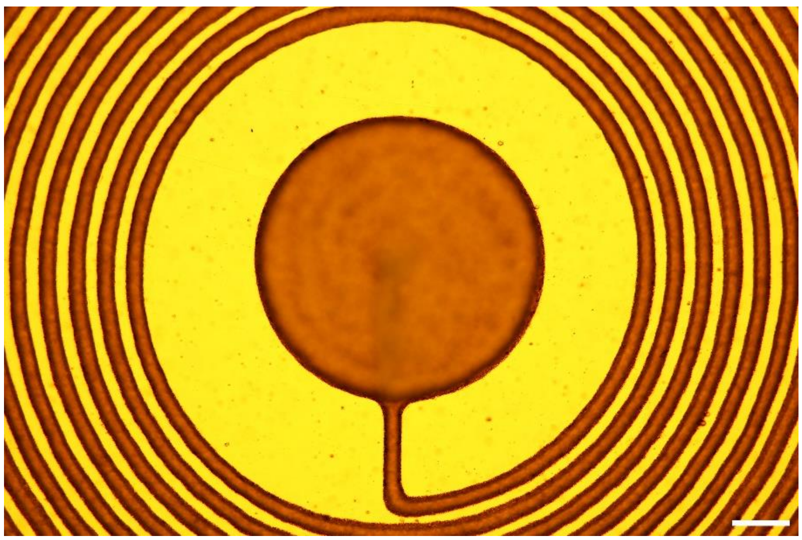
Fast Prototyping of flexible PCBs using LPKF ProtoLaser

Comparison of different materials and systems



Laser & Electronics

Fast Prototyping of flexible PCBs

For decades, flexible printed circuit boards have been the solution for connections that need to be movable, that require little space and/or weight, or that require a fast data connection. Flexible PCBs usually have only the passive function of transmitting signals. They replace cables and are often found in keyboards - as a part of switches - and include electronic components for signal transmission. Flexible circuit boards are often combined with one or two rigid PCBs (rigid-flexible PCB), which connects the rigid boards directly without connectors. They thus eliminate problems caused by the connector in the high-speed data transmission. Other current applications include LED lighting, PC, mobile and IoT antennas, 5G networking applications, various sensors such as motion controls or drug delivery sensors. They are indispensable in wearables, medical applications and fast-growing electric vehicle market.

Flexible PCBs

Flexible PCBs (FPCBs) are typically based on a thin polyimide (PI) film as a substrate or core to which copper plating is adhered. After processing, the copper layer is protected by a cover layer. Contact points should be open for access. Polyimide offers high mechanical stability over a wide temperature range, is chemically resistant, has high thermal conductivity and dielectric strength. Flexible printed circuit boards use different film polymers, such as polyester (PET), various polyethylenes (PEN, PEI), fluoropolymers, ... FPCBs are multifunctional and can be produced as a single, double or multilayer with plated through holes and surface treatment similar to rigid circuit boards. Although the copper layer is structured by chemical etching in mass production, laser systems are preferably used to open the cover layer and precisely cut the flexible PCBs.

Prototyping

Single-sided flexible printed circuit boards can be easily milled as a flat substrate with the LPKF circuit board plotters of the ProtoMat series. However, the processing of double-sided flexible PCBs is nearly impossible with mechanical milling, as structuring the copper on top or bottom will result in unevenness in the thin film. On laser ablation or controlled delamination with a laser, the uneven surface caused by the machining of the opposite outside does not have much influence on the removal of copper or metal. Rather, the laser processing depends essentially on the type and method of adhesive used, as well as the core material and the thickness of the metal layer compared to the thickness of the core polymer. With the exception of picosecond lasers, laser ablation introduces a certain amount of heat that can affect the core material. Polymers are also cut by (preferably UV) lasers.

LPKF uses two main strategies for the laser processing of flexible printed circuit boards:

1. Structuring with LPKF patented hatch & delamination of larger areas where adhesives are released under heat (faster method with minimal impact on a substrate).
2. Structuring with line by line material removal, in which the bonding material is not melted by laser heat (i.e. extremely high-temperature-resistant special materials, materials without an adhesive layer, ...).

Until recently, not all materials can be processed successfully or suitably with the various ProtoLasers. LPKF ProtoLaser R4, based on a new green picosecond laser source, opened many new possibilities. For a better understanding of the differences between the laser systems as well as the application evaluations, the technical data is listed as a reference in the following table:

Feature	ProtoLaser U4	ProtoLaser S4	ProtoLaser S*	ProtoLaser ST	ProtoLaser R*	ProtoLaser R4
Max. material size and layout area (X x Y x Z)	229 x 305 x 10 mm	229 x 305 x 10 mm	229 x 305 x 10 mm	229 x 305 x 7 mm	229 x 305 x 10 mm	229 x 305 x 10 mm
Laser wavelength	355 nm	532 nm	1064 nm	1064 nm	1030 nm	515 nm
Laser pulse frequency	25-300 kHz	25-300 kHz	15-200 kHz	25-400 kHz	40/100/200 kHz	50 – 500 kHz
Laser pulse duration	25ns**	20ns**	30ns**	120 ns	1 ps	1.5 ps
Laser power (max.)	6 W	12 W	16 W	15 W	4 W	8 W
Laser spot diameter in focus position	20 µm	23 µm	25 µm	27 µm	15 µm	15 µm

Table 1: Technical Data ProtoLaser U4, ProtoLaser S4, ProtoLaser S, ProtoLaser R and ProtoLaser R4
*Discontinued
**@50kHz

In the following, the processing results of the different ProtoLaser systems on some material examples are presented.

