Material Effects of Laser Energy When Processing Circuit Board Substrates during Depaneling

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ABSTRACT
Using modern laser systems for the depanelization of circuit boards can create some challenges for the production engineer when it is compared to traditional mechanical singulation methods. Understanding the effects of the laser energy to the substrate material properly is essential in order to take advantage of the technology without creating unintended side effects. This paper presents an in-depth analysis of the various laser system operating parameters that were performed to determine the resulting substrate material temperature changes. A theoretical model was developed and compared to actual measurements. The investigation includes how the temperature increase resulting from laser energy during depaneling affects the properties of the PCB substrate, which varies from no measurable change to a lowering of the surface resistance of the cut wall depending on the cutting parameters. In addition the amount and properties of the ejecta that are potentially resulting from the laser processing is investigated. Understanding the composition and quantity of any resulting residue may have a great impact to both the board design and the selection of the appropriate circuit board singulation method that will achieve the best possible results. An Energy Dispersive X-ray Analysis method (EDX) was performed to investigate if any unwanted material compounds are present on the cutting sidewalls of an FR4 circuit board substrate as a result of laser energy induced during the depaneling process.

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DEPANELING METHODS:

Many depaneling methods are being used in the industry, like: 1) punching / die cutting, 2) v-scoring, 3) wheel cutting / pizza cutter, 4) sawing, 5) water jet, 6) routing (+nibbling). Some of these are useful only in very low cost, minimal quality applications; others can only be used for rectangular boards. Several can do damage to the board edges because of significant pressure and/or bending forces potentially causing some delamination which may impact long term reliability. All this means that during the board layout care must be exercised to keep fragile components and sometimes circuit traces away from board edges. And the waterjet method has hardly been explored.

The most commonly used method is the routing where a kerf is cut around each board, regardless of board shape, by the panel manufacturer. To keep the board in the panel during the assembly process in a few locations the kerf is interrupted. The routed kerf in the panel typically is about 3 mm wide, which means that in a case with many small boards a significant amount of panel space is used for cutting slots. Sometimes, with many slots in the panel, the panel becomes less rigid and panel supports or a pallet is required during the assembly process. Typically holes are being drilled in the connected areas to make it easier to break the boards from the panel which means that during board layout these locations must be decided and fragile components must be kept away from them.

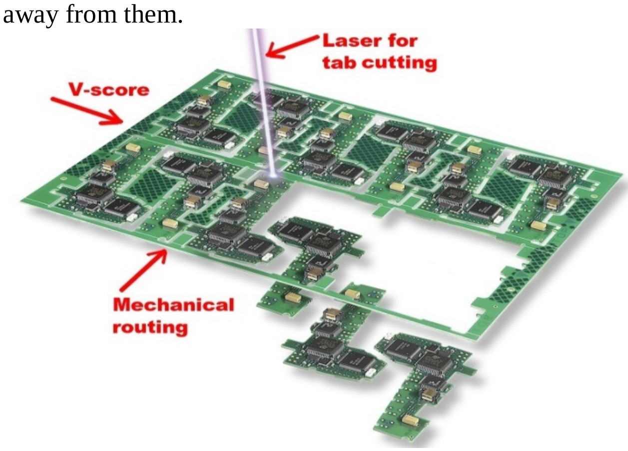

Figure 1. Combining various singulation methods in the one panel

LASER CUTTING

The latest method added is laser routing which can be done after the last step in the board assembly process. This means the panel retains its rigidity throughout the previous assembly steps. Like a router, the laser cuts completely through the board, so no bending or pressing on the edges of the board occurs, which means no stresses are exerted on the board material. With the use of a laser, cutting any shape board can be accommodated and the changeover to different boards is very quick as the process is completely computer controlled.

LASER SYSTEM.

The three main parts of a laser cutting system are the laser, the X-Y table for panel movement and the scanner to move and locate the beam.

Figure 2. Example of a laser depaneling system in an in-line setting for automatic loading and unloading.

To cut various materials several types of lasers are available. These have varied from CO2 at about 10 um wavelength available for well more than 20 years to UV lasers at about 350 nm wavelength showing up around 10 years ago. About 20 years ago the Nd:YAG lasers at 1054 nm wavelength were introduced to be used in stainless steel stencil cutting systems.

As the wavelength gets shorter the lasers have been more difficult to be produced economically, which has led to the gradual timewise availability of the different systems. Shorter wavelength lasers and those with very short pulse widths have typically been much more expensive, which is why it has taken time to get them deployed in the industry.

Infrared lasers can be called “hot” lasers as they heat and burn a path in the material to be cut. With UV lasers it is possible to ablate the material. A short high energy pulse enters the top layer of the material and evaporates and explosively removes a layer of the material. By going over the same path several times ultimately a cut is obtained through the material. As very little heat is produced by the UV beam, there is very little or no burned material on the edges of the cut depending on how the laser is being used (Figure 3.).

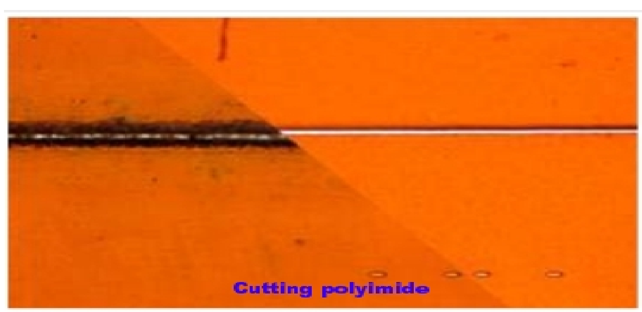

Figure 3. Infra Red cut versus Ultra Violet cut

Depending on the wavelength of the light, some materials reflect it and some are completely transparent. For the ablation method to work, the laser beam has to penetrate into the material to be cut. Figure 4 shows how various circuit board constituents react with different wavelengths. To be able to ablate all of them the UV laser is a good choice and UV lasers (wavelength ~350 nm) have become economically attractive only for the past 10 years.

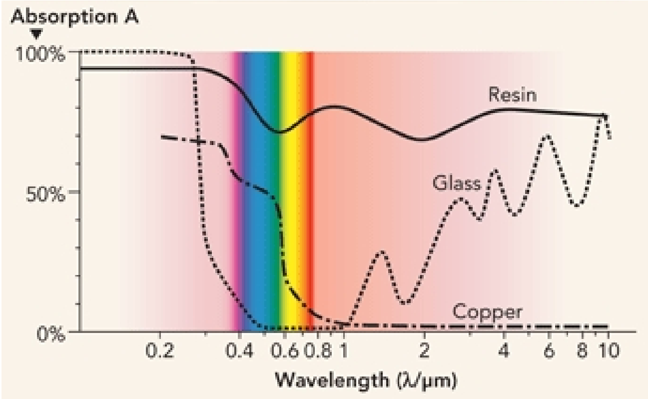

Figure 4.

Shorter wavelength and excellent optics allow for a very small beam size, often around 15 to 25 um. This allows cutting a very narrow kerf in the panel resulting in minimal waste between boards, especially as the mechanics of the system allow very precise beam location. The example in Figure 5 shows part of a panel with very small boards. When the routing process was used the number of boards per panel was approximately 125 and after re-layout of the panel to use laser cutting the number of boards increased almost three-fold. This resulted in a very significant economic advantage.

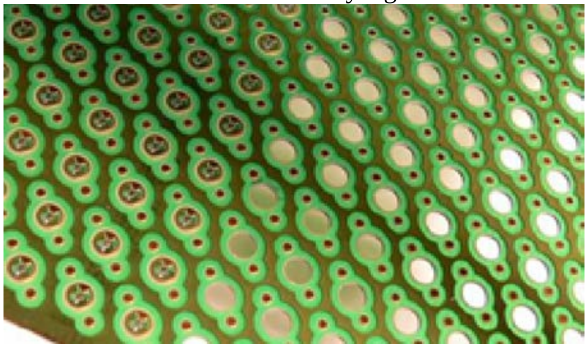

Figure 5. Example for a panel with very small circuits

In the laser system used in this example, a panel is placed on a perforated surface with downdraft, or mechanically mounted on the high precision X-Y movable table to prevent the panel from moving during the cutting operation. For boards with components on both sides a special support pallet is required.

To cut all the paths on a panel the area is divided in blocks of 50 x 50 mm in which the laser beam is moving using precision computer controlled mirrors mounted on galvanometers. The beam movement speed within this area is well controlled and can be as high as 1000 mm/s. While cutting an airflow passes across the panel as is shown in Figure 6 to remove debris minimizing any deposits on top of the panel. When the cutting inside the 50 x 50 mm area is finished the table is moved to the next square, until the project is finished.

Location precision

From the original design data (e.g. Gerber file) the laser system can use panel fiducials to locate where the cut is intended to go. The table movement in conjunction with the galvo movements are computer controlled and allow the beam to be located within 25 um of where it is supposed to be. However when singulating boards or flex circuits, the precision of the panel image is typically less and therefore it often becomes necessary to use additional fiducials for smaller portions of the panel. It is even possible to use recognizable sections of the board pattern for more precise board edge location requirements.

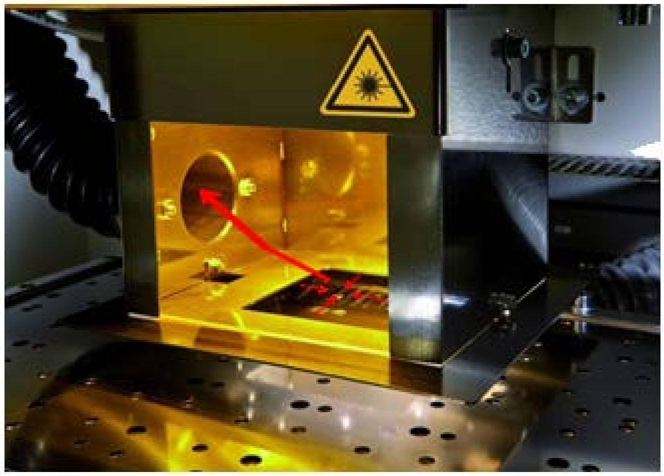

Figure 6. Airflow and exhaust

Residue on board surface

Even though an airflow passes across the area being cut (Figure 6), not all of the material expelled from the kerf is caught. Some remaining particles are powdered epoxy and glass particles. None of these are measured to be larger than 20 um and they averaged around 10 um. (For reference see the circled area in Figure 7) Their size and quantity should not raise any concerns.

