse widths, excessive heating is relatively easy to avoid. Figure 1 shows entry and exit surfaces of 200 µm thick FR4 as cut with the IceFyre GR50 laser.

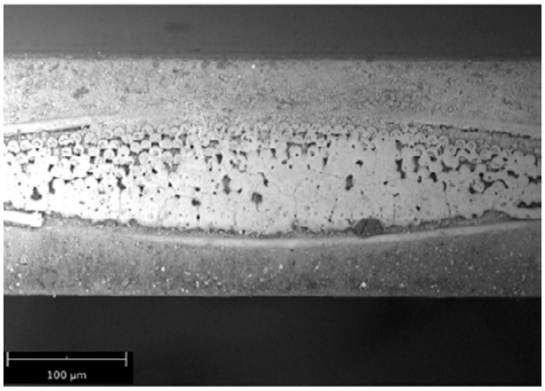

Figure 2. SEM sidewall view of cut from Figure 1 showing only minor melting of fiber end faces.

Using the laser's nominal output of 50 W at 500 kHz pulse repetition frequency (PRF), a high-speed, multi-pass process optimized at a scanning speed of 4 m/s resulted in an effective cutting speed of 83 mm/s. The entry surface shows minimal debris deposition and an apparent heat affected zone (HAZ) of ~10 µm. When viewed in cross-section with SEM imaging (Figure 2), a high-quality cut is verified, with individual fibers readily apparent and only slight evidence of melting.

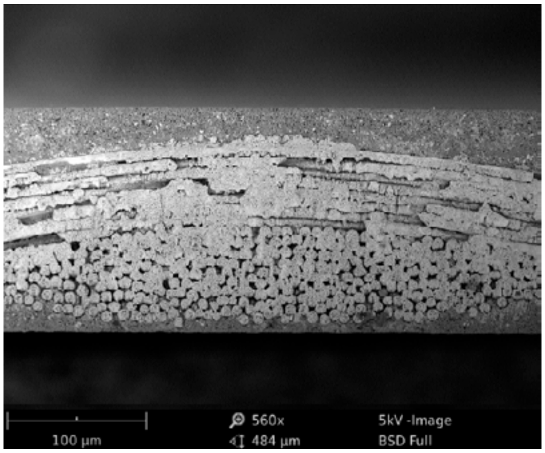

Figure 3. SEM sidewall view of FR4 cut with superior quality and minimal fiber melting.

For many processes being performed with USP lasers, it is often possible to improve upon an already good-quality result and achieve something far superior. For example, if one intends to further reduce the amount of glass fiber melting when cutting FR4, adjustments such as reduced laser pulse energy and/or PRF, increased beam scanning speed, etc., can allow for such a superior result, as shown in Figure 3.

This result clearly demonstrates that USP lasers can produce excellent cutting results with very low thermalization in sensitive materials.

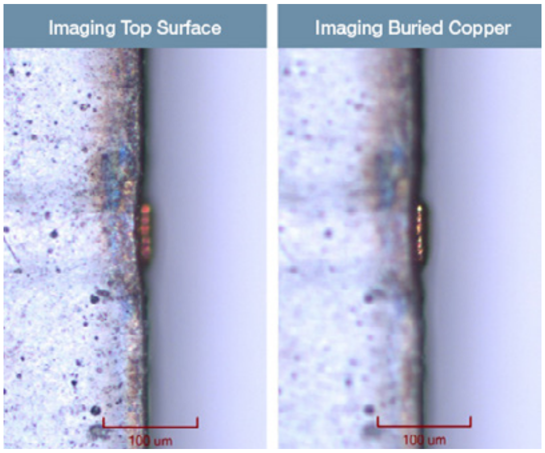

Figure 4. Laser entrance side microscope images of the higher speed cutting result with excellent surface cut quality but some evidence of heating around the buried copper trace.

Having demonstrated excellent quality cutting of thin FR4 and characterizing achievable throughput, the laser was then used to cut thin SiP PCB substrate material. The material is comprised of ultrathin FR4 (~100 µm thick) with polymer solder mask protective layers, is laminated on both sides and includes intermittently embedded copper trace lines layered along the intended cutting path. The combined thickness of all layers was 200 µm. Due to the presence of multiple layers including embedded copper trace lines, it was anticipated that some process fine-tuning would assist in achieving best-quality results. Hence, after defining a process targeting high throughput, parameter adjustments were made to focus on an improved-quality result.

The results indicate that such an approach was warranted. With a process developed for high speed using full power from the laser, top-down microscope photos (Figure 4) of the entry side of the cut indicate that the embedded copper does indeed have some effect on cut quality. While the surface quality is excellent overall, with good cut edge quality and only a small debris field, there is evidence that excess heating around the copper layer has caused a slight erosion of the polymer/FR4 material around it, resulting in a minor protrusion of the copper from the sidewall. The effective cutting speed of the process was 57 mm/s.

