PCB Machining And Repair Via Laser

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Lasers of different wavelengths and their interaction with typical PCB materials are being investigated in order to find new and economical methods for precision machining of both flex and rigid PCBs as well as for the repair of fine-line boards. Typical laser drilling machines are usually too expensive and too slow for these jobs. UV lasers with different pulse lengths, solid-state infrared lasers and new q-switched CO_2 lasers are promising alternatives. We take a look at the technological and economical aspects involved with the use of these lasers, especially for the cutting and separation of boards, and a new technology for laser-based repair of printed circuit board shorts.

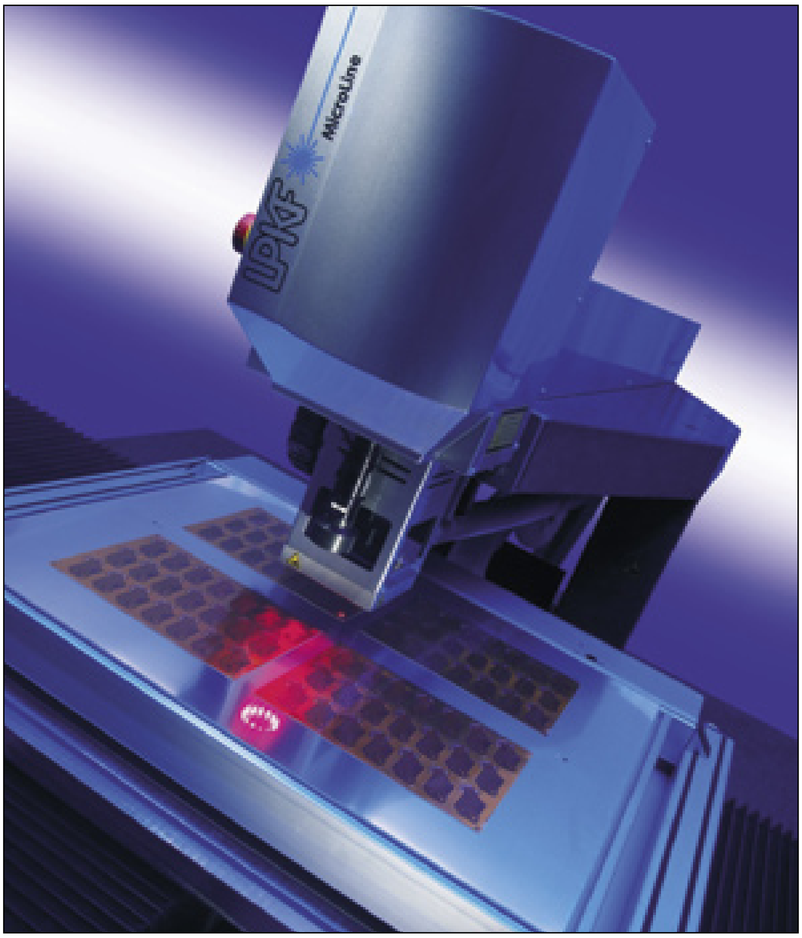


Figure 1 - LPKF's MicroLine Series laser systems for high-speed machining of rigid and flexible PCBs

HDIs and modern flexible PCBs require increasing precision in the cutting of outlines, slots and cavities. Lasers in general have a number of technological advantages over mechanical tools, such as the small size of the working spot (allowing almost any shape to be cut), the high cutting precision (due to online scaling capabilities) and a narrow impact zone around the cutting line. For small quantities in particular, one can also save on the costs of stamping dyes.

Today, the primary use of laser systems in PCB production is for drilling microvias. Laser drilling of microvias has been studied extensively and has worked very well for years; there is no question that it is a cost effective production process. Cutting applications are growing in a price sensitive environment, while removal of cover foils and solder mask as well as structuring of circuits are still an exception because of economic reasons. On the laser technology side, there has been a great development over the last few years, with even more promising trends for the future. Industrial solid-state UV lasers have reached an output power level of about 15 watts at 355nm, which starts to get critical for the optical components inside the laser.

New opportunities

Near infrared lasers like the well known Nd:YAG lasers are available with an output power of tens of watts and pulse lengths of a few nanoseconds. Modern concepts like disk lasers and fibre lasers are on their way to extending the usable output power of lasers, while the price per watt is dropping. A lot of effort is being put into developing lasers with very short pulses in the picosecond and femtosecond range, where interaction of laser radiation with materials follows different rules and could lead to new effects and new applications.