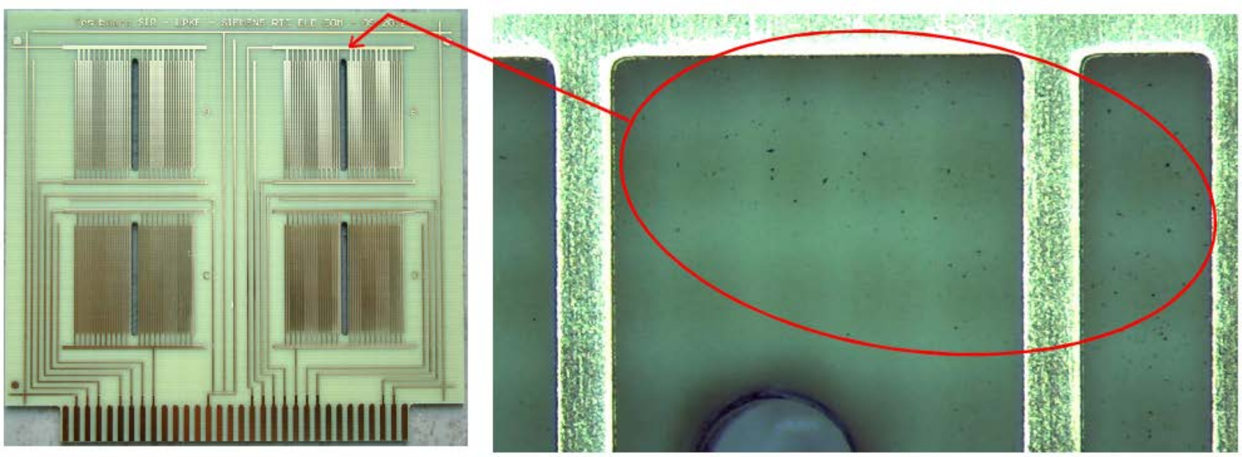

Fig 7. Surface after laser cutting

But to determine if the redeposited material can cause any problems, a test board was designed made of FR4 material, 800 um thick (Figure 7). The test board had four patterns with sets of 2 groups of interdigitized fingers. Each pair of these fingers is connected to the edge of the board for easy measurement of the Surface Insulation Resistance (SIR). As part of the test a slot was cut in close proximity to the fingers. After cutting the slot these test boards they were subjected to a climate test (40° C, RH=93%, no condensation) for 170 hours and the SIR was measured. In all measurements the values exceeded 10E11 Ohm indicating that the SIR is not negatively impacted (Figure 8).

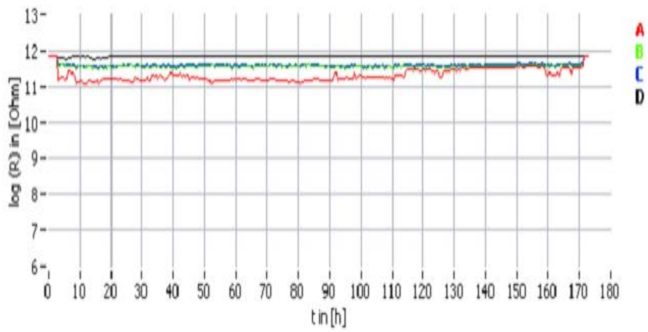

Figure 8. Surface resistance measurement

If so desired a simple cleaning process can be added and will remove the remaining particles. This can be done by wiping with a smooth dry or wet tissue, using compressed air or brushes.

Thermal Effects

Even though UV laser can be called "cold" lasers, there still is some heat being generated. Its impact is very dependent on the settings of the laser system. The laser beam inserts some heat into the material being cut and heat is being removed by dispersion into the material, radiation into the environment and convection into the air using forced air flow over the material.

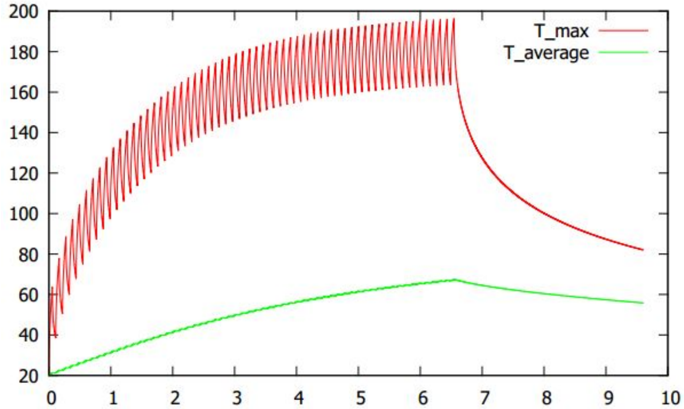

Figure 9. Simulation of heat accumulation

The heat equation is a parabolic partial differential equation that describes the distribution of temperature in a given region over time.

$$\frac{\partial u}{\partial t} = \beta \frac{\partial^2 u}{\partial x^2} - \alpha(u^4 - u_0^4) + q(x,t)$$

The resulting graph (Figure 9) shows the gradual increase in temperature for multiple passes with the laser beam along a cutting path. Ultimately a balance will be reached between applying heat and dispersing, radiating and convection of heat away from the cut area.

In order to determine what actually occurs in the circuit board material near the kerf cut by the laser, linear temperature sensors were placed on a test board. (Circled in Figure 10.)

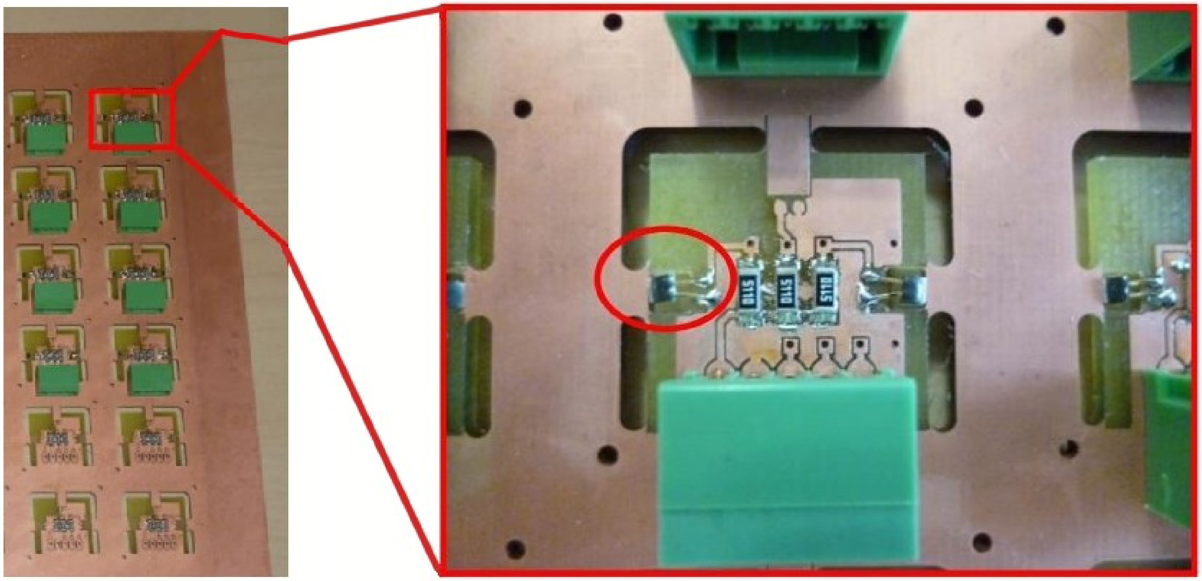

Figure 10

In this test the tabs were cut, some of which are bare FR4, some are FR4 with copper and some are FR4 without the routed slots and the nearby temperature rise was measured.

The tabs where the sensors were placed were cut with the cutting path at different distances from the sensor. Even when cutting within 0.1mm from the sensor, the temperature reached only 100 °C, well below any temperature the board is normally being exposed to during the soldering process.

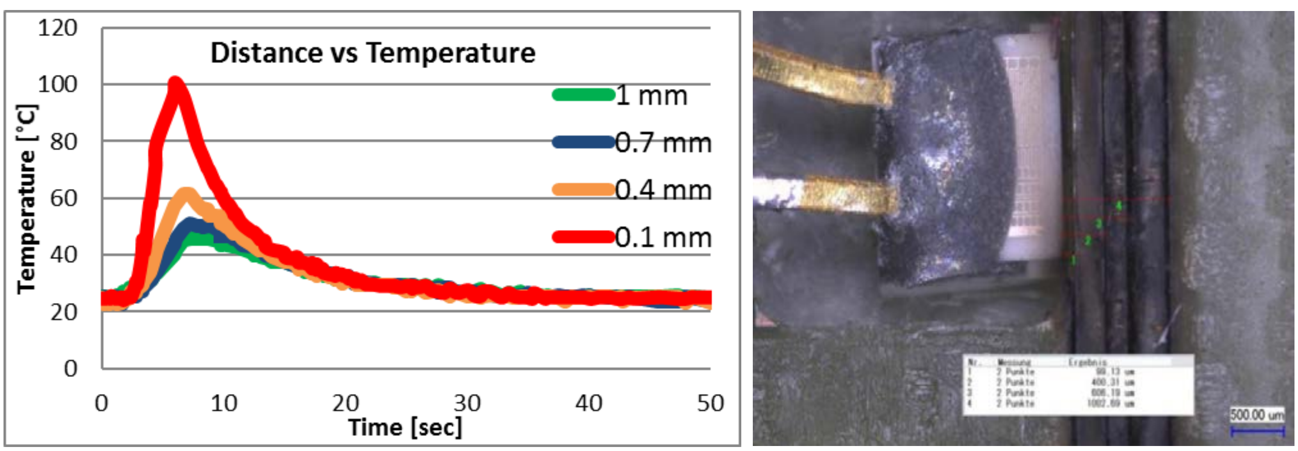

Figure 11. Cutting in one material type, measuring at different distances.

The cutting parameters for this example were : P = 12.4W, v=244 mrn/s, rep = 30, CT = l00 ms, full-cut FR4 (thickness 400-450 µm.

Cooling time (CT) is the time it takes for the beam to return to the same location. During this time other sections of the outline are being cut and it can also include a rest period between repetitions. The cooling time in this example was 100 ms.

To compare examples of cutting through the different materials, bare FR4, FR4 with copper and a full-cut FR4 were investigated, with the results showing in Figure 12.

