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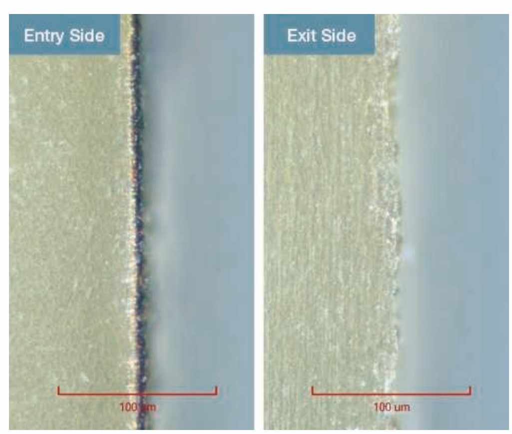
System-in-package materials cutting using MKS Instruments' Spectra-Physics IceFyre GR50 green picosecond laser

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 (nanometres-micrometres) and printed circuit board (PCB) dimensions (micrometres-millimetres), a space spanning roughly three orders of magnitude. Such a large dimensional mismatch affords various approaches for further miniaturisation. 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 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 and earpods, and many other devices.

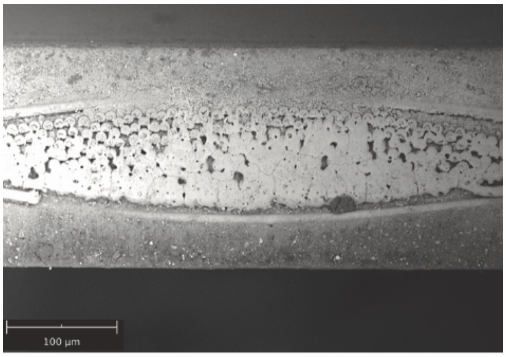
For singulation of SiP devices, lasers in the nanosecond (ns) pulse width regime at UV and green wavelengths may be suitable. However, there are challenges if excess heating cannot be tolerated, especially as these devices become even more condensed. This leads to an interest in processing with shorter 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 optimise cutting processes for SiP-related materials using MKS Instruments' Spectra-Physics IceFyre GR50 green picosecond laser.

A primary component of SiP boards is thin or ultrathin FR4, glass reinforced epoxy laminate material, typically 100–250 µm thick. Laser cutting of FR4 is challenging due to its inhomogeneous constitution of glass fibres 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 carbonisation. With thinner FR4, and when using picosecond pulse widths, excessive heating is relatively easy to avoid.

Entry and exit surfaces of a 200 µm thick FR4 cut made using the Spectra-Physics IceFyre GR50 laser are shown in figure 1. Using the laser's nominal output of 50 W at 500 kHz pulse repetition frequency (PRF), a high-speed, multi-pass process optimised at a scanning speed of 4 m/s resulted in an effective cutting speed of



▶ ***Figure 1***: *Entry (left) and exit (right) side views of the 200 µm thick FR4 cut made using MKS Instruments' Spectra-Physics IceFyre GR50 green picosecond laser.* ▶

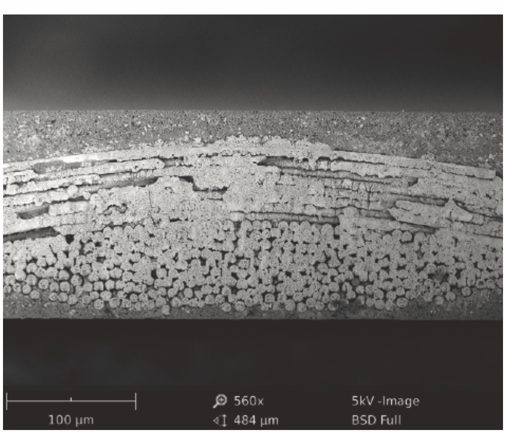


▶ ***Figure 2**: A scanning electron microscope (SEM) sidewall view of the cut in figure 1 shows only minor melting of the fibre end faces.* ▶

83 mm/s. The entry surface shows minimal debris deposition and an apparent HAZ of ~10 µm. A high-quality cut, with individual fibres readily apparent and only slight evidence of melting, was verified through scanning electron microscope (SEM) sidewall viewing, as shown in figure 2.

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 fibre 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 by the SEM sidewall view in figure 3. This result clearly demonstrates that USP lasers can produce excellent cuts with very low thermalisation in sensitive materials.