Processing of Kapton® from DuPont™

Kapton® from DuPont ™ is a common and popular polyimide core material. With high thermal stability over a wide temperature range, high electrical insulation, low moisture absorption, flammability to UL 94 V-0, Kapton® is a common choice for flexible printed circuit boards.

The cutting of Kapton foil or the cutting of SMD stencils works perfectly with UV based laser systems like ProtoLaser U4 (and former ProtoLaser U3), also good with the ProtoLaser S4 (see figure 1), but very bad with the ProtoLaser S (1,064 nm) or ST (1030 nm). Shorter wavelengths are better absorbed by the material and the ablation process works better, while longer IR wavelengths usually melt the Kapton® by heat. This leads to blurred edges and clearly visible charring.

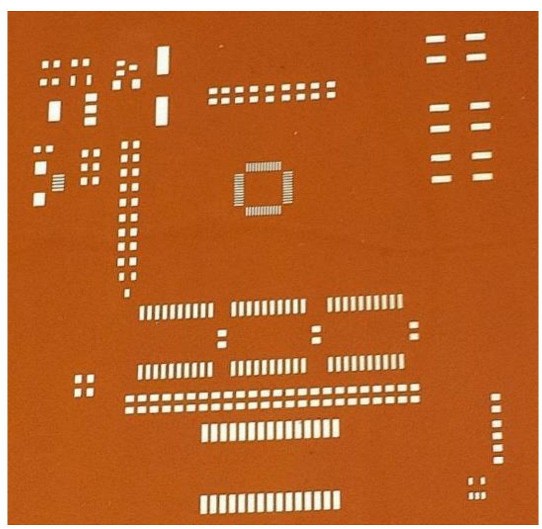


Figure 1: DuPont® Kapton™ stencil 125um (5mil), pitches in the square are 500 µm

With advanced features, such as the precise low-power mode of the ProtoLaser U4, it is possible to control the depth of the ablation process on a Kapton® film very well. It is useful for example in microfluidic applications such as Lab-on-a-Foil or masters for PMDS molds (Figure 2).

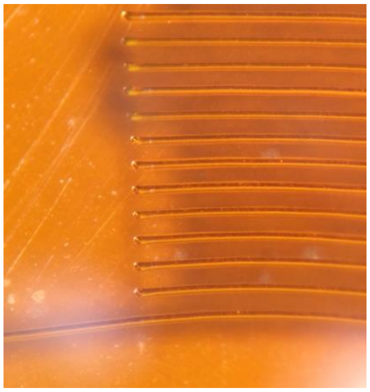


Figure 2: Deep engraving with ProtoLaser U4

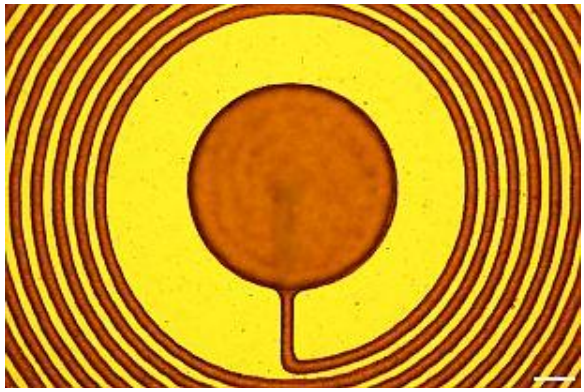


Figure 3: Precisely controlled depth engraving with ProtoLaser R4

Cold ablation with picosecond laser enables perfectly trimmed and smooth edges of channels in Kapton® foil. Detail of a microfluidic example with spiral seen on Figure 3 has 30 µm channels (scale 100 µm).

DuPont™ Pyralux® is a family of copper-clad laminates based on Kapton® core material. The laminates differ because of the bonding layer between core and copper that could be:

- Acrylic based adhesive (i. e. Pyralux® LF)
- All polyimide (i. e. Pyralux® AP, Pyralux® AC, Pyralux® CG) or
- High performance fluoropolymer based – Teflon® (i. e. Pyralux® TK)

The copper structuring (laser etching) depends on the bonding layer. LPKF's patented technology, which removes larger areas of copper rather than removing them line by line, cuts selected larger areas into thin strips that are removed by laser heating.

DuPont™ Pyralux® TK

The LPKF ProtoLaser S4 as well as the ProtoLaser U4 can easily process the special material for high-speed digital and high-frequency applications, Pyralux® TK. Due to the Teflon™ layer, which is practically transparent to laser

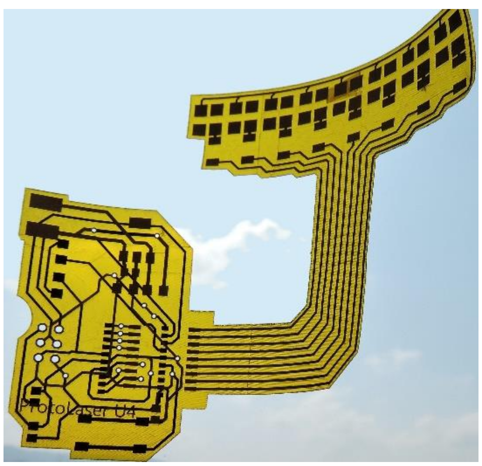


Figure 4: Double-sided flexible sample processed with ProtoLaser U4

Figure 5: Double-sided flexible sample detail (100x) processed with ProtoLaser U4

light and, on the other hand, only limited adhesion, large areas of copper are removed very smoothly with very little effect on the substrate. Drilling and cutting in any form also works well. Figures 4-5 show a double-sided pattern made with a ProtoLaser U4: DuPont® Pyralux® TK 127512 drilling, both sides structuring (laser etching) and contour cutting. Figures 6-7 show the same sample produced with a ProtoLaser S4 at a glance and magnified 100 times.