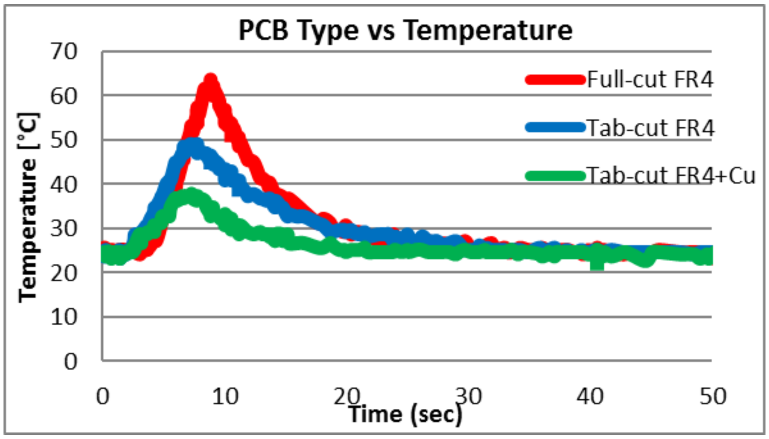

Figure 12. Comparing temperatures in different materials

Because different efforts are needed to cut through different materials, different cutting times result and for the more difficult situations higher temperatures are being measured. Still the temperatures at a distance of about 0.1 mm remain quite acceptable.

Quality versus Time

As mentioned, the laser beam does apply some heat to the workpiece. In order to minimize the impact of the heat the beam is scanned multiple times over the cutting path to distribute and minimize heat build-up. For this reason the beam control system allows adjustment of the movement speed and beam power, but it is also possible to insert rest periods between cutting paths. These rest periods are more important when the cutting path is short and the beam would be back in the same location more quickly.

When board layout and component placement are done well away from the sides of the individual boards, the cleanliness of the sidewalls is of less concern and the laser parameters can be selected for maximum cutting speed, meaning higher beam power, faster beam speed and shorter rest periods between cutting paths.

On the other hand when the cleanliness of the sidewall is critical, more care has to be taken in the selection of the machine settings. Figure 13 presents a visual difference between these two strategies.

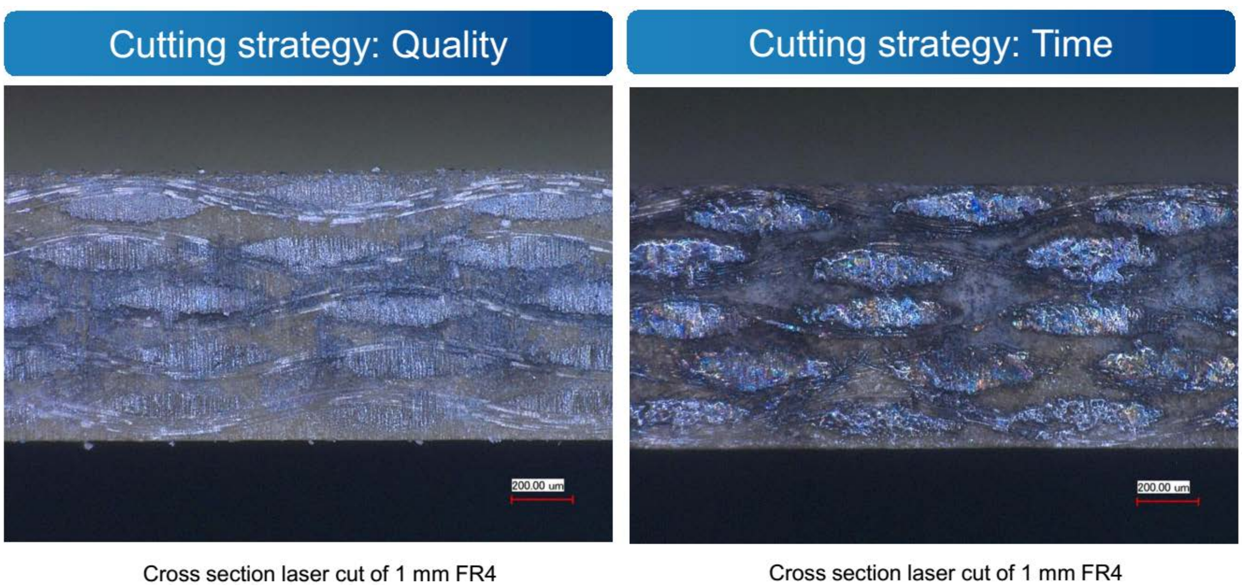

Figure 13. Visual difference between high quality / low speed and fast speed / lower quality.

Surface analysis

To determine the spectrum of chemical components left on the cut surface the Energy Dispersive X-ray (EDX) Analysis method was performed. For reference a routed sidewall was carefully polished and cleaned to show the normal composition of a board. Spectral lines from four chemical components are displayed in false color for the polished sidewall (Figure 14) and for the laser cut sidewall (Figure 15). The variation is too small to expect significant issues.

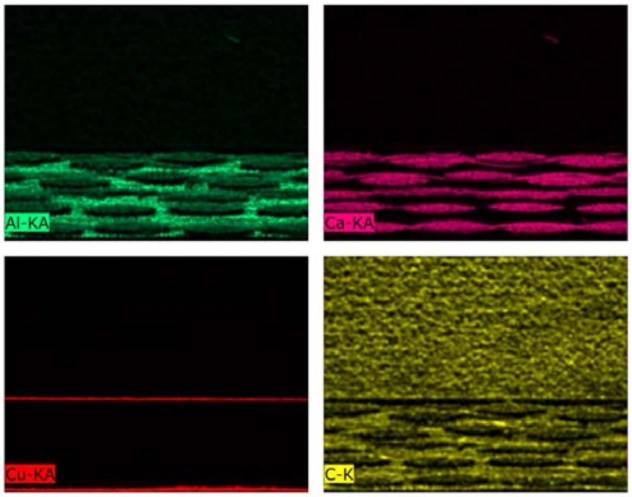

Figure 14. Polished and cleaned sidewall

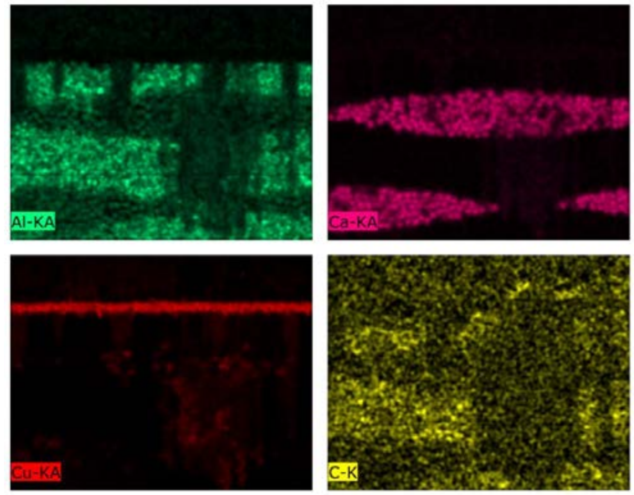

Figure 15. Un-treated laser-cut sidewall

Pin point EDX analysis

Additional EDX probing was done on cut walls of boards with different thicknesses and with differences in laser system setups. From those there were selected the ones for an 800 um board (33 mil) cut with setup conditions as in Table 1 and comparing those to a cut made in a similar board which was depaneled with a router.

A finely focused beam was used to be able to measure the chemical components on the epoxy and also on the glass fibers. In the tests, probes 3 and 4 are done with different cooling (or rest) times between passes thereby allowing the surface to remain cooler.

Table 1.

	P [W]	f [KHz]	v [mm/s]	Repetition [x]	Cooling time [ms]	FR4 Thickness [µm]
Probe6	12,4	40	600	180	300	800
Probe5	12,4	40	100	30	300	800
Probe4	12,4	40	244	35	385	800
Probe3	12,4	40	244	35	175	800

Pin point EDX analysis epoxy areas.