Also in the infrared spectrum, where most organic materials as well as glass absorb light very well, significant progress has taken place. Well known CO_2 lasers are no longer limited to their nominal continuous wave output power. A new series of CO_2 lasers can be q-switched, providing high peak

power in pulses as short as 150ns over a kHz pulse repetition range. These lasers can be controlled and operated like solid-state lasers in the near infrared and UV ranges. In the PCB industry, the question we should ask is:

"Can we use these promising new technologies to extend our manufacturing capabilities, speed up processes and improve the economics of precision machining?"

In answering this question, we should consider the most interesting PCB machining processes, the properties of the materials involved and the building up of composite materials. Inasmuch as the laser is an optical tool interacting with a material, the optical properties of the material are of particular interest. Each material can be characterised by its specific absorption spectrum, its threshold and its thermal conductivity, in addition to other parameters. Differences in threshold values from material to material are especially important for selective laser machining of printed circuits.

Laser cutting of PCB materials

Routing, de-panelisation and most PCB cutting processes involve the machining of organic materials, like polyimid, epoxy, acrylic adhesives, PTFE and LCP. The absorption characteristics of these materials show strong similarities. They are almost transparent in the visible and near infrared range, so that solid-state lasers with a wavelength around 1 µm cannot be used for machining them.

At the common wavelength of industrial UV lasers (355nm) these materials absorb the laser radiation, but not completely. The high photon energy of short wavelength radiation and short pulses with high peak power lead to an almost cold ablation process and to excellent cutting results in homogeneous organic materials.

At the infrared side of the spectrum we notice that all mentioned materials absorb the radiation of CO_2 lasers from about 9.2 to 10.6µm very well, making these lasers an interesting cutting tool. But long wavelength, lower photon energy radiation turns the cutting process into a thermal one. In such a process, the material is mainly burned away, leaving residues and melted material around the cutting area. With PCBs, reinforcements like glass fibres often have to be taken in account. Glass is opaque to CO_2 radiation but almost transparent at 355nm. Only the high peak power of q-switched UV lasers induces enough absorption for a cutting process. Compared to organic materials, the threshold of glass is high also for infrared radiation. Therefore, with reinforced materials, it is the reinforcement that determines the level of infrared laser energy that must be applied for the cutting process. With standard CO_2 lasers, this level can only be reached by extending the time of interaction, which in turn increases the extent of the melting of the surrounding organic materials.

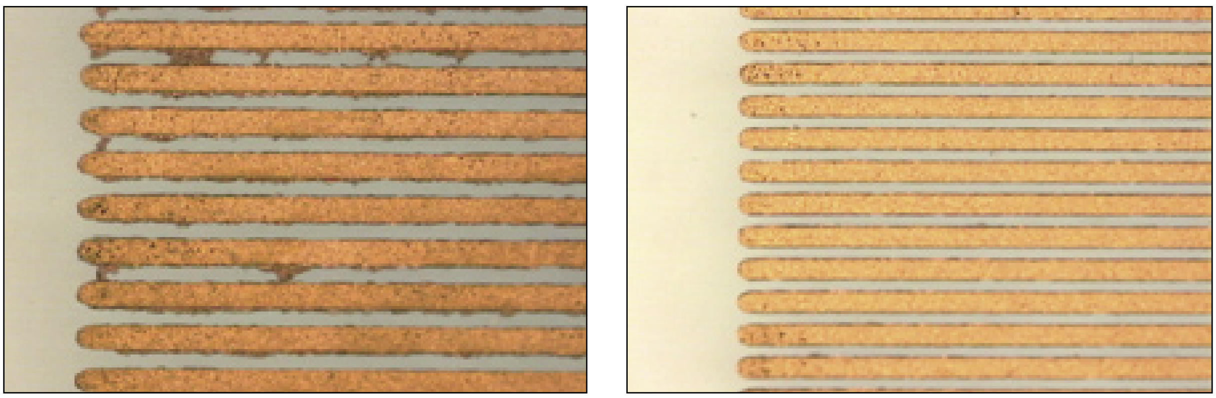
Short infrared pulses vs. UV lasers

At this point, we posed the question about short infrared pulses for cutting organic and reinforced materials, especially in comparison to UV lasers. As discussed before, laser cutting of PCBs remains a price sensitive process. Comparison between lasers should include both costs of the equipment as well as quality of the work and required post treatments. We investigated different PCB materials, in particular polyimid foil 75µm thick, laminated flex boards with 50µm basic foil, 50µm cover foil and 25µm acrylic adhesive in between, FR4 prepregs and boards of different thickness and type. Both UV and q-switched CO_2 lasers were deflected by galvo scanners. Process and control parameters were optimised for maximum speed.

