Electrical analysis of laser depaneled PCBs

LPKF Laser & Electronics AG

Introduction

The miniaturization trend in electronics has enormous effects on the printed circuit board. On the one hand, the density of components has increased significantly. On the other hand, the highly integrated components have become both considerably more compact and more powerful. With the significant increase in components on a board, the number of connections has increased dramatically.

LPKF's UV laser systems are used for the depaneling and contour cutting of PCBs. The laser is the most suitable tool for machining printed circuit boards when high precision and low mechanical load are required. The selection of suitable processing parameters optimizes the cutting process and prevents unwanted changes in the electrical properties of the printed circuit substrate.

Electrical effects of laser cutting

SMD (Surface-Mounted Device) components and conventional components are connected to the printed circuit board in completely different ways. Wired components are soldered by means of through-hole technology (THT) in mounting holes. SMD elements are placed with their flat connection surfaces directly on the pads of a printed circuit board.

The connections of conventional components are soldered with traces on the back of the board or via inner layers. The component pins protrude from the back of the board. The direct soldering of the SMD components on the pads allows a dense, two-sided mounting. The greater number of connections per component leads to greater complexity with significantly less space. The devices are considerably smaller and cheaper.

For highly integrated PCBs, SMD components are often placed very close to the contour or panel edges. Contour cutting and depaneling with the LPKF UV laser systems enables minimized cutting channels, is non-destructive and does not cause mechanical stress or dust generation. The depanelization with UV laser systems is thus not only simpler and more comfortable, the individual boards can also be placed closer to each other. Last but not least, the risk of failure is minimized since the mechanical load on the boards is lower and no drills can break off. But the laser beam may cause local changes in the electrical isolation properties on the cut sidewalls of the board substrate material if the process parameters were not optimally selected.

Two measurements are crucial for determining the electrical properties of the cutting edges:

- Sidewall resistance
- Arc voltage

The sidewall resistance of the laser-cut PCB should be high enough to eliminate the risk of electrical shorts, even if there are traces or components on both sides of the PCB near the cutting edges. In high voltage PCB applications where the risk of electrical arcing and electrical breakdown must be avoided, the dielectric strength of the PCB substrate may become critical. The arc voltage should therefore be as high as possible.

The aim of the LPKF project "Electrical analysis of laser depaneled PCBs" is to determine the best possible setting parameters of the LPKF UV laser in order to achieve maximum protection of the printed circuit boards with optimum edge cutting quality and high performance. For this purpose, the effects of different laser settings on the electrical properties of the printed circuit board substrates were investigated and evaluated.

It was also investigated how the distance between the cutting channel and the traces influences the electrical properties.

In the test series, the electrical/dielectric properties of FR4-based PCBs were measured after laser cutting. The test setup determines the sidewall resistance and the voltage at the occurrence of an arc on a 1.6 mm FR4 substrate.

Measurement Methods

The printed circuit boards are 28 x 28 mm in size with a FR4 thickness of 1.6 mm and a copper layer thickness of 32 μm. On top, a copper track has a T-shape (Figure 2). The tab (20 mm) on the upper edge of the T-conductor is cutted parallel to the trace by the laser. The cutting distance to the edge of the trace is varied. The lower short web (2 mm) is mechanically cut.

