APPLICATION NOTE 58

CUTTING 5G FLEX PCB MATERIALS WITH A HIGH ENERGY, HIGH POWER NANOSECOND UV LASER

Laser processing continues to have a strong impact on printed circuit board (PCB) manufacturing, helping drive the development of devices with improved performance and lower power consumption. Today, a highly diverse set of materials—from thick fiber composites like FR4 to thin flexible laminates—are processed in a variety of ways with a range of laser sources. Of particular note is flex-PCB (FPCB) technology, where developments are frequent since it is tied to the rapidly evolving mobile device market. One such development is 5G mobile communications, which allows for significant increases in wireless data rates. Unsurprisingly, new materials are required to receive, manipulate, and transmit data at such dramatically higher speeds, and the conventional polyimide dielectric layer must be replaced with advanced materials such as modified polyimide (MPI) and liquid crystal polymer (LCP), both of which provide superior dielectric performance at 5G frequencies. For various reasons including suitability for much higher frequencies as well as for antenna related components, LCP is seen as a preferred material for 5G. In terms of laser processing, full-depth cutting (our focus here) is relevant to the profile cutting/routing application in FPCB manufacturing, in which the final designed shape of a device or component is cut from the material sheet or web.

Using a high-power ultraviolet (UV) hybrid fiber laser (Quasar® UV80 with 80 W average power and up to 400 µJ per pulse), our industrial laser applications researchers performed a series of cutting experiments with LCP-based FPCB materials, including bare LCP sheet and copper-clad LCP laminates. The Quasar laser offers the flexibility of TimeShift™ programmable-pulse technology, which allows a range of temporally tailored pulse outputs (pulse widths, burst mode, pulse shaping) to be explored at a wide range of pulse repetition frequencies (PRFs), from single-shot to 3.5 MHz. All tests were performed using a 2-axis scanning galvanometer for high-speed, multi-pass processing, and an f-theta objective (f = 330 mm) was combined with a variable beam expansion telescope to explore a range of focal diameters (20–35 µm, $1/e^2$ diameter).

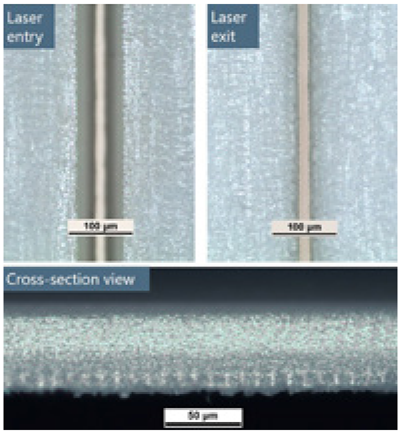

Figure 1. Bare 50 µm thick LCP cut with Quasar UV80 laser. Entry (top left), exit (top right), and cross-section (bottom) views indicate excellent quality and minimal excess heating.

Our first machining results are for bare LCP sheet material with a thickness of 50 µm. Preliminary tests indicated that, similar to polyimide, the material has a relatively low ablation threshold with the UV light. Unlike polyimide, however, LCP is sensitive to excessive heating, and careful process optimization is required to avoid melting and charring. The optimal cutting results were found using short laser pulse widths (~2–3 ns) and modest pulse energies delivered at high PRFs (>750 kHz). Optical microscope images in Figure 1 show entry, exit, and cross section views of the resulting cut.

The images demonstrate the excellent quality achieved with the ns UV pulses, showing little or no evidence of melting and charring. The cross-section view shows a finely textured machined surface that is free of thermal melt reflow (i.e. surface "smoothening'). The cross-section view does reveal some "channeling" towards the exit side of the cut. This is due to the high speed/low pulse overlap nature of the process and the diminishing ablation diameter that occurs with increasing depth, which results in nearly separated ablation "dots" towards the exit side of the cut. In practice, this effect can be reduced or eliminated by reducing the beam scanning speed as the cut progresses deeper. The cut was achieved using 13 overlapping scans at 8 m/s scanning speed resulting in a net cutting speed of ~615 mm/s.