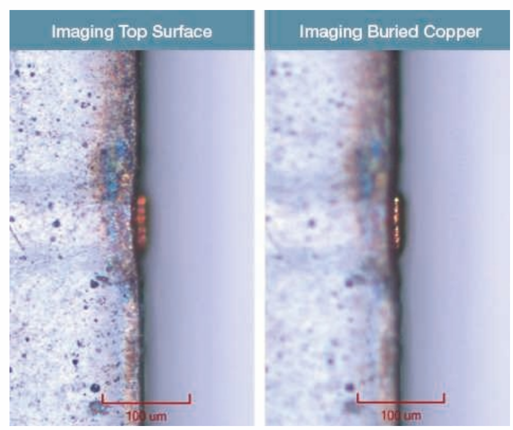
Having demonstrated excellent quality cutting of thin FR4 and characterising achievable throughput, the laser was then used to cut thin SiP PCB substrate material. The material was comprised of ultrathin FR4 (~100 µm thick)



▶ ***Figure 3**: A SEM sidewall view of the superior quality FR4 cut shows minimal fibre melting.* ▶

with polymer solder mask protective layers, was laminated on both sides and included 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.

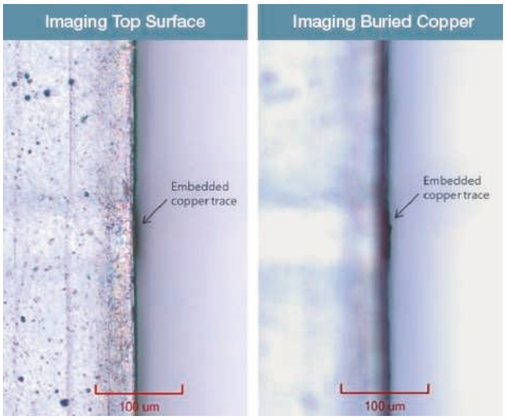
The results indicate that such an approach was warranted. Using the laser at full power in a process developed for high-speed, an effective cutting speed of 57 mm/s was achieved. As expected, the embedded copper did have some effect on the cut quality, as shown by the microscope images in figure 4. Although the



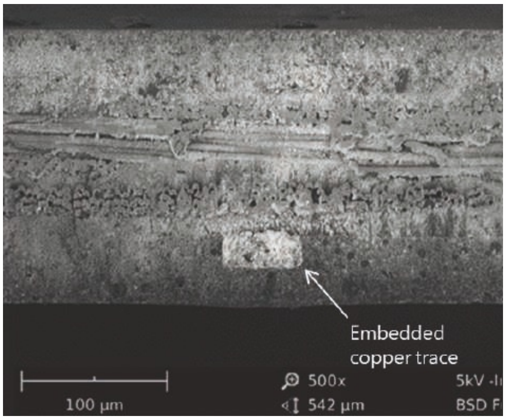
▶ ***Figure 4**: Entry side microscope images of the high-speed system in package (SiP) printed circuit board (PCB) substrate material cut show excellent surface cut quality but some evidence of heating around the buried copper trace.* ▶

surface quality is excellent overall, affording 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 FR4/polymer material around it, resulting in a minor protrusion of the copper from the sidewall.

Hence, while a throughput-centric process achieves generally good quality, there is room for improvement. Using the laser at 50 percent reduced power and making various other parameter adjustments, an effective cutting speed of 38 mm/s was achieved. The cut quality was improved, as shown by the microscope images in figure 5. The left-hand image shows the surface polymer layer has only slight debris deposition compared with the full power result,



▶ ***Figure 5**: Entry side microscope images of the SiP PCB cuts made using 50 percent laser power show improvement upon the already good results achieved with full power in figure 4.* ▶



▶ ***Figure 6**: A SEM image showing the sidewall of the SiP PCB cut made using 50 percent laser power.* ▶

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. With usage of the laser at full power (in a two-beam split configuration, for example), the overall combined cutting speed equates to 76 mm/s, which is 33 percent greater than the speed achieved with a single beam at full power.

Viewing the sidewall cross-section of the laser cut offers further insight on the quality of the result, as shown by the SEM image in figure 6. The image shows a cleanly ablated sidewall, achieved using 50 percent laser power. Clear indicators of excellent quality are apparent, such as individual fibre 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 endeavour. While ns pulse lasers can sometimes meet the requirements, the close proximity of densely packed integrated circuits (ICs) along with various sub-packaging components can present a challenge. With USP laser technology, particularly at green (and ultraviolet (UV)) wavelengths, high throughputs can be achieved. Moreover, with careful laser and process parameter tuning, exceptional cut quality with minimal thermal impact can be realised. ●

MKS Instruments
www.spectra-physics.com

MKS Instruments' Spectra-Physics IceFyre industrial picosecond lasers

	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 @ 1,250 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 @ 1,250 kHz	>200 µJ @ 200 kHz
Repetition rate range	Single shot to 10 MHz			
Pulse width, FWHM	<15 ps (13 typical)	<15 ps (13 typica <12 ps (10 ps typical) l)		<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