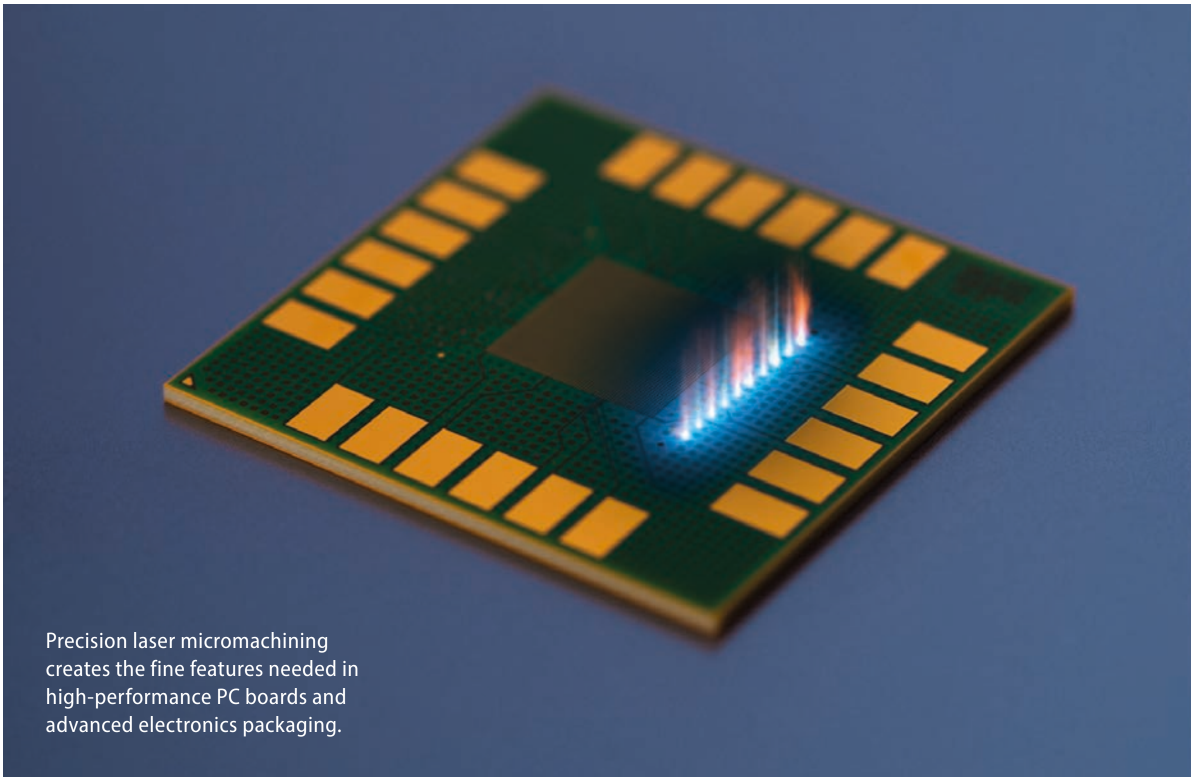
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Precision laser micromachining creates the fine features needed in high-performance PC boards and advanced electronics packaging.

Sustainable and Efficient Micromachining Solutions

Cutting 5G flex PCB materials with a high energy, high power, nanosecond UV laser

Jim Bovatsek

The global shortage of semiconductor chips is not only leading to new perspectives on how to organize global supply chains, but it also pinpoints the need to further enhance quality and efficiency in production processes. By exploring new options on how to use and measure ultrashort-pulse lasers, MKS Instruments is highlighting ways on how to optimize production processes.

Laser technology has significantly improved micromachining applications and continues to have a strong impact on advanced electronics packaging and printed circuit board (PCB) manufacturing, helping to drive the development of devices with improved performance and lower power consumption. Pulsed ultraviolet laser technology in particular has paved the way to high-volume manufacturing applications with more consistent and environmentally friendly processes. At the same time, there is a strong need for the measurement industry to keep pace with the latest laser developments. Synchronized research and innovation in both areas are therefore essential for the further improvement of the process chain and the evaluation of how to use sensitive materials.