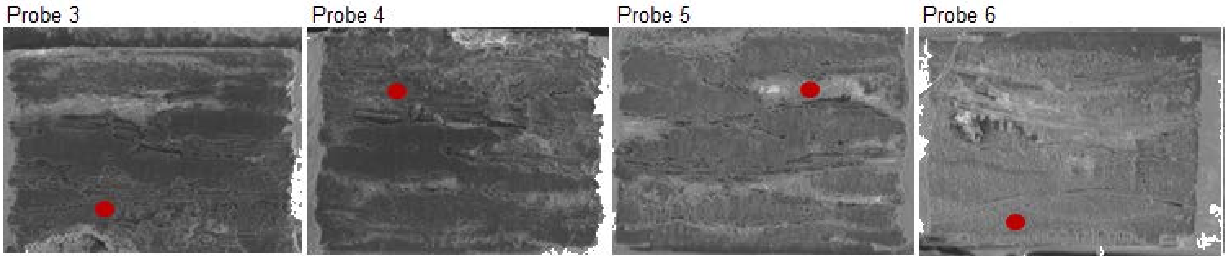

Figure 16. Inspecting epoxy areas

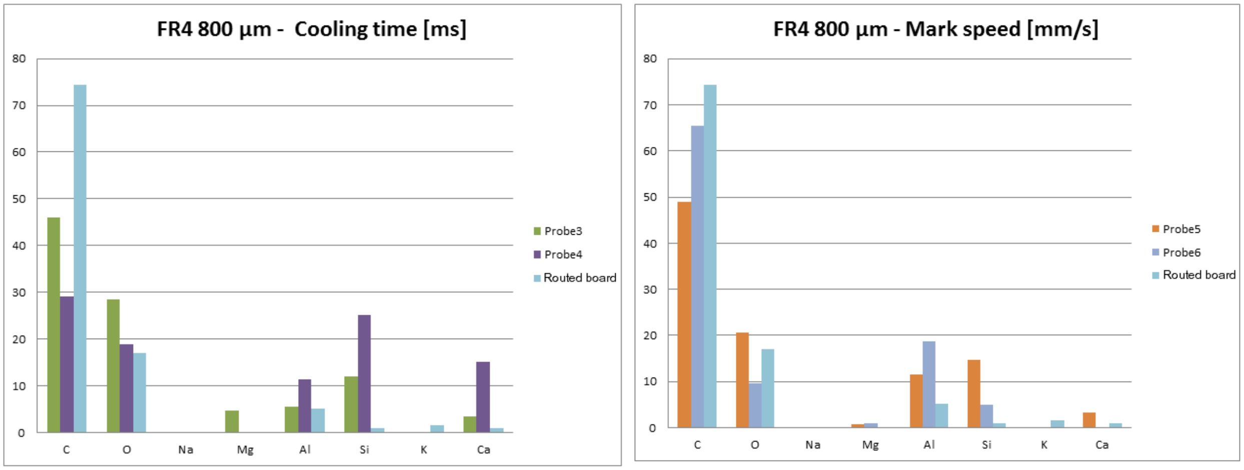

Figure 17

Pin point EDX analysis of glass areas

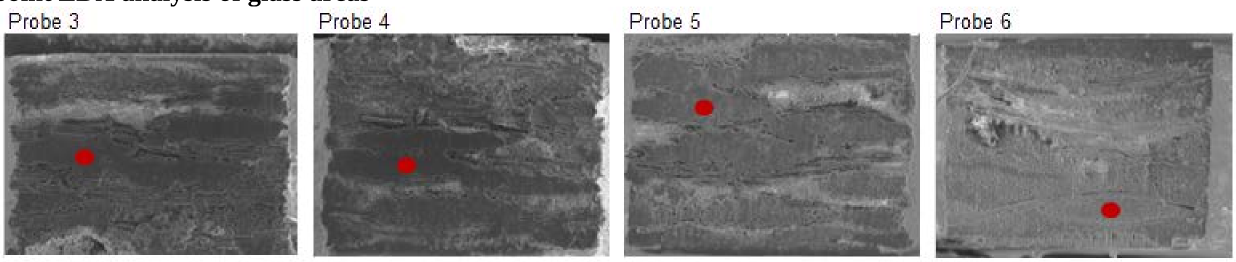

Figure 18. Inspecting surface of glass fibers

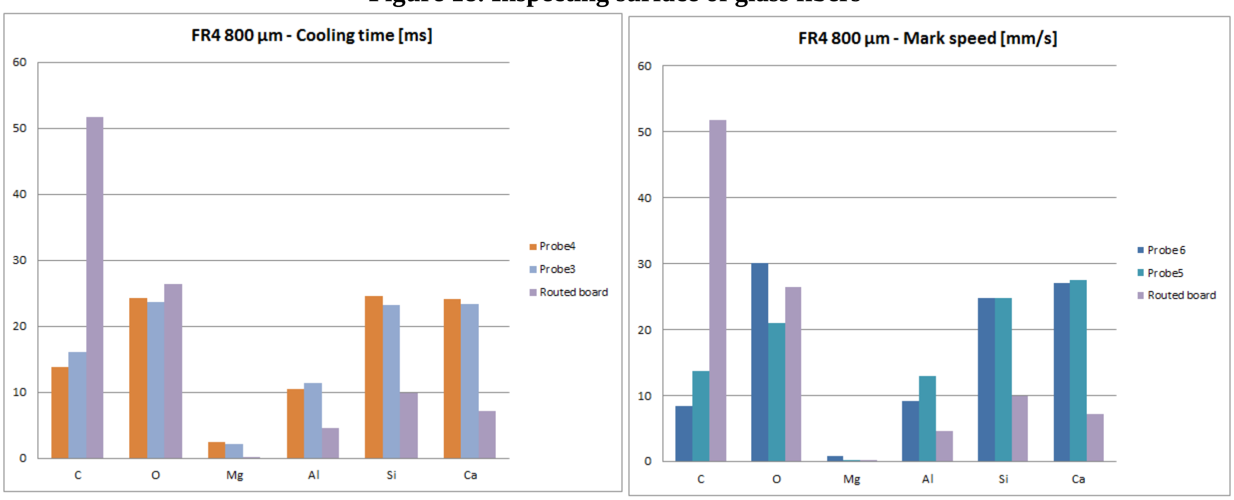

Figure 19

Figure 17 shows that with shorter cooling times a slightly higher amount of carbon and oxygen are present.

For probes 5 and 6 the cutting speed was changed significantly, which means that with the slower speed a complete cut is obtained with fewer repetitions. With the higher cutting speed more carbon and less oxygen remains present.

All the tests were compared to a routed side wall where in each case more carbon was present there while the amount of oxygen did not vary significantly.

The chemical element that would raise most concern is carbon, yet in all these laser cut cases the presence of this element is lower or at most similar to that in the routed board.

CONCLUSIONS

Using a laser for depaneling can have significant economic advantages because more boards can be placed on the same panel. But also one can expect better long term reliability as the boards edges are not exposed to bending strain when breaking the last connecting points to the panel.

In addition the board edges are not seeing high levels of compression when they are being cut. The panels retain their original rigidity during assembly which may make it possible to work without pallets.

During the laser cutting, process temperatures near the edges are lower than temperatures encountered during soldering and therefore no negative impacts are detected. When the cutting is well controlled by the system operator no carbonization is occurring which otherwise might reduce the surface resistance of the cut edge.

Finally the high precision of locating the outline of the board insures that the cuts do not encroach into the areas of the board where runs or even components are located and also assure a proper fit in a tight and well-designed enclosure.

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ACKNOWLEDGEMENTS

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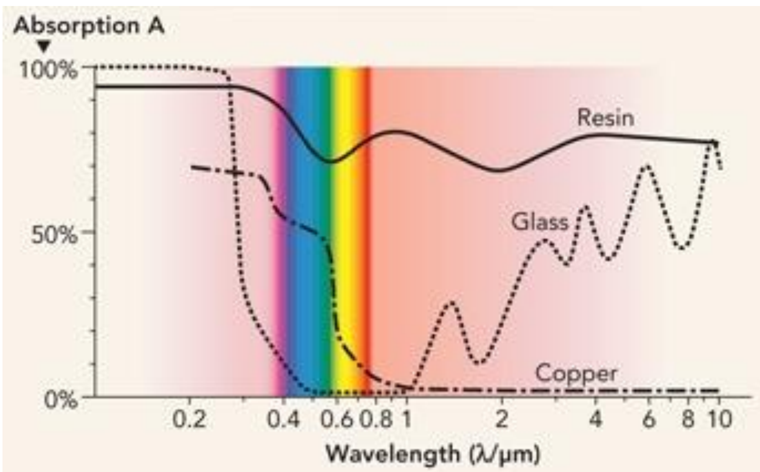
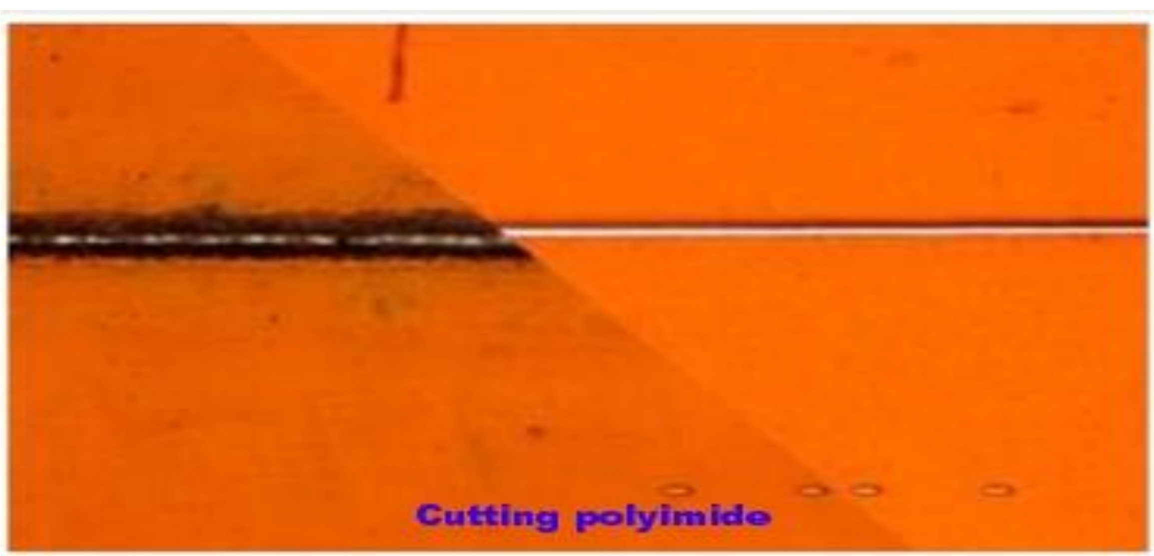
FORWARD THINKING
FOR TOMORROW'S TECHNOLOGY

Material Effects of Laser Energy When Processing Circuit Board Substrates During Depaneling

1. Electrical Engineering degree from the HTS in Leeuwarden, The Netherlands,
2. Design engineering work at Philips in The Netherlands and Tektronix in Beaverton, OR. Many years as engineering manager and also manufacturing engineering manager at Tektronix.
3. Founded A-Laser, using laser systems to make stencils for the surface mount assembly process and also cutting parts from thin metals and plastics for many different industries.
4. Consulting.