Hence while a throughput-centric process achieves generally good quality, there is room for improvement. Using a 50% reduced laser power level and making various other parameter adjustments, the quality was further improved as shown in figure 5. This result was achieved with a net cutting speed of 38 mm/s. Therefore, with full usage of the power (in a two-beam split configuration, for example), the overall combined cutting speed equates to 76 mm/s, which is 33% greater than the speed achieved with a single beam at full power.

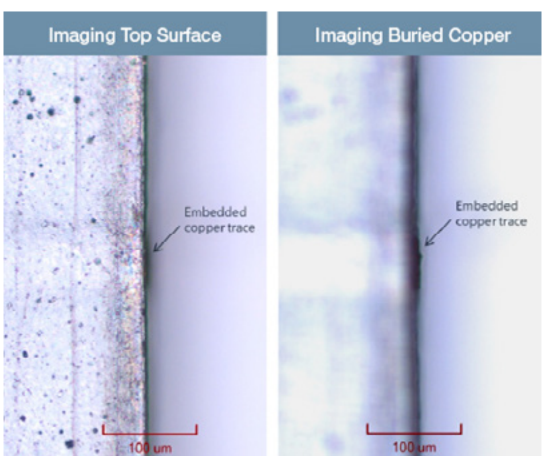

Figure 5. Entrance side images of cuts using 50% laser power show improvement upon the already good results achieved with full power.

The left-hand image in Figure 5 images the surface polymer layer and shows only slight debris deposition compared to the full power result, and there is no detectable deviation of the cutting path. Likewise, the right-hand image shows only a barely detectable protrusion of the buried copper trace in a direction away from the cut edge. Viewing the sidewall cross-section of the laser cut offers further insight on the quality of the result, as indicated by the SEM image in Figure 6 below.

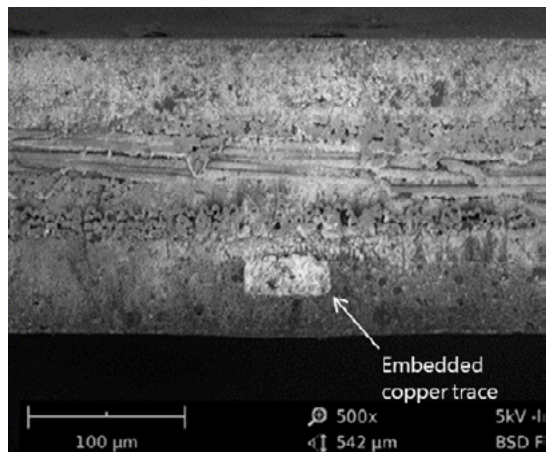

Figure 6. SEM image showing the sidewall of the SiP board cut with 50% laser power.

The SEM image shows a cleanly-ablated sidewall using 50% laser power. Clear indicators of excellent quality are apparent, such as individual fiber end faces detectable with no/low melting, no delamination between layers, and cleanly ablated copper trace with no melting or deformation in and around the copper.

SiP architecture enables increasing electronics performance in ever shrinking form factors, and laser singulation of packaged devices is an important factor in the overall endeavor. While ns pulse lasers can sometimes meet the requirements, the close proximity of densely packed ICs along with various sub-packaging components can present a challenge. With USP laser technology, particularly at green (and ultraviolet or UV) wavelengths, high throughputs can be achieved. With careful laser and process parameter tuning, exceptional cut quality with minimal thermal impact can be realized.

PRODUCT

IceFyre Industrial Picosecond Lasers

The IceFyre GR50 delivers >50 W of green output power at pulse energy >100 µJ at 500 kHz. 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 µJ) with 100's µJ pulse energies in burst mode, and pulsewidths of 10 ps. The IceFyre UV50 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 µJ (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. IceFyre laser's unique design exploits fiber laser flexibility and Spectra-Physics' 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 GR50	IceFyre UV30	IceFyre UV50	IceFyre IR50
Wavelength	532 nm	355 nm		1064 nm
Power	>50 W @ 500 kHz	>30 W typical @ 500 kHz >25 W @ 800 kHz >20 W typical @ 1 MHz	>50 W @ 1250 kHz	>50 W @ 400 kHz
Maximum Pulse Energy, typical (greater pulse energy per burst possible with TimeShift ps)	>100 µJ @ 500 kHz	>60 µJ typical @ 500 kHz >31 µJ @ 800 kHz >20 µJ typical @ 1 MHz	>40 µJ @ 1250 kHz	>200 µJ @ 200 kHz
Repetition Rate Range	Single shot to 10 MHz			
Pulse Width, FWHM	<15 ps (13 typical)	<12 ps (10 ps typical)		<15 ps (13 typical)
TimeShift ps	yes			
Pulse-to-Pulse Energy Stability	<2.0% rms, 1 σ			<1.5% rms, 1 σ
Power Stability (after warm-up)	<1%, 1 σ, over 8 hours			

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