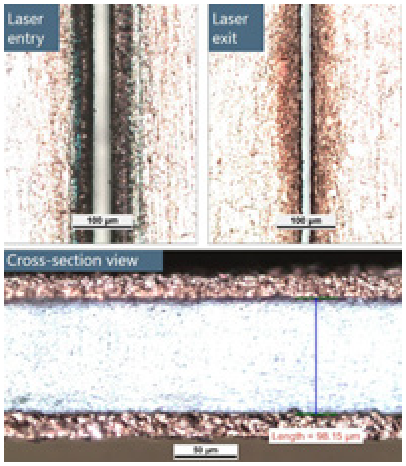

Figure 2. Thick copper-clad LCP cut with Quasar UV80 laser. Entry (top left), exit (top right), and cross-section (bottom) views demonstrate clean, high quality cuts realized with temporally-tailored ns pulses.

Cutting of copper-clad LCP laminates was also undertaken, with two different thicknesses of Cu/LCP/Cu layered stacks available for our tests: 18/100/18 µm and 9/25/9 µm. The thicker material is particularly challenging, and higher pulse energies are helpful to avoid widening the cutting kerf width (such as by implementing a parallel line/raster scan process). With the Quasar laser's high pulse energy of up to 400 µJ, however, such measures were not required. The laser's TimeShift pulse tailoring capability was exploited to study a variety of conditions, including short vs. long pulse widths and burst mode output. With longer (10 ns) pulses, cutting speeds were in the higher end at 100–120 mm/s, and quality tended towards smaller edge burrs but larger oxidation zones. Shorter (2.5 ns) pulses on the other hand were slower (~90 mm/s) and had taller edge burrs but exhibited significantly less oxidation. The best overall result was generated using a burst of short (2 ns) pulses, which gave the highest cutting speed of 130 mm/s and with quality characterized as moderate in both burr height and amount of oxidation. Optical microscope images in Figure 2 show such a cut from the entry and exit sides as well as a cross-section perspective.

The microscope images show the overall good quality that can be achieved with careful process optimization and temporal tailoring of pulse intensity output. The excellent LCP cutting shown previously is preserved even when cut in tandem with copper cladding. In addition, since copper peel strength with LCP is generally much lower compared to that for polyimide, it is important to note that there is no evidence of delamination at the Cu-LCP interfaces. For the thinner 9/25/9 µm layered stack, similar results were observed but with a significantly higher net cutting speed of >350 mm/s.

Optical microscopy clearly highlights any oxide growth and areas of molten copper such as burrs, rough edges, etc. that occur when machining copper with ns pulse lases. For very close-up imaging of fine surface structures and modulation thereof, scanning electron microscopy (SEM) is a preferred alternative and was applied for further analysis of the cut samples. Figure 3 shows a macro perspective of the 18/100/18 µm stack as viewed through an SEM.

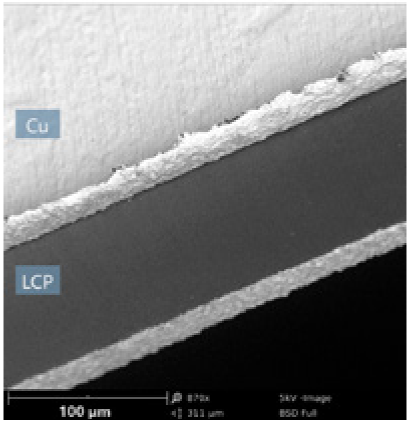

Figure 3. SEM imaging reveals smooth material surfaces and crisp geometries of the copper-clad LCP cut with Quasar UV80 laser.