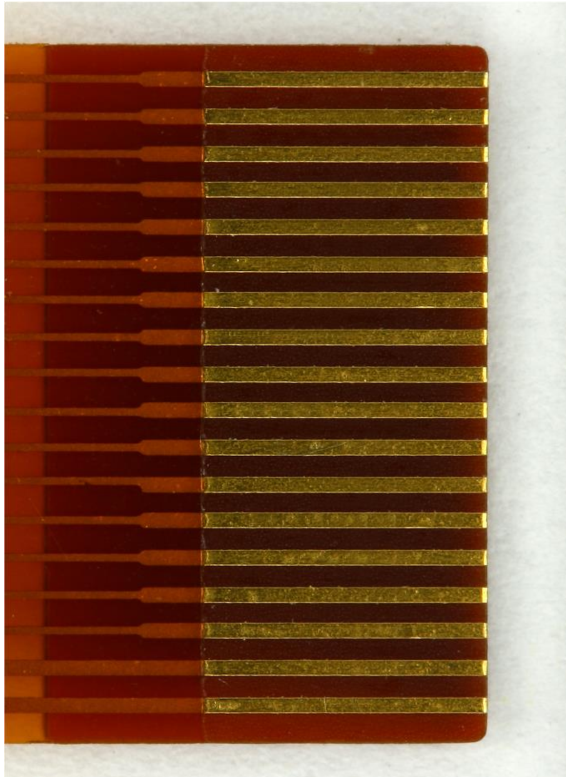
Choosing the Right Laser

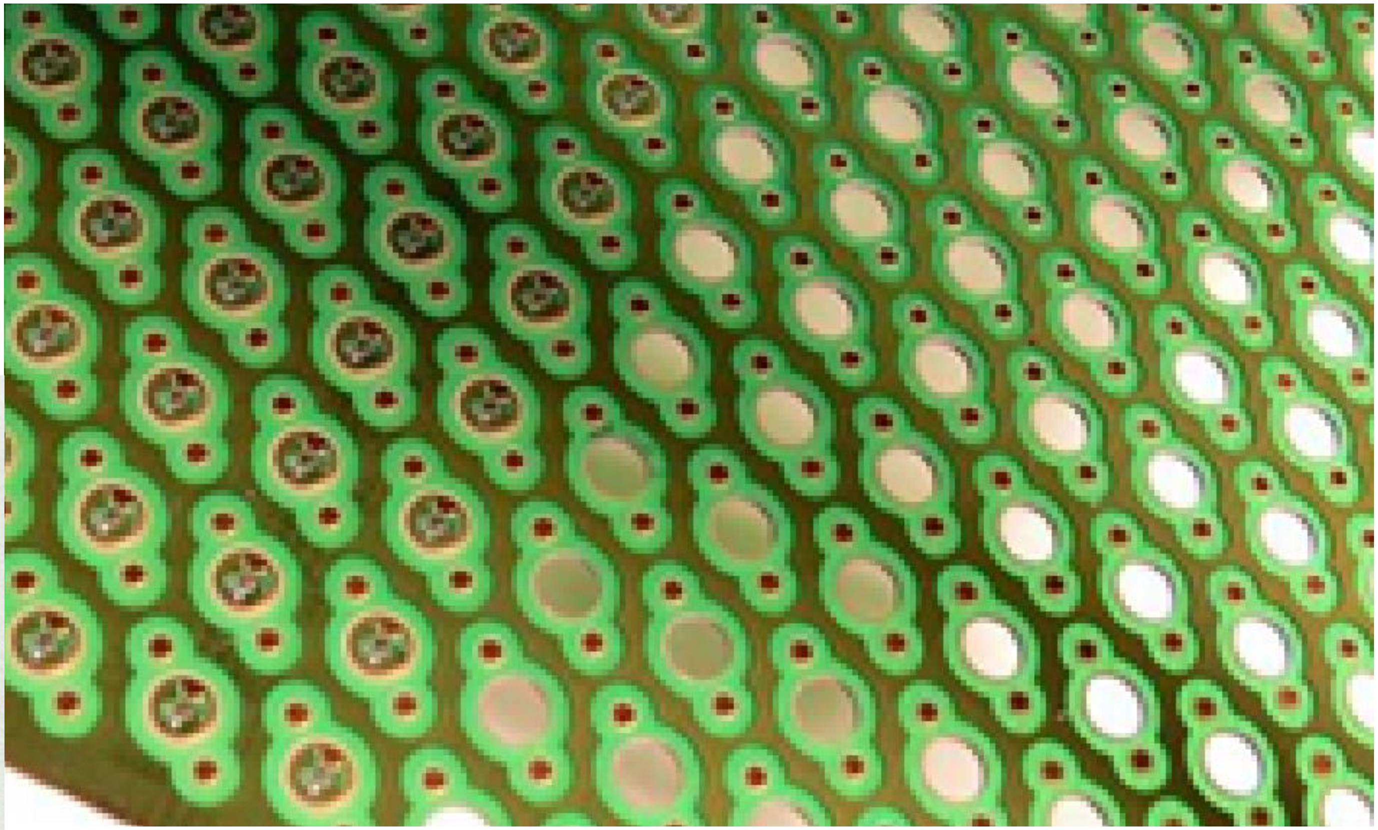




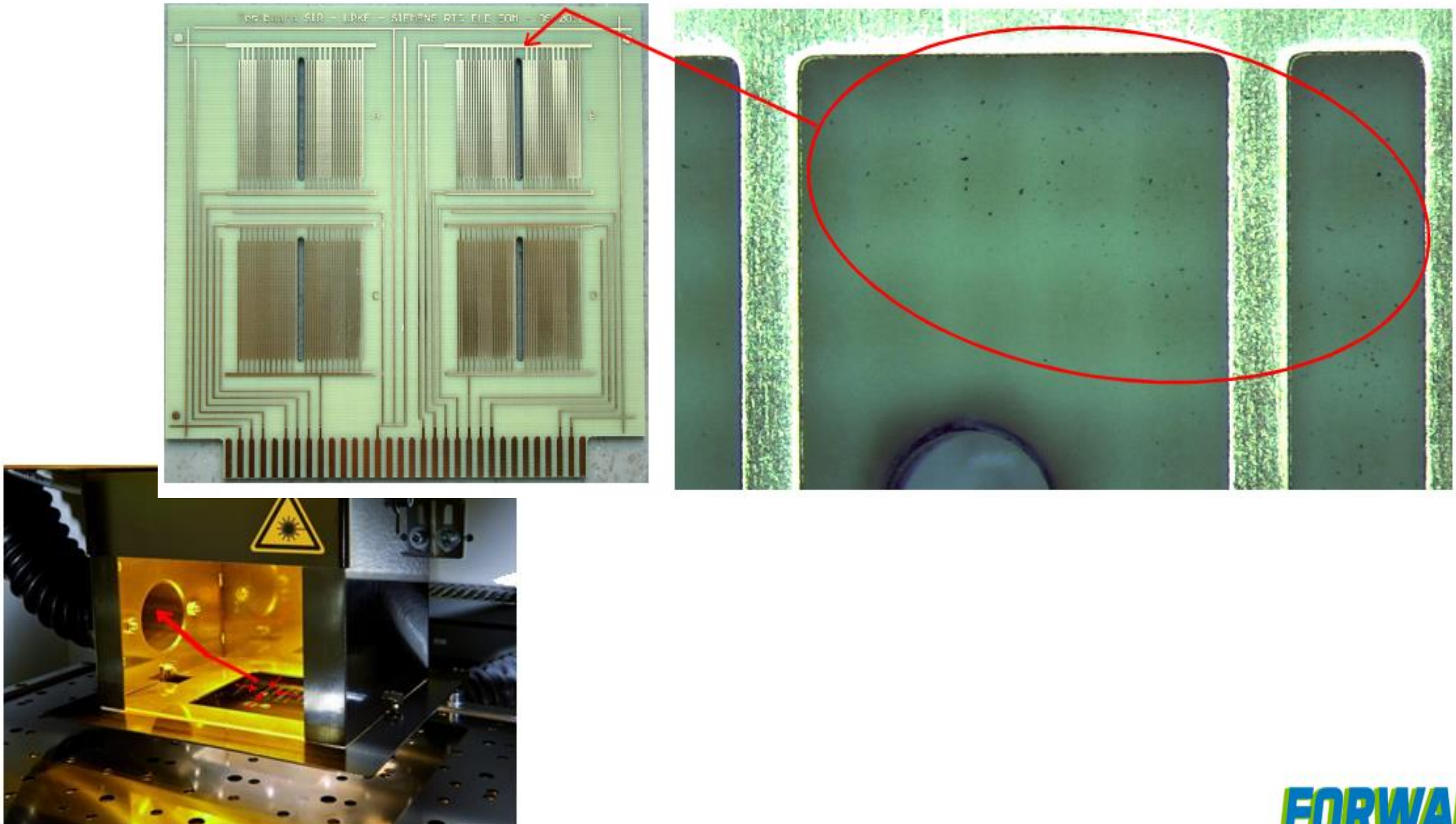
What causes the difference?