New materials to enable 5G mobile communications

The mobile device market is one of the drivers in the development of advanced electronics packaging and printed circuit board (PCB) manufacturing, with laser technology playing a key role. A highly diverse set of materials – from thick fiber composites like FR4 to thin flexible laminates (flexible PCB or FPCB) – are now processed in a variety of ways using a range of laser sources. One such development is in 5G mobile communications, which enables significantly increased wireless data rates. Unsurprisingly, new materials are required to receive, manipulate, and transmit data at dramatically

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higher speeds, and the conventional polyimide dielectric layer has to 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 and including its 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 profile cutting/routing is carried out in FPCB manufacturing in which the final shape of a device or component is cut from the material sheet or web.

High-power UV lasers for full-depth cutting

High-power ultraviolet (UV) hybrid fiber lasers are ideally suited for full-depth cutting in FPCB manufacturing. MKS industrial laser application researchers took a closer look to the quality of the cuts: they performed a series of cutting experiments with a Spectra-Physics Quasar laser with 80 W average UV power and up to 400 µJ per pulse. LCP-based FPCB materials, including bare LCP sheet and copper-clad LCP laminates were tested. 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, multipass 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).

Challenges in measuring the beams

The cutting depth of the laser depends greatly on the energy applied to the material. It is essential to keep the pulse energy of the beam exactly in spec, but measuring the laser beam is difficult because the peak power of the beam is high due to the high pulse energies and short pulses. Measuring the average or intermittent power of the beam is only possible with dedicated sensors that are able to withstand higher power densities. By using a newly-developed coating, thermal sensors like the Ophir F80 (120) A-CM-17 enable the measurement of the nanosecond pulsed UV laser in the application described above. Due to its unique absorber, the sensor will not suffer from the ablation usually caused by very short pulses and can withstand high power densities up to 7 kW/cm² at 80 W.

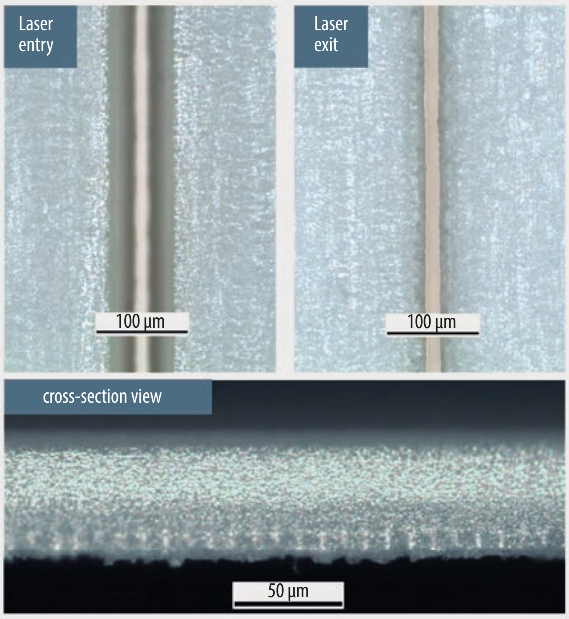

Fig. 1 Bare 50 µm thick LCP cut with Quasar UV80 laser. Entry (top left), exit (top right), and cross-section (bottom) views indicate excellent quality and minimal excess heating.

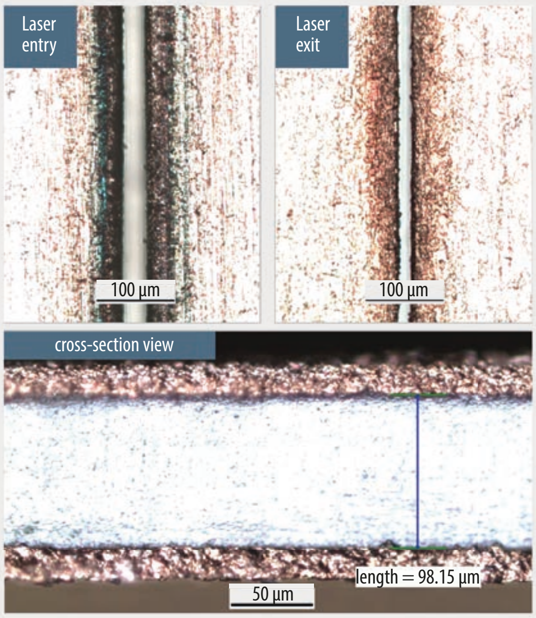

Fig. 2 Thick copper-clad LCP cut with Quasar UV80 laser. Entry (top left), exit (top right), and cross-section (bottom) views demonstrate clean, high quality cuts realized with temporally-tailored ns pulses.