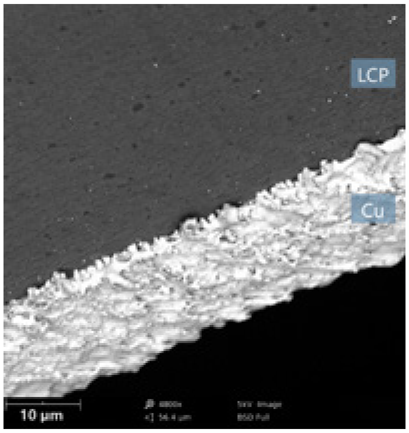

Figure 4. Close-up SEM view shows Cu-LCP is fully intact after laser cutting with no LCP pull-back from the copper cut edge.

Viewed with electron vs. light microscopy, the optical effects of thin oxides and scattering/reflective nature of previously molten copper are not as strongly apparent, allowing one to focus on the true dimensional aspects of the surfaces, including modulations, edge straightness, and the like. Here, the SEM image reveals a clean and precisely machined feature with high-quality surfaces. Of particular note is the smoothness and verticality of the LCP cut edge, with no apparent “barreling” or pull back from the cut edges of the copper layers. A highly magnified SEM view of the interface is shown in Figure 4 and confirms that the bond between the LCP and Cu layers is nicely preserved. Furthermore, we confirm in greater detail a smooth and flat LCP surface, without any pull-back from the edge of the cut copper.

New materials are often ushered in with new technologies, and manufacturing methods and equipment must adapt accordingly. For 5G mobile devices, the high data rates and high speed electronics require replacement of traditional polyimide dielectrics in FPCBs, in many cases with LCP films and laminates. In this work, a high power and high pulse energy Quasar UV laser was used to cut such materials with excellent results. The flexibility inherent in TimeShift programmable-pulse technology was beneficial in addressing the widely varying thermal and optical properties presented by the materials, allowing for the development of a high quality and high throughput precision laser cutting process.

PRODUCT

Quasar

The breakthrough performance of the Quasar series leads the industry with unprecedented highest UV average power and energy at high rep rate for fast micromachining. Quasar features novel TimeShift technology for programmable pulse profiles for the ultimate in process speed, flexibility, and control.

Breakthrough Technology

Quasar combines advanced fiber laser, power amplifier and patented harmonics technologies to achieve breakthrough results. This unique design exploits fiber laser flexibility and robustness to enable TimeShift technology. Adding Spectra-Physics' exclusive power amplifier technology, Quasar enhances this flexibility at unprecedented high output power levels. Finally, with Spectra-Physics' patented harmonics, known for exceptional stability, Quasar continues to provide an innovative synergy of power, flexibility and control in a reliable 24/7 OEM laser for the most demanding applications.

	Quasar UV80	Quasar UV60	Quasar UV60-T	Quasar UV45	Quasar GR95	Quasar GR75
Wavelength	355 nm	355 nm	355 nm	355 nm	532 nm	532 nm
Output Power	>80W @ 200 kHz, 10 ns	>60 W @ 200 kHz, 10 ns >60 W @ 300 kHz, 10 ns	>38 W @ 3 MHz, 2 ns	>45 W @ 200 kHz, 10 ns >45 W @ 250 kHz, 10 ns >41 W @ 300 kHz, 10 ns	>95W @ 200 kHz, 10 ns	>75 W @ 200 kHz, 10 ns
Maximum Pulse Energy at Optimization Point	>400 µJ	>300 µJ	>12 µJ	>225 µJ	>475 µJ	>375 µJ
Repetition Rate Range	0–3.5 MHz	0–3.5 MHz	0–3.5 MHz	0–1.7 MHz	0–3.5 MHz	0–1.7 MHz
Optimized TimeShift Setting (Nominal setup for beam optimization)	200 kHz, 10 ns	300 kHz, 10 ns	3 MHz, 2 ns	300 kHz, 10 ns	200 kHz, 10 ns	200 kHz, 10 ns

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