Precision

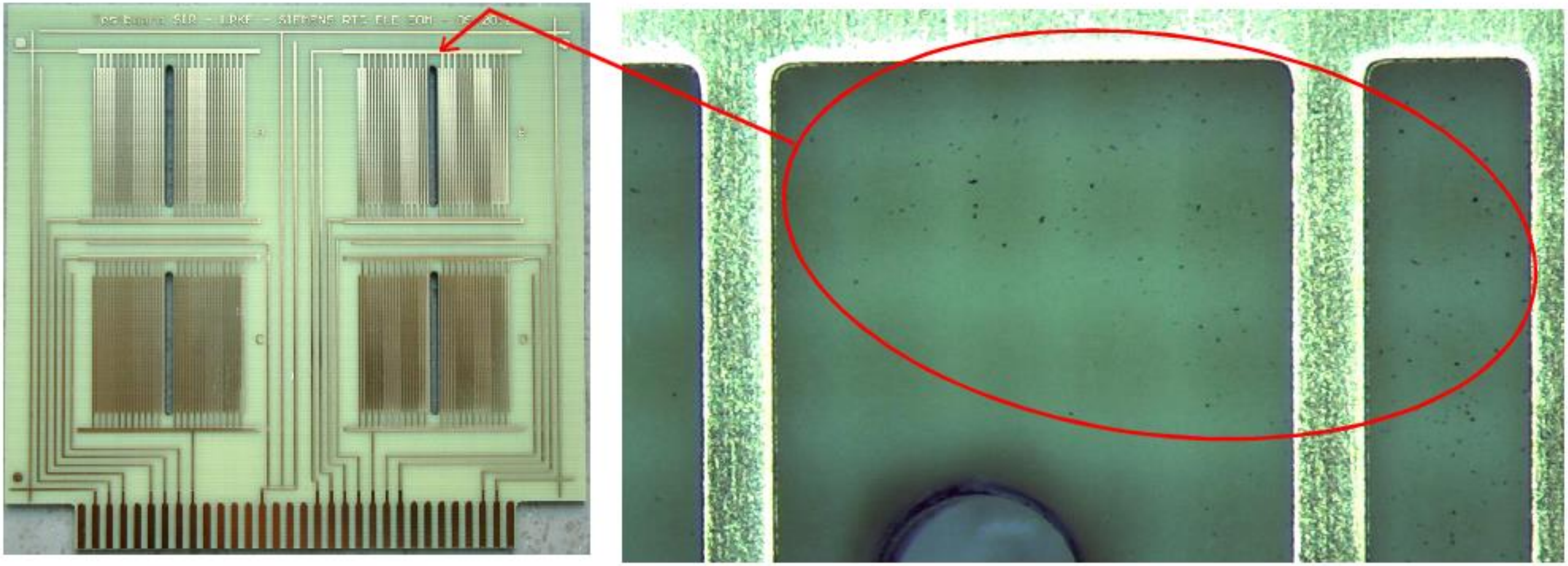




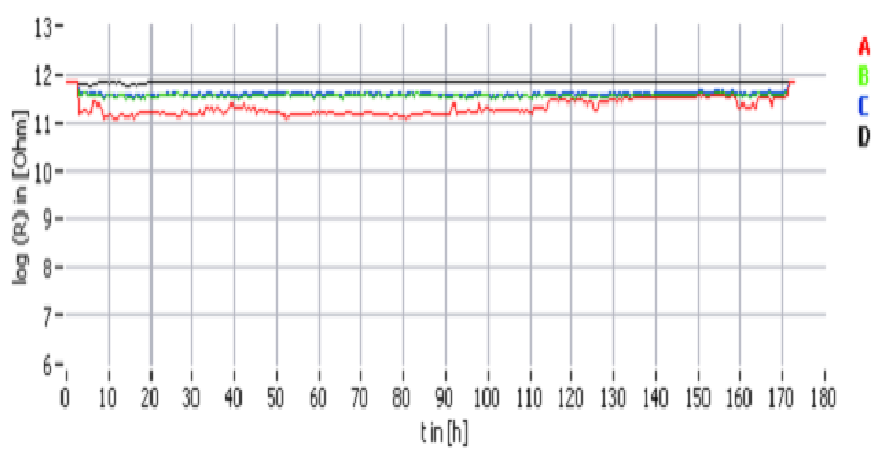
Cutting Debris



Impact of Debris

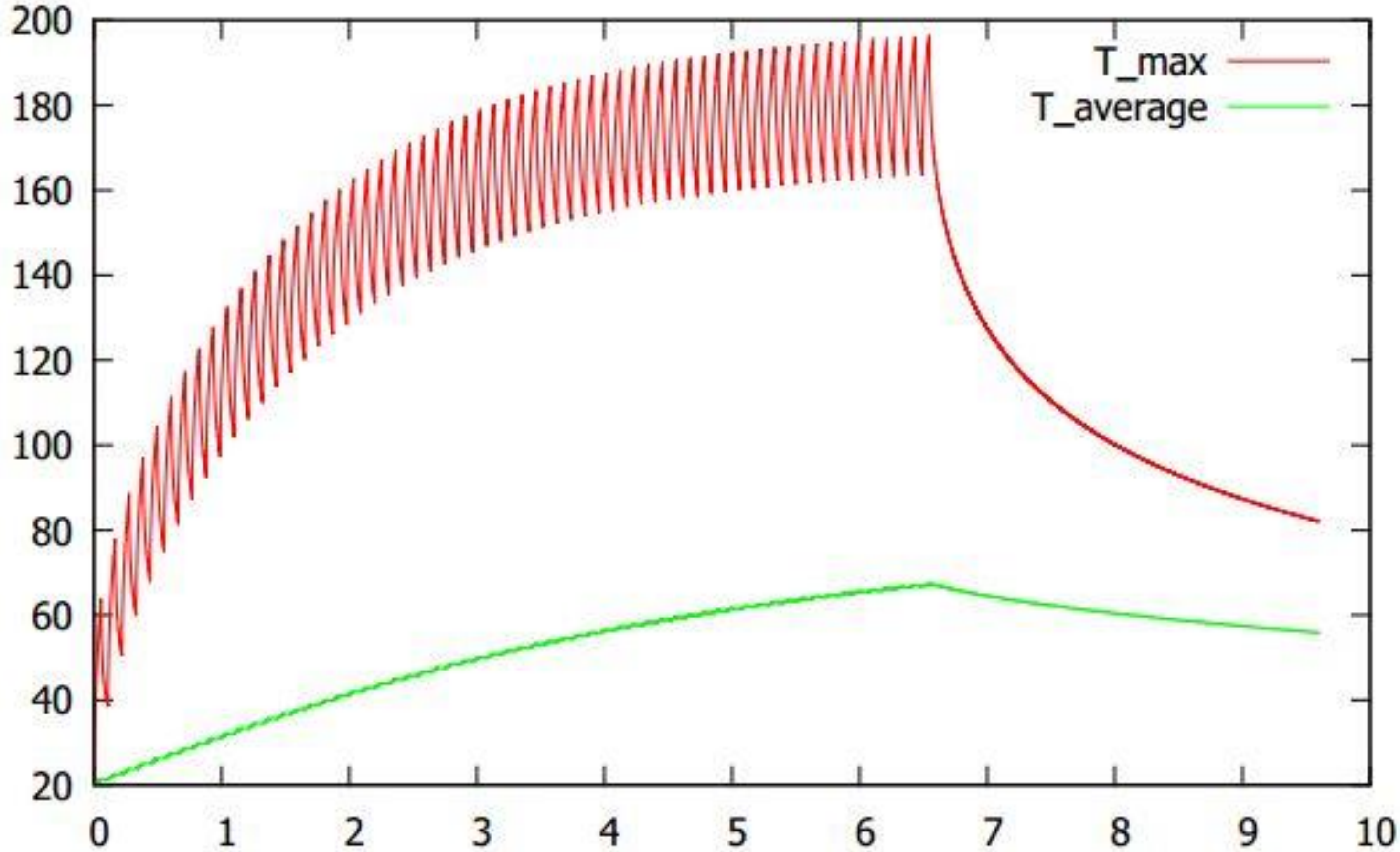


testing

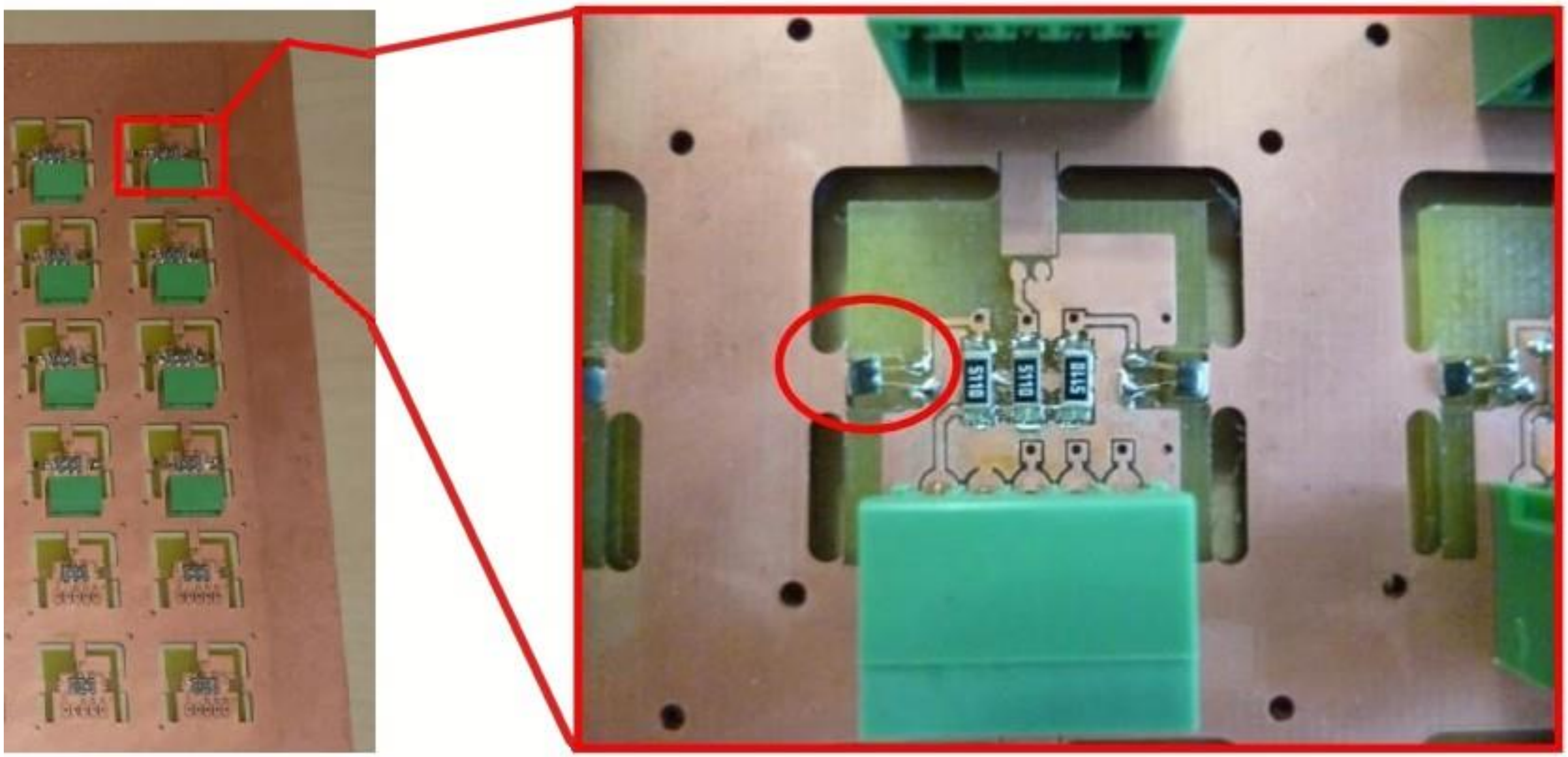


Temperature Rise

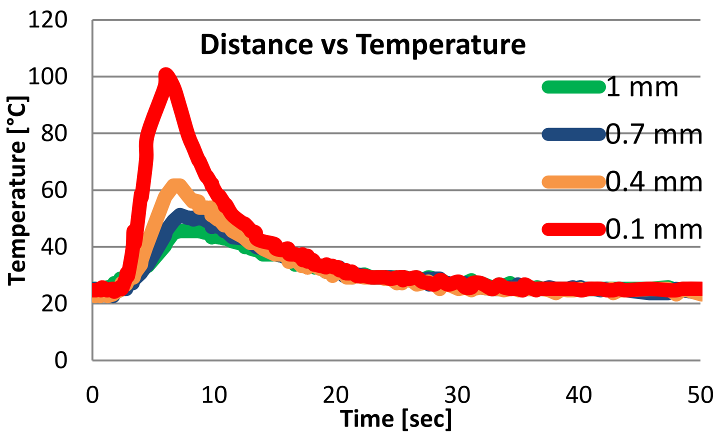
$$\frac{\partial u}{\partial t} = \beta \frac{\partial^2 u}{\partial x^2} - \alpha(u^4 - u_0^4) + q(x,t)$$