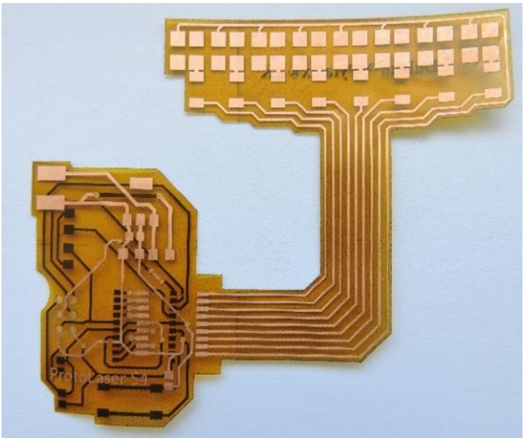


Figure 6: Double-sided flexible sample processed with ProtoLaser S4

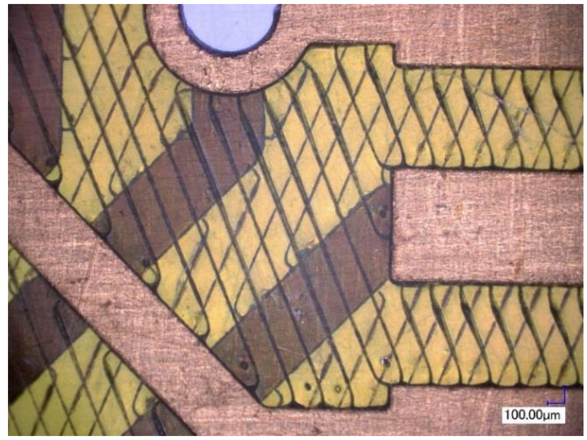


Figure 7: Double-sided flexible sample detail (100x) processed with ProtoLaser S4

Processing using ProtoLaser S4 offers two approaches. Similar as figures 4 - 7. above, with hatch & delamination process - result looks similar, visible hatching lines remain on surface as seen on the figure 8. Another possibility offered only by ProtoLaser R4 is a combination of ablating in a combination of X and Y direction in a thermal regime and final 2 microns of copper and thin layer of Teflon® are ablated in a cold regime. With this approach, surface of Kapton remain without any thermal stress and marks (Figure 9).

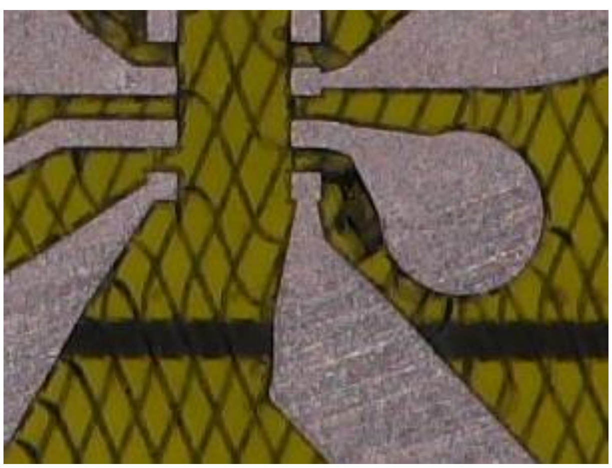


Figure 8: Double-sided flexible sample detail (50%) processed with ProtoLaser R4 (hatch & delamination)

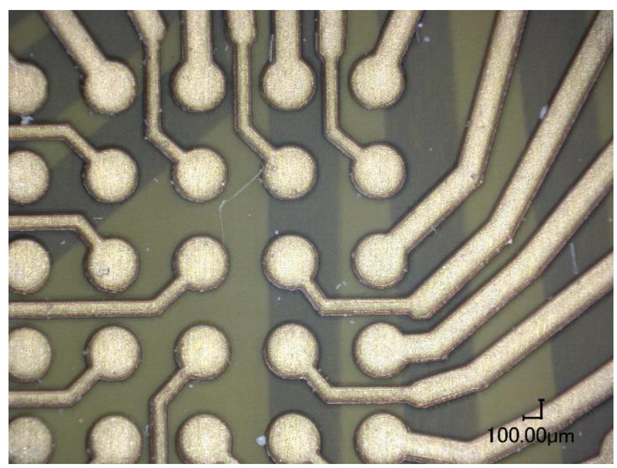


Figure 9: Double-sided flexible sample detail (100x) Processed with ProtoLaser R4 in combination with cold ablation

Details on drilling

Drilling and cutting thin flex materials is a standard process for the ProtoLaser systems and the most suitable material for laser surface treatment from our tests is Dupont ™ Pyralux® TK with two layers of Teflon with a Kapton® core. However, material suppliers advise against UV laser drilling in part due to the transparency of Teflon in the

UV wavelength. The cross-section images demonstrate effect of processing Teflon layer with nanosecond pulses of 355 nm or 532 nm laser: on figure10, processing stopped on a laser light transparent Teflon™ layer.