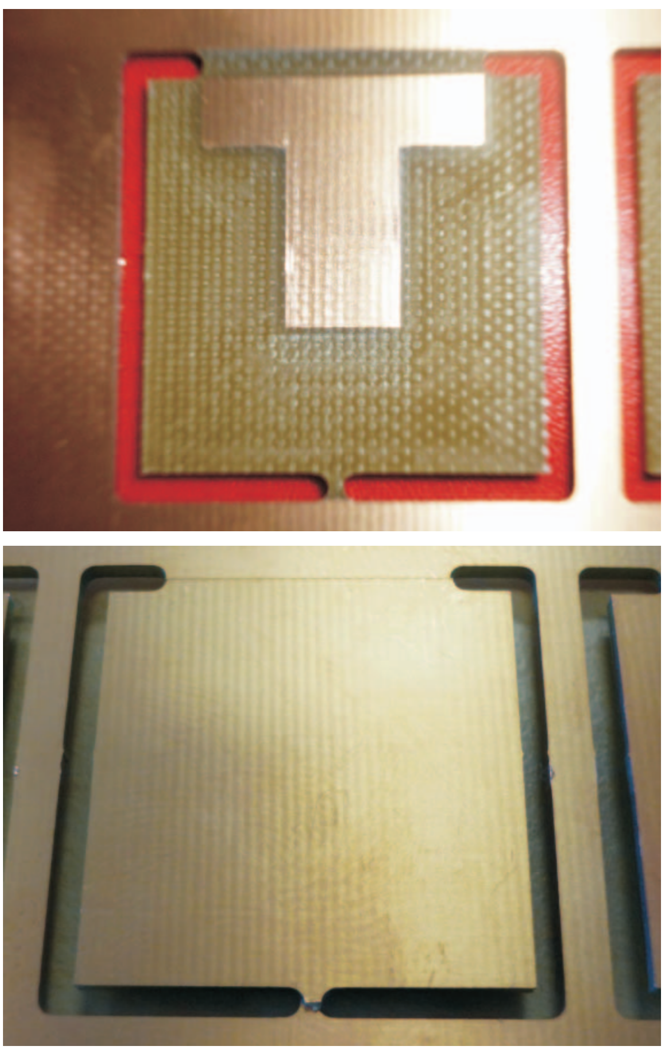

Figure 1: T-Shape copper conductor on PCB top side (left) and PCB bottom side

Electrical isolation test

The electrical insulation tests on the boards are made with the high resistance meter METRISO 2000. The device is specialized for the measurement of resistance to ground and surface resistance. The insulation resistance is measured at specially developed printed circuit boards with a T-shaped trace between the top and the bottom of the cut-off tab of the board. The resulting measured value is called sidewall resistance, R_s [Ω].

Sidewall resistance measurements	
Test voltage	100 V (DV)
Range of measurement for the Sidewall resistance (R_s)	1 kΩ to 1 TΩ
Measurement duration	1 min
Test probes	Flat bottom probes, 70mm diameter

Table 1: Technical data for METRISO 2000

Flat bottom probes are used to contact both sides of the PCBs and a test voltage of 100 V (DC) was applied during 1 minute. The measurements were repeated five times on each sample and the samples were kept under lab environment during the measurements.

Figure 2: Flat bottom probes for surface resistance measurements

Dielectric strength test

The breakdown voltage of an insulator is the minimum voltage at which a part of an insulator becomes electrically conductive. The high voltage tests were carried out with the PROFITEST 204+ Equipment. The device is specialized for protective conductor, insulation and residual voltage measurements. In the measurements, high voltage (AC) of 250 V to 2.5 KV in steps of 100 V was applied for every 10 seconds until an arc occurred on the side wall. The resulting voltage at which the arc occurred is called arc voltage, V_{arc} [V].

High voltage test	
Applied voltage until arc Voltage, V_{arc} (V)	250 to 2500 V (AV), in 100 V steps
Measurement duration	10 sec.
Test probes	High voltage pistols with switch