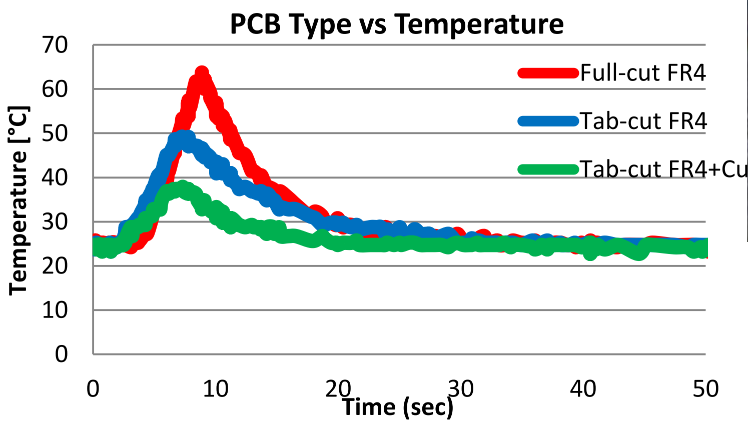


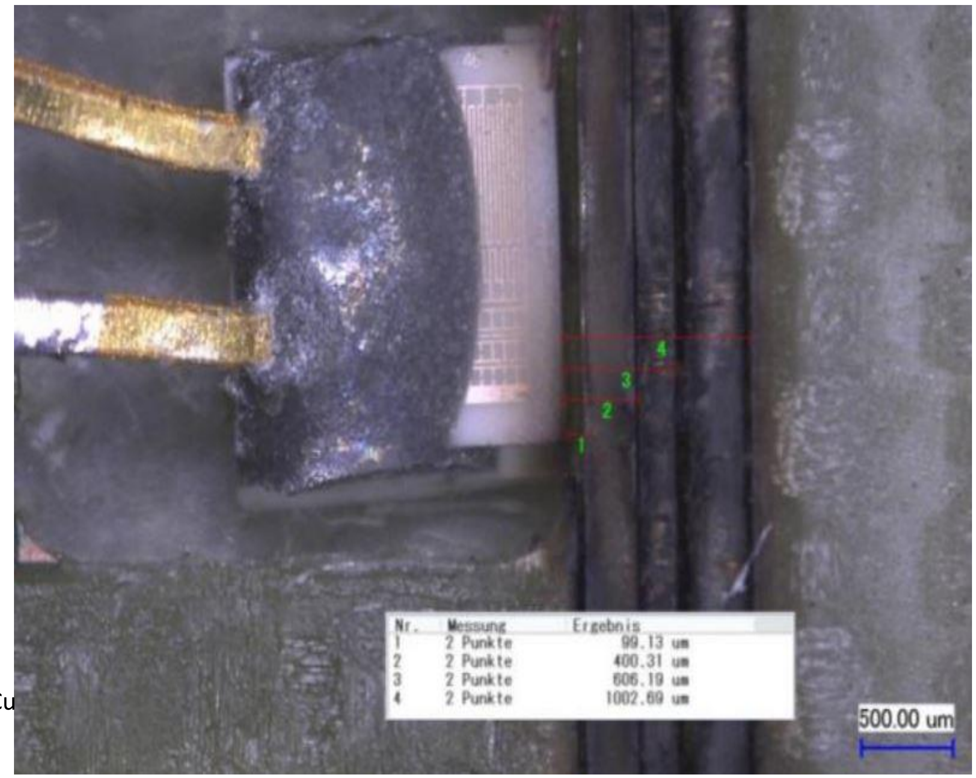
Investigating Temperature Rise



Measuring Temperature Rise

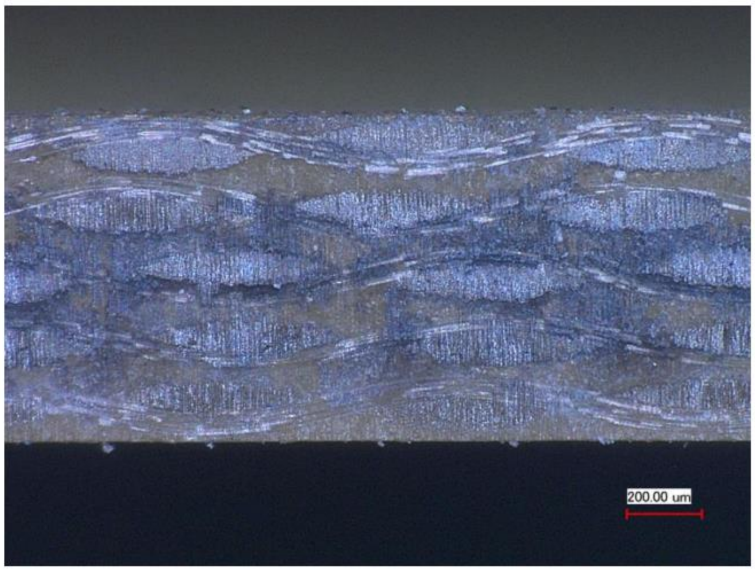






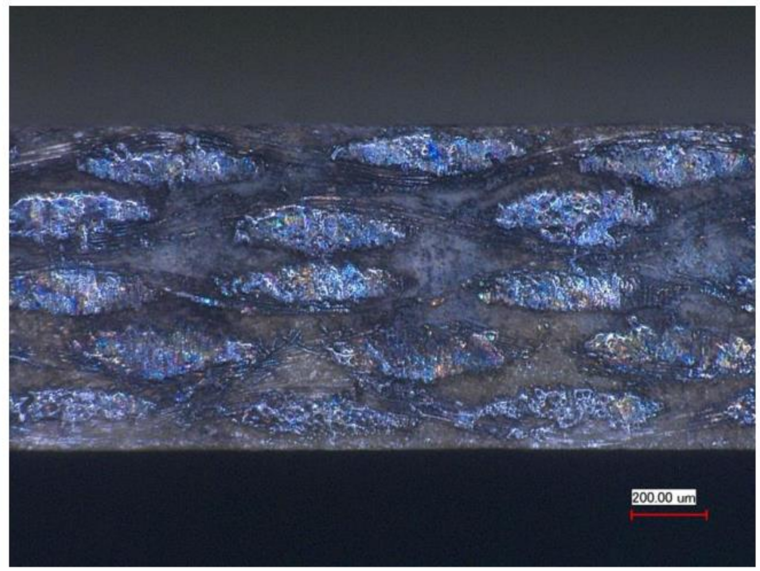
Appearance of cut wall

Cutting strategy: Quality



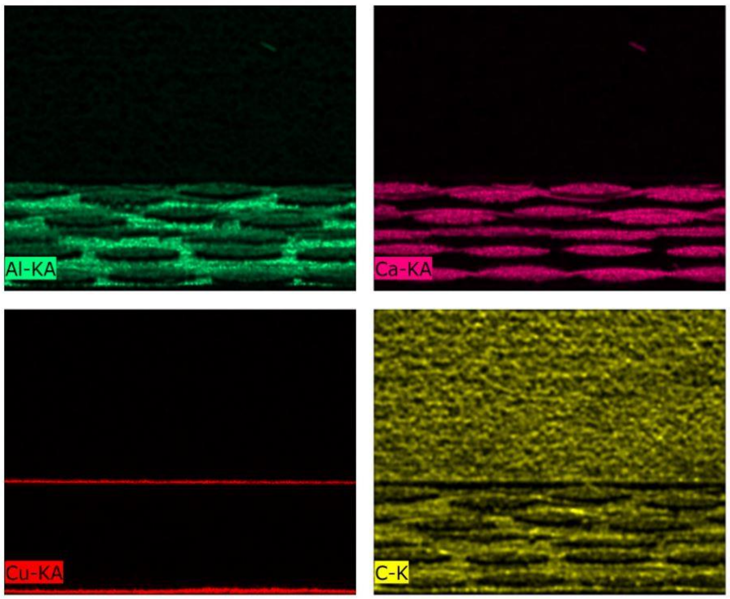
Cross section laser cut of 1 mm FR4

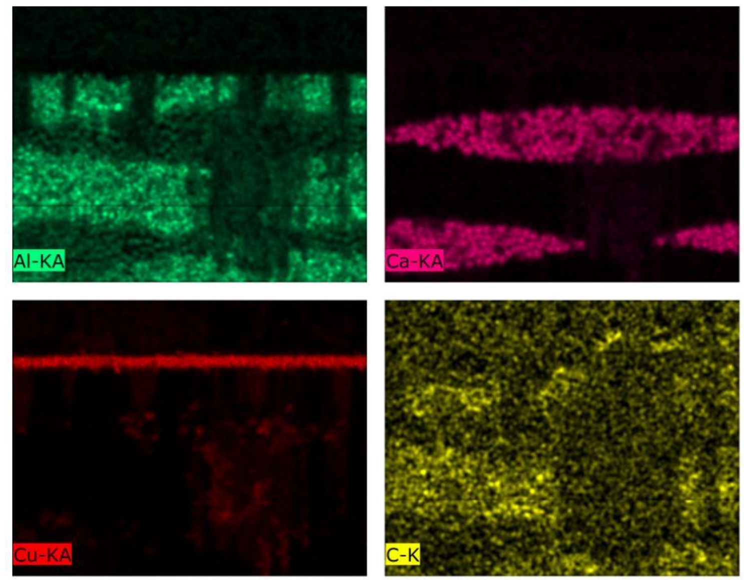
Cutting strategy: Time



Cross section laser cut of 1 mm FR4

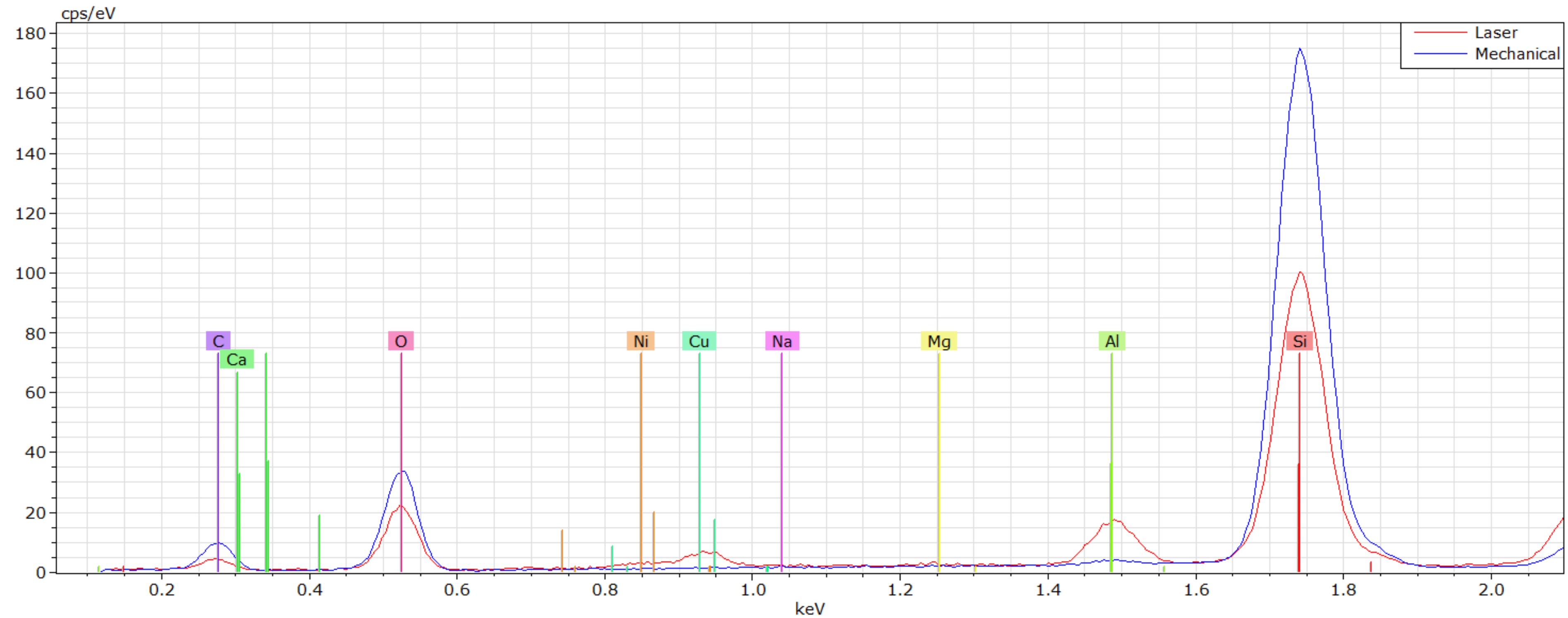
Chemical Analysis





Energy Dispersive X-ray Analysis method (EDX)