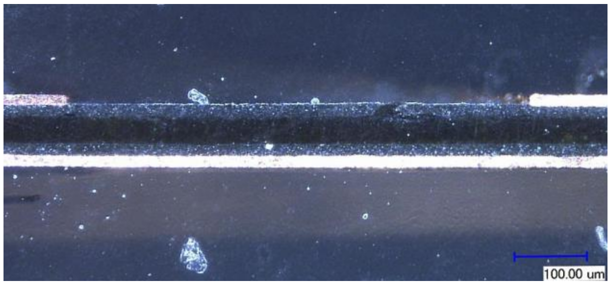


Figure 10: Cross-section of Pyralux® TK 1810018 with visible Kapton® core, Teflon™ layer on both sides and ablated copper from one side – processed with ProtoLaser S4

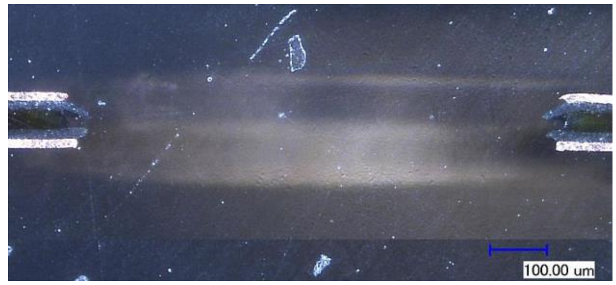


Figure 11: Cross-section drilled hole, from top, on the Pyralux® TK 1810018, taper is visible as well as Teflon layer looking out of cut clad – processed with ProtoLaser S4

While drilling material the same material (Figure 11), first top copper layer is cut, then laser light goes through Teflon™ and polyimide core is cut and then the copper on bottom as light pass through second layer of PTFE. As the drilling circle is few laser spot diameters thick, the evaporated metal melt the Teflon above. Such surface might not be reliable for through-hole plating. See also chapter: Drilling and through-hole platting flex. Regardless long description, such hole is cut in a fraction of a second.

The phenomena of ultra-short pulses, so pulses in a range around 1 or few picoseconds, is ability, to absorb in, otherwise, laser transparent material like PTFE. ProtoLaser R4 is able to drill and cut Pyralux® TK with pristine edge quality.

The drawback of excellent drilling and cutting of Teflon™ layer lies in a very small process window for structuring (laser etching) of copper. Absorption for pico-second pulses can easily lead to surface damage layer, what we can partially control with cold ablation and lower energy pulses. This enables also extremely precise processing of all-polyimide families of Dupont® flexible materials described on next pages.

DuPont™ Pyralux® AP

The results processing traditional, double-sided, Pyralux® AP family with the ProtoLaser U4 (or earlier U3) are less encouraging. Small double-sided samples were structured. The thermal effect on the material is relatively high. The following examples show Pyralux® AP 8565R double-sided structured (6 mil/150 µm dielectric thickness, 0.5 oz/18 µm Cu thickness) and hatch and delamination techniques on Pyralux® AP 8535R. Circular traces of width 50 µm are also 50 µm apart (figure 13).

Processing AP material is only conditionally possible; as there is no additional bonding layer, released copper tracks still slightly stick surface – consequently, some additional mechanical force should be used to completely release them.

We experienced, that with thinner core materials, processing single side with hatch only method is feasible as long as opposite layer successfully disperse the accumulated heat. Processing second layer is affected by heat stretched Kapton layer. Geometries slightly moves during processing. As absorption of UV light is higher in a polyimide layer than green, the second could provide even slightly better results.

Figure 12: Double-sided Pyralux AP 8565R

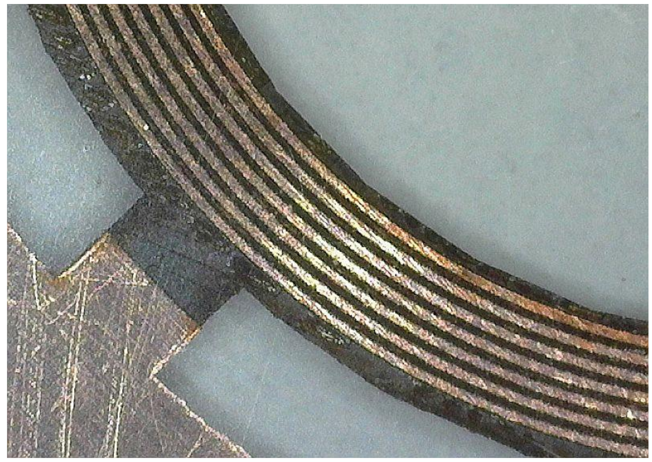
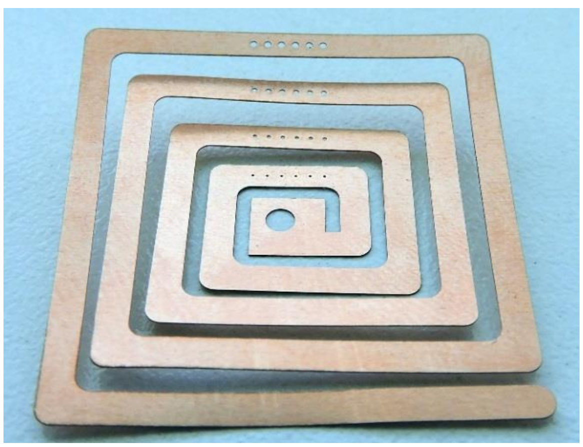


Figure 13: DuPont Pyralux AP 8535R processed with ProtoLaser U4

The ProtoLaser U4 and the ProtoLaser S4, due to same absorption, can drill and cut Pyralux® AP successfully and quickly. Figure 14 shows an example of cutting and drilling Pyralux® AP 8535R (3 mil/75 µm dielectric thickness, 0.5 oz/18 µm Cu thickness)



All-polyimide materials are bonded without adhesive layer, advantage of delamination is limited. Processing with hatch only, means removing metal line by or, in LPKF jargon, technology for processing non-laminated material, is also limited due to heat absorption and core deformation. Answer could be in a cold ablation with ultra-short pulses with maximum 50% overlap. To keep efficiency, job is split into two phases: rougher but still precise removal of majority of conductive layer and a gentle, cold ablation for cleaning last micron or two without applying thermal stress to Kapton layer. Samples on figures 15-18 were processed using LPKF ProtoLaser R4.

Figure 14 (left): Drilling and cutting Pyralux AP 8535R; holes pitch 1 mm, smallest holes are 200µm, largest 500 µm; sample width 2.9 mm

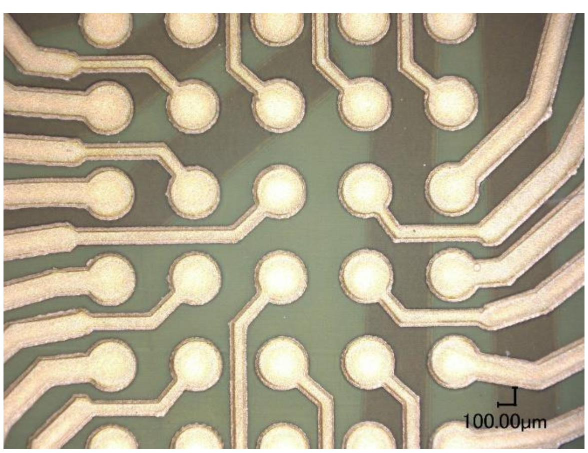


Figure 15: Detail of double-sided Pyralux AP 7163E (9 µm Cu, 25 µm dielectric) processed with ProtoLaser R4

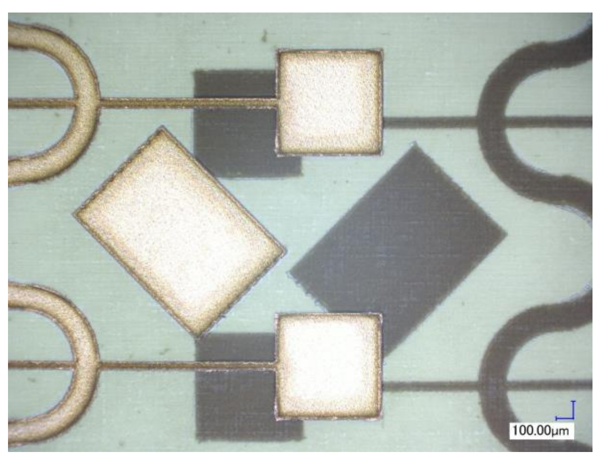


Figure 16: Detail of double-sided Pyralux AP 7163E (9 µm Cu, 25 µm dielectric) processed with ProtoLaser R4

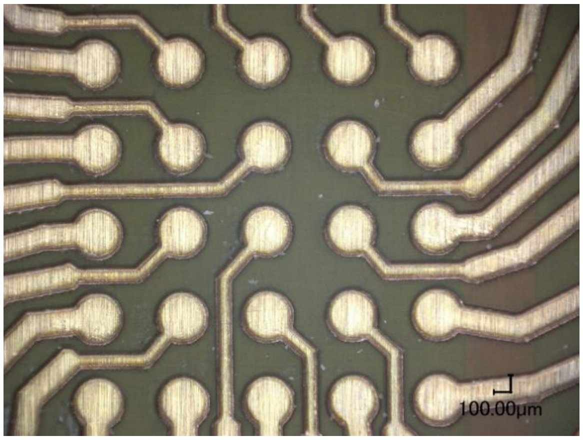


Figure 17: Detail of double-sided Pyralux AP 8525E (18 µm Cu, 50 µm dielectric) processed with ProtoLaser R4

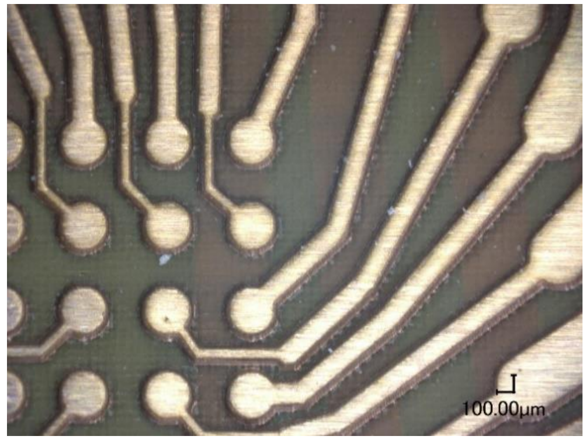


Figure 18: Detail of double-sided Pyralux AP 9121R (35 µm Cu, 50 µm dielectric) processed with ProtoLaser R4

DuPont™ Pyralux® CG

CG is another all-polyimide material with thin dielectric (25 or 50 µm) and stronger copper layer (18 or 35 µm). As previous, processing is possible using ProtoLaser R4, due to combination or fast heat effected ablation and final cold ablation.