Table 2: Technical data for PROFITEST 204+

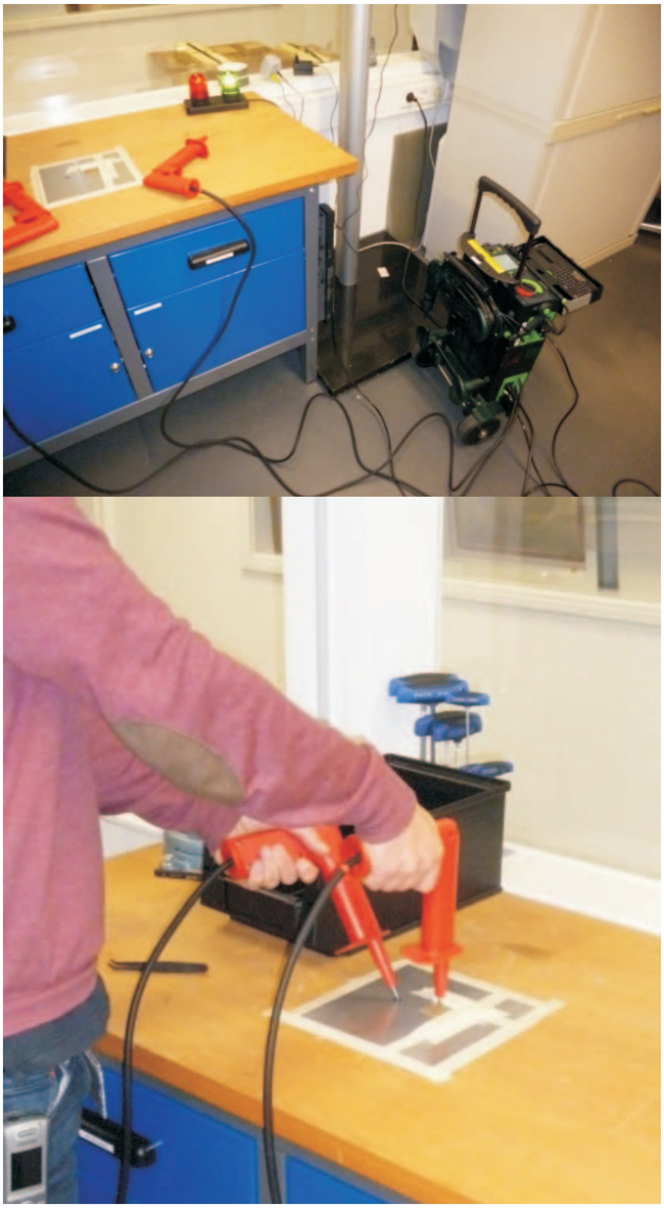

Figure 3: Dielectric breakdown test, high voltage is applied until arc occurs on the sidewall

The measurement described was made only once for each board since it is destructive. A breakdown can affect the dielectric properties of the material.

Test series

For the investigations, following process parameters are considered:

Variable Parameters	Fixed Parameters	
Laser power, P	Laser pulse Frequency, f	40 kHz
Scan speed, v_{scan}	Laser Spot Diameter, d_{spot}	20 µm
Cooling time, t_{cool}	Laser Pulse Duration, t_p	20 ns
Distance to conductor, Dist	Laser Wavelength, λ	355 nm

Table 3: Variable and fixed parameters during the investigations

The electrical measurements on the boards were made with different parameter combinations from Table 3. As reference values mechanically cut boards were tested. The test series was carried out based on the statistical method DoE (Design of Experiments). This specifies the process input variables that significantly influence the process result. With these results, in turn, the input variables can be optimized for the desired result.

Sidewall resistance

The sidewall resistance measurements show the isolation of the substrate material after cutting. In the mechanical cut samples, the sidewall resistance values are higher than 1TΩ. Resistance values higher than 1TΩ cannot be measured with the used equipment and are considered as completely electrical isolated.

The measured values were analyzed with the statistical evaluation software Minitab. The results show that the scan speed and the distance from the cutting channel to the copper conductor have the highest impact on the sidewall resistance. In contrast, the cooling time has little influence and the laser power has no statistically significant influence on the sidewall resistance.

For applications where traces are spaced less than 0.5 mm from the cutting channel on both sides of the board, scan speeds and cooling times should be set high to ensure sidewall resistance values as in the mechanical reference.

Arc Voltage

In high voltage PCB applications, the dielectric strength of the board substrate becomes a critical factor. The occurrence of electric arc must be prevented at all costs. In the mechanical cut PCB samples, the arc occurs at 2 KV. This value is used as a reference.

The experiments showed that the scanning speed and the distance of cutting channel to copper conductor have the greatest influence on the arc voltage - where the distance has the biggest influence. The cooling time and the laser power have no significant influence on the arc voltage.

Sidewall resistance and arc voltage as a function of the distance

Because the distance has got the biggest influence, sidewall resistance and arc voltage are further analyzed only as a function of distance, while the other process parameters, scanning speed and cooling time, remain fixed. The results obtained to optimize these significant parameters are used to maximize sidewall resistance and arc voltage.

The cutting channel is arranged at a distance of 0.1 to 2 mm from the traces on both sides of the boards. The thickness of the FR4 boards is 1.6 mm and that of the copper layers is 32 μm. The electrical measurements are also made on PCBs cut in the same way with a CO_2 laser to compare the results with the UV laser.

The measured values show approximately the same values of sidewall resistance for the UV laser and the mechanically cut boards. Even with a small gap between the cut edge and the trace, the resistance values are only slightly lower than the mechanical reference values. At distances of >1 mm there is no significant difference in the insulation resistance between laser and mechanical cut boards. The results show that even when cutting traces on both sides of the PCBs a galvanic isolation can be guaranteed.

The measured sidewall resistance of the boards cut with the CO_2 laser are significantly lower compared to the UV laser. The difference between UV and CO_2 lasers is more significant at distances of less than 0.4 mm.

After the resistance measurements, the high voltage tests were carried out on the same boards. In the case of UV laser-cut boards, the arc occurs at a distance of 0.1 mm at 1.55 kV, whereas in the case of mechanically cut boards the arc only occurs at 2 kV. At a distance of 1.3 mm, comparable voltage values are measured. This limitation should be considered for high voltage boards to avoid the risk of electrical breakdown. In the case of the CO_2 laser, the breakdown occurs even at voltages below 1 KV, when the conductors are closer than 0.4 mm to the cutting channel.