Energy Dispersive X-ray Analysis Method (EDX)



Differences in Cutting Parameters EDX Analysis on Epoxy Area

P [W]	f [KHz]	v [mm/s]	Repetition [x]	Cooling time [ms]	FR4 Thickness [µm]
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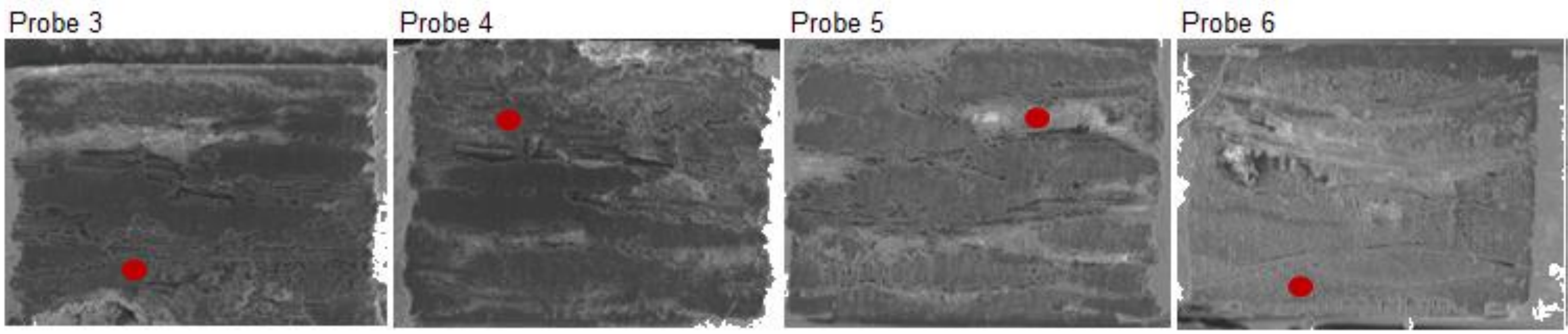

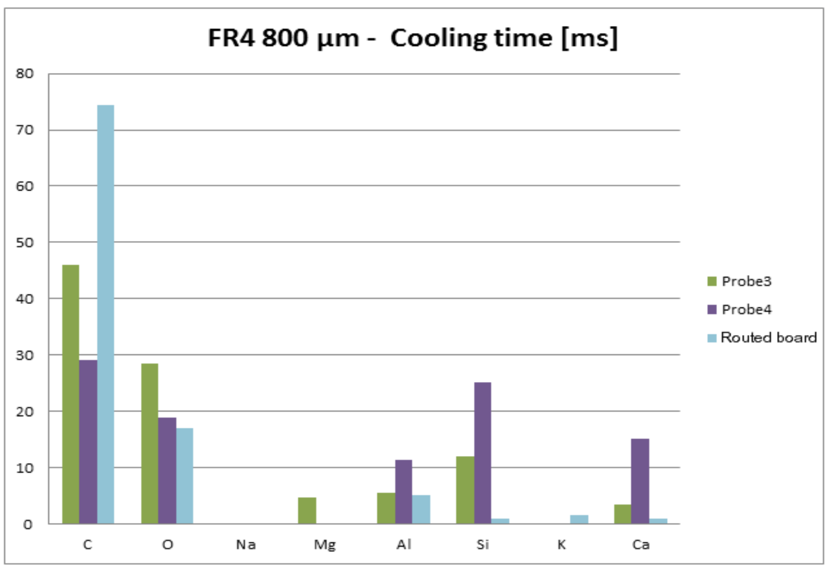

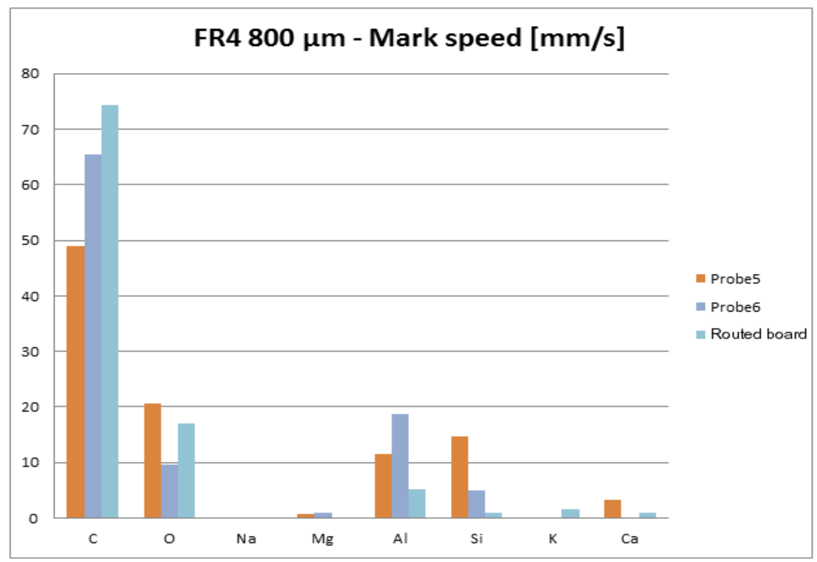

Differences in cutting parameters
EDX Analysis on glass fibers

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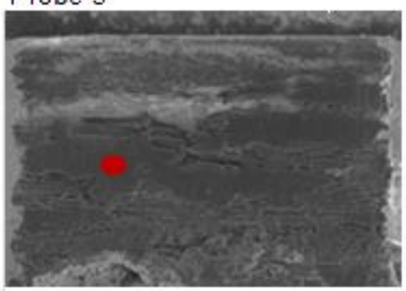
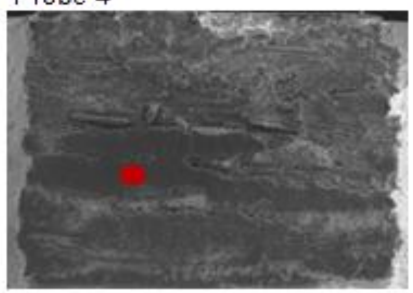
Probe5	12,4	40	100	30	300	800
Probe4	12,4	40	244	35	385	800
Probe3	12,4	40	244	35	175	800

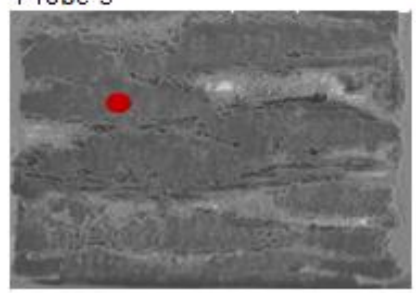
Probe 3



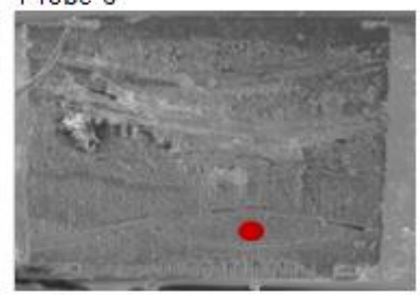
Probe 4

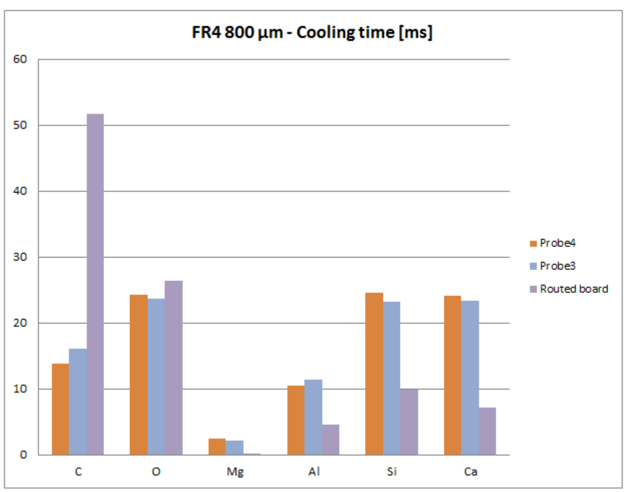


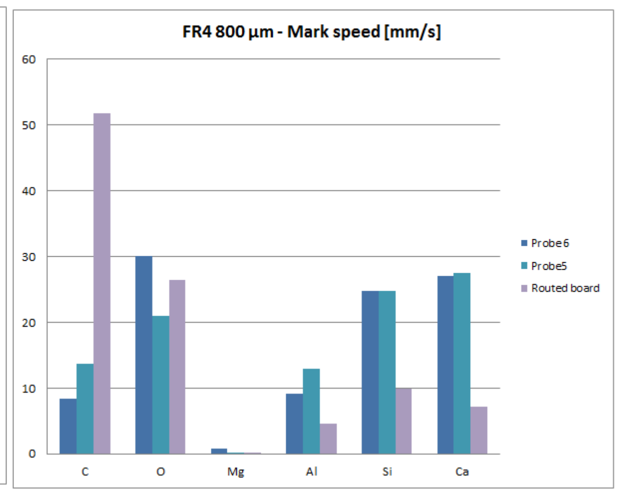
Probe 5



Probe 6







CONCLUSION

- more boards can be placed on the same panel
- better long term reliability
- the panels retain their original rigidity
- lower temperatures than during soldering
- no carbonization
- high precision of locating the outline of the board

QUESTIONS ? ?

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Thank you for your attention.

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