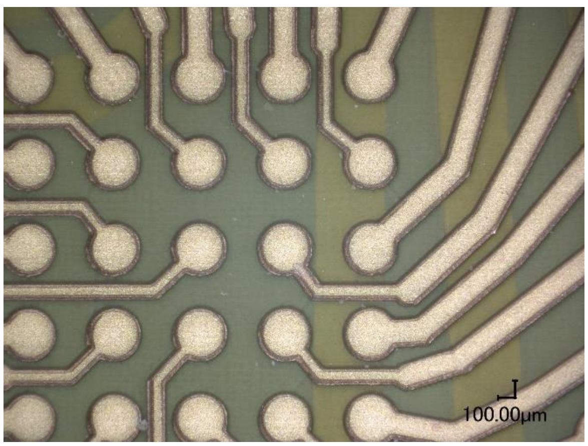


Figure 19: Detail of double-sided Pyralux CG 185018 (18 µm Cu, 50 µm dielectric)

Figure 20: Double-sided Pyralux CG 185018 (18 µm Cu, 50 µm dielectric)

DuPont™ Pyralux® AC

This single-sided version of all-polyimide materials (bonded without adhesive) is based on thin dielectric foil due to target applications. Processing using ProtoLaser R4 is feasible, due to cold ablation with picosecond pulses. See figures 21 and 22.

Alternatively, very decent results were achieved on a Pyralux AC354500R, 45 µm dielectric thickness and 35 µm Cu, with hatch and delamination process with ProtoLaser ST. Figures 23 and 24 on next page show related overview and detail.

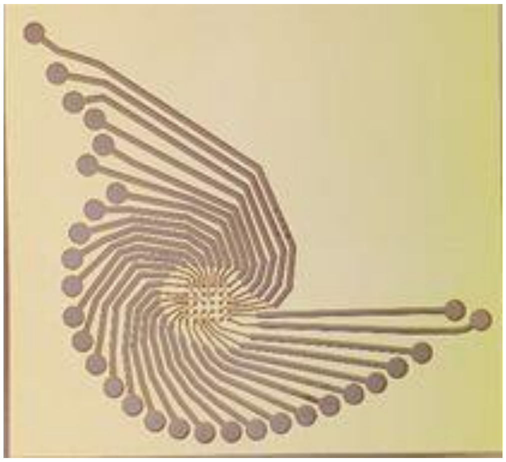


Figure 21: Fun-out sample – single sided Pyralux AC 092500EV (9 µm Cu, 25 µm dielectric)

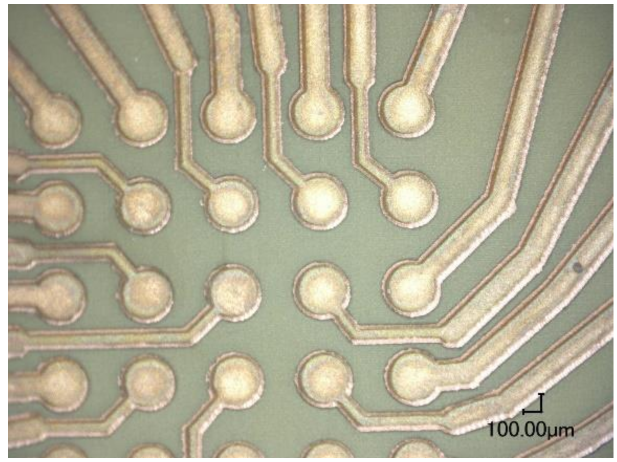


Figure 22: Detail of single sided Pyralux AC 092500EV (9 µm Cu, 25 µm dielectric)

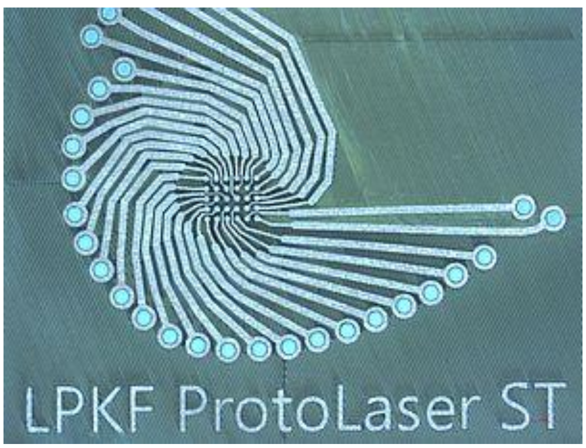


Figure 23: Fun-out sample on single-sided Pyralux AC 354500R (35 µm Cu, 45 µm dielectric)

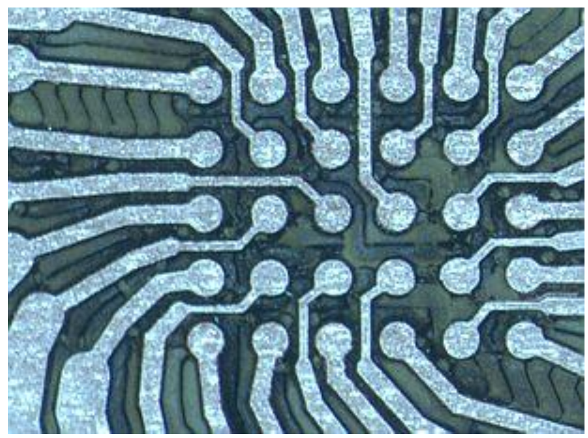


Figure 24: Detail of Fun-out sample on single-sided Pyralux AC354500R (35 µm Cu, 45 µm dielectric)

Cover layers

Opening the cover layers is a typical process for UV lasers in flex PCB manufacturing. The cover layer can also be cut before lamination. For both methods, preferably the ProtoLaser U4 can be used. The ProtoLaser S4 is also a suitable system, edges might be les defined comparing ProtoLaser U4.

Figure 25: Cover layer processing

Flex through-hole platting

Often flex PCB consist of 2 or more layers, and through-hole plating is necessary. As worst case scenario, we took Pyralux TK, where supplier advice against UV laser drilling. On the other hand, PTFE materials should be sodium etched for better bonding. The layer of Teflon is thin, so our tests were done without it. To see the difference, the cross-section images below demonstrate through-platting after mechanical and laser drilling. The via was fabricated using the LPKF electroplating system Contac S4 for rigid PCBs.

The effect of worst-case UV drilling is can be clearly seen in Figure 26, where in a cross-section a shorter Kapton® layer in the middle is connected to a top and bottom layer of Teflon®. Average result is seen in figure 27.

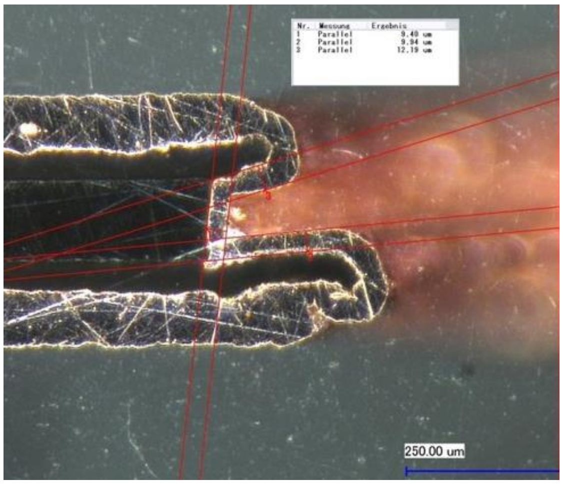


Figure 26: Cross section of an UV drilled and through-plated hole; material thickness 125 µm

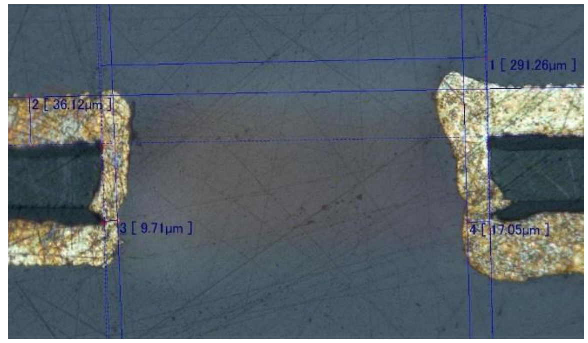


Figure 27: Through-plated hole UV laser drilled; material thickness 125 µm

Mechanical drilling produces a straighter cut (Figure 28), but also the coating of the laser drilled holes seems reliable enough. The samples were not exposed to additional thermal or mechanically stress test for long term reliability.

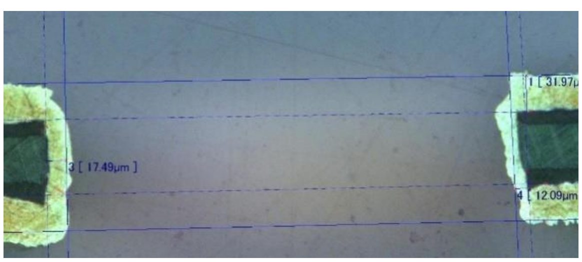


Figure 28: Through-plated hole mechanically drilled

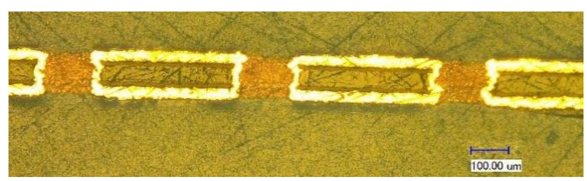


Figure 29: Series of electroplated through-hole vias drilled with ProtoLaser S4 on Pyralux® TK127512; material thickness 125 µm

For better illustration, the test was repeated with the ProtoLaser S4 (532 µm), revealing the same effect of the shrinking Kapton® core associated with the Teflon® laser resistant layer. Irrespective of the geometry, the deposited copper layer appears to be constant (Fig. 29).