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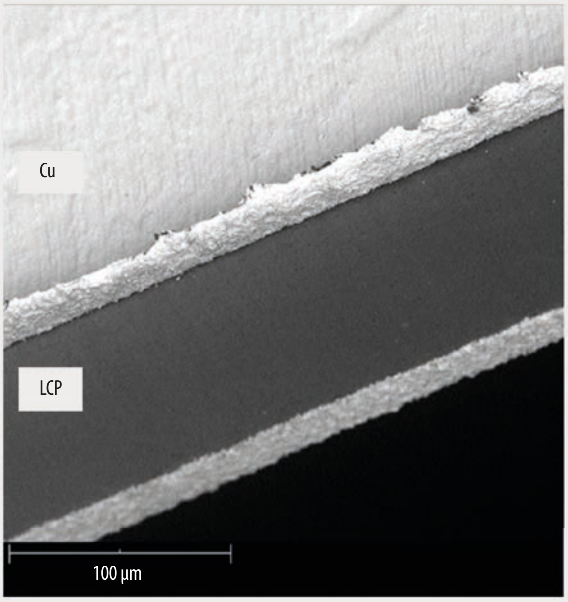

Fig. 3 SEM imaging reveals smooth material surfaces and crisp geometries of the copper-clad LCP cut with Quasar UV80 laser.

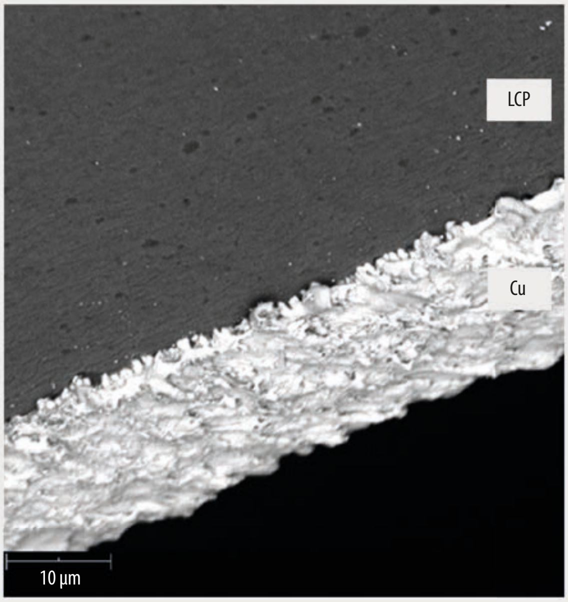

Fig. 4 Close-up SEM view shows Cu-LCP is fully intact after laser cutting with no LCP pull-back from the copper cut edge.

Achieving optimal cutting results with LCP sheet material

In addition to the energy applied to the material, there are many other parameters that influence the quality of the cuts. The first tests in the series were performed on 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 (**Fig. 1**) 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 'smoothing'). 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.

High pulse energy for copper-clad LCP laminates

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 at 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 pulses (2 ns), 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 (**Fig. 2**) show the overall good quality that can be achieved by 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 clad-

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ding. In addition, since copper peel strength with LCP is generally much lower compared to that of 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 lasers. Scanning electron microscopy (SEM) is a preferred alternative for the very close-up imaging of fine surface structures and the modulation thereof, and was applied for further analysis of the cut samples. **Fig. 3** shows a macro perspective of the 18 / 100 / 18 µm stack as viewed through an SEM.

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 such as modulations, edge straightness, and the like. Here, the SEM image reveals a clean and precisely machined feature with high-quality surfaces.

Of particular note are 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 (**Fig. 4**) confirms that the bond between the LCP and Cu layers is nicely preserved. Greater detail also shows a smooth and flat LCP surface, without any pull-back from the edge of the cut copper.

UV laser approved for high quality cutting processes

New materials are often ushered in with new technologies, and manufacturing methods and measurement equipment must adapt accordingly. For 5G mobile devices, the high data rates and high-speed electronics require the replacement of traditional polyimide dielectrics in FPCBs, in many cases with LCP films and laminates. To optimize the manufacturing process of those materials, it is essential to choose the best-suited laser technology, fine tune the parameter set and – when using the laser – check the energy of the laser beam regularly with suitable devices. The experiments performed in the MKS lab showed excellent cutting results with a high power and high pulse energy Spectra-Physics Quasar UV laser. 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.

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