The investigation shows that the q-switched CO_2 laser cuts 75µm polyimid foil 2 times faster than the high power UV laser, using a comparable machine setup. A 60µm prepreg FR4 1080, a 200µm FR4-Interposer and a 400µm FR4 board were all cut at about 4 times the speed of the UV laser. The quality of the cut edges was similar for both systems, and much smoother than that of usual CO_2 lasers. Cutting lines were significantly wider with the CO_2 laser due to a wavelength that is 30 times longer, but accuracy of cuts is comparable to UV. Cuts with the CO_2 laser show more carbonisation and residue. Cleaning will be a must for most applications.

Beyond these results we will con-

Figure 2 - Ultra fine lines before (left) and after (right) laser repair



tinue to investigate q-switched CO_2 lasers especially for processing of reinforced PCB materials. Due to differences in system cost between the two types of laser sources, the cutting speed values have to be normalized for a realistic cost comparison. We estimate a factor of 1.2 to 1.5 in investment cost for a q-switched CO_2 cutting system compared to the same setup equipped with a UV laser. Running cost are nearly comparable. In conclusion, we see about 60 percent lower cutting cost per part with the q switched CO_2 laser machine for applications where the wider cutting line is bearable. Higher expenses on cleaning the parts might reduce the advantage in some cases.

PCB machining with NIR lasers

Structuring circuitry directly by laser, using digital data and online scaling, has been the dream of many people in the electronics manufacturing industry for years. People ask this for different reasons: they like to produce precise fine line circuitry with sharp edges, they want to scale the circuitry online according to an inner layer or they want to produce RF circuits in their laboratory without chemicals. We have investigated ways to speed up the digital structuring process of boards in two ways: resist ablation and Copper ablation.

Resist ablation

In contrast to structuring processes based on exposure, a resist for direct ablation does not have to be photosensitive and should be thin for two reasons. The first advantage of a thin resist regards the etching process itself, which provides enhanced fine line capabilities. Secondly, the ablation speed depends on the volume of material to be removed and thus on the resist thickness. The use of a q-switched Nd:YVO_4-laser for the structuring of an ED resist of 1.5 µm thickness has been studied.

The first trials have shown promising results, both in terms of accuracy and process speed. Operating vector data has delivered smooth line edges independently of the line angles. Calculations based on these experiments show that one side of a fine line board with 50µm lines/spaces in the standard format 457 x 609 mm could be structured in less than two minutes.

Copper ablation

Direct ablation of Copper can also be performed with q-switched NIR lasers. Copper absorbs the radiation of 1064 nm wavelength and can be vaporised this way. Epoxy and glass, the usual substrate materials present beneath the copper both have low absorption at 1064 nm. Even the high power pulses necessary for copper removal do not damage the substrate significantly. This process is well known and so are its significant limits in terms of throughput. In order to vaporise large areas of Copper from a board it would obviously take much more laser energy and time compared to laser structuring of the ED resist, and even more than laser direct exposure of a photosensitive resist.

With a new approach to this problem, about 20 times higher process speed, less impact on the substrate and less smear can be achieved. One of the problems faced when soldering on a PCB is overheating. We noticed that the adhesion between the Copper layer and the substrate material is significantly reduced by heat. This usually "undesirable" effect is now used for fast Copper structuring in three steps. First, the remaining "dead" Copper is cut into areas thermally isolated from each other. Second, the laser performs isolation channels of about 30µm around all conductive lines. In the third step these Copper pieces are heated up by the laser to a temperature at which their adhesion with the substrate is lost.

The pieces are easily removed from the board surface during or after the heating process. About four square centimetres per minute have been structured with this laser-only technique without using any chemicals at all. Different substrate materials like FR4 and PTFE-based RF materials have been tested. A first laser machine based on this concept has been launched by LPKF.

Laser repair

Shorts between conductor tracks caused for example by the etching process are a common problem throughout the PCB industry. Identified by AOI, they are mostly corrected by hand using a scalpel or a needle. With spaces smaller than 200µm, these tools become too large and the success of the repair depends a lot on the experience, the skill and the condition of the operator. These factors become even more relevant with an increasing share of boards with spaces of 100µm and less. LPKF was asked to develop a tool for manual use that could reliably repair shorts on all types of boards and inner layers independently of the operator's skills and form, especially on boards with ultra fine line circuitry.

Removing Copper from a substrate is an operation very similar to direct Copper structuring discussed above. NIR lasers are able to ablate Copper without harming the substrate any more than a scalpel. And laser radiation can be focused in spots of a few microns in diameter (much smaller than the tip of a needle). As this is a manual operation, single laser pulses should be fired. Different Copper thicknesses at the shorts require different power levels. Looking through a microscope, the operator guides the laser beam to the short with a joystick and fires single pulses or a series of pulses while moving the spot (Figures 2). The device, called the LaserScalpel, has run field tests and has already been launched on the market.

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