Precise material ablation

The LPKF ProtoLaser R pico-second laser enables ablation with virtually no heat-affected zone (HAZ) and very precise material removal. The following figures show a sample with 12 µm Cu on 50 µm polyimide (Pyralux TK125012R). Figure 30 shows a uniform level of remaining copper after one pass, Figure 31 shows the completely removed copper after the second pass. After such an analysis, the process can be optimized as needed to further reduce damage to the base layer.

Various flexible and thin layer polymers were processed. For successful processing, it is crucial to find the right laser wavelength threshold for each material.

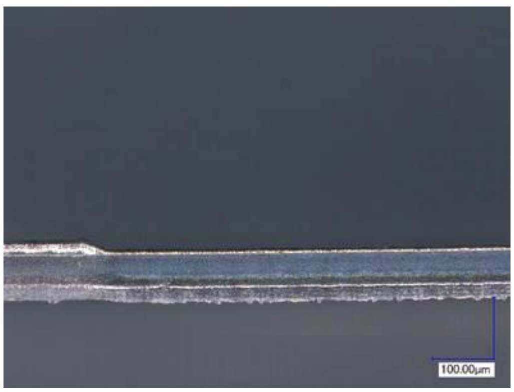


Figure 30: Partially removed copper after first pass

Figure 31: Fully removed copper after second pass

PEEK UHMWPE with Au layer

With a ProtoLaser U4, PEEK UHMWPE with Au coating was processed. The sample was successfully structured with 50 µm traces and 20 µm spacing. In addition, a sample was processed with the picosecond laser system ProtoLaser R, which achieved 25 µm traces and 15 µm spacing. However, drilling and cutting was not possible.

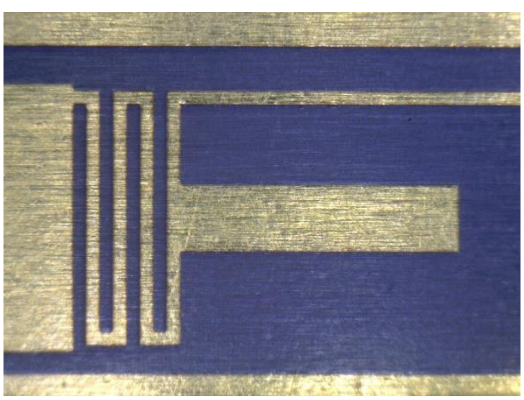


Figure 32: PEEK UHMWPE Au ablated with ProtoLaser U4

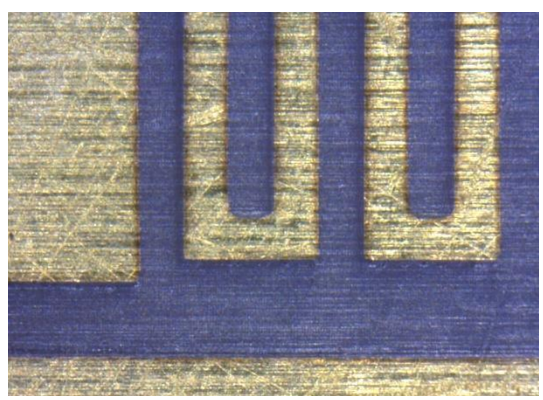


Figure 33: PEEK UHMWPE detail 150x magnification

Mylar® PET

Enhanced PETs are traditional materials in electronics. Thanks to chemical resistance, thermal stability, good insulation properties, transparency, moisture resistance, printability and easy-to-apply aluminum coating, they have been used for capacitors since the early 1950s. Among other things, PETs are today used in special keyboards, flexible electronics and smart packaging.

The flexible PET film antenna (Figure 34) was structured by ablation of the aluminum with a ProtoLaser S IR laser (1064 nm). The product is out of production for years, but ProtoLaser ST uses the same wavelength (1030 nm). When Al on PET is your main subject next to FR4, ProtoLaser ST may be most economical solution. The figures 36 and 37 shows some details. Working samples with less transparency were produced also with ProtoLaser S4.

Figure 34: Al on PET, ProtoLaser S; size approx. 50 mm x 50 mm

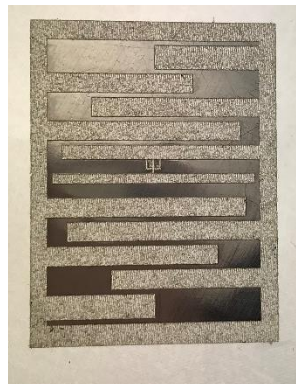


Figure 35: Al on PET, ProtoLaser S4, 33 mm x 25 mm; smallest track width 500 µm, smallest space 200 µm

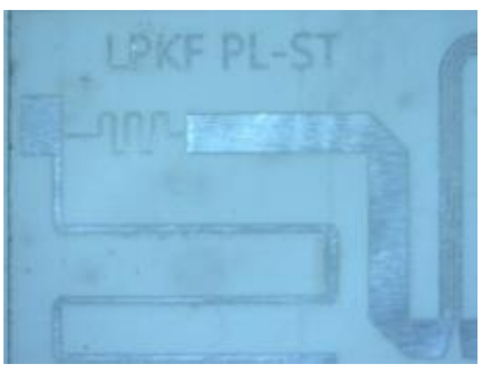


Figure 36: detail Al on PET, ProtoLaser ST