Electrical and thermal effects

Earlier investigations by LPKF document the temperature changes of SMD components during laser cutting of printed circuit boards. It was determined that at lower scan speeds, the peak temperature in SMD components increases as more energy is induced with a larger spot overlap. In the same way, the sidewall resistance is lower when cutting at lower scan

Distance, Dist [mm]	Sidewall Resistance, R_s [Ω]		Arc Voltage, V_{arc} [V]	
	UV laser	CO_2 Laser	UV Laser	CO_2 Laser
0.1mm	6.4E+11 Ω	5.6E+08 Ω	1555 V	437 V
0.4 mm	6.4E+11 Ω	1.8E+10 Ω	1950 V	1000 V
0.7 mm	7.2E+11 Ω	2.7E+10 Ω	1670 V	1700 V
1 mm	9.3E+11 Ω	3.1E+10 Ω	1800 V	1900 V
2 mm	9.1E+11 Ω	4.8E+10 Ω	2500 V	2250 V
Reference (mechanical cutting)	*1.0E+12 Ω*		*2016 V*	

Table 4: Electric measurements as a function of the distance to the cutting channel

speeds. At high scanning speeds, peak temperatures remain below typical soldering temperatures, even when cutting at distances of 0.1 mm to SMD components. The same parameter settings would ensure comparable sidewall resistance to mechanical cutting. The scan speed and the distance from cut edge to conductors or components have the greatest impact on changes in temperature and electrical resistance in PCBs and components.

The cooling time has a significant influence on thermal and electrical effects. These mainly depends on the layout of the board. The more tabs to cut, the longer the cutting path and thus the cooling time between repeats. Additional cooling pauses can be added, but result in longer cycle times. The cooling time has a greater influence on the temperature than on the sidewall resistance.

The investigations of the cut quality clearly showed that the scan speed has a much greater influence on the cut quality than the laser power and cooling time. It mainly determines the carbonization and charring of the cutting edge.

The investigations of both thermal and electrical effects show how to prevent any risk of electrical or thermal damage in printed circuit boards or SMD components. The determined influences of the process parameters and their valence should be used to optimize the quality of the cut. The better the cut quality, the lower the generated carbonization or charring in the cut area and the lower the thermal and electrical effects in the board and the components.

Summary and conclusions

The investigations consider the electrical effects of laser cutting on printed circuit boards with a 1.6 mm FR4 substrate. With statistical analysis tools, the most important parameters for UV laser systems are determined to optimize the cutting process.

The focus of the investigations is on the resulting sidewall resistance of the laser cut edges and the electrical arc voltage. The series of measurements show that both values are to be controlled via a suitable selection of the process parameters. The aim is to approximate the measured electrical values to the values of the mechanical cutting in order to exclude the possibility of electrically induced damage to the printed circuit board.

The most important variables influencing the sidewall resistance of the laser cut edges were identified as the scan speed and the cooling time. With proper adjustment of the laser parameters, the sidewall resistance remains close to the values of the mechanical cutting, even at cut edges that are close to the conductors.

For high voltage PCBs, dielectric breakdown strength should be considered. The distance between the cutting channel and the traces has been found to be the most significant factor. For 1.6 mm FR4 substrates and traces on both sides of the board, the cutting channel should be positioned at least 1.3 mm from the conductors. At this distance, the arc or breakdown occurs at 2 KV, which is the same voltage as at the mechanically cut reference.

Furthermore, the influence of process parameters on the thermal and electrical effects was determined and compared. Table 5 lists the recommended parameter ranges to optimize the cut quality for FR4 1.6 mm substrates.

Response optimization	HAZ < 40 μm	Tmax in SMD components < 100 °C	Sidewall resistance > 1 TΩ	Arc voltage > 2 KV
Laser power, P	Pmax	Pmax	Pmax	Pmax
Frequency, f	40 kHz	40 kHz	40 kHz	40 kHz
Scan speed, v_{scan}	400 - 600 mm/s	400 - 600 mm/s	400 - 600 mm/s	200 - 600 mm/s
Cooling time, t_{cool}	100 - 300 ms	100 - 300 ms	100 - 300 ms	100 - 300 ms
Distance to cutting channel, Dist	-	> 0,1 mm	> 0,1 mm	> 1,3 mm

Table 5: Summary of optimal process parameter ranges for minimal thermal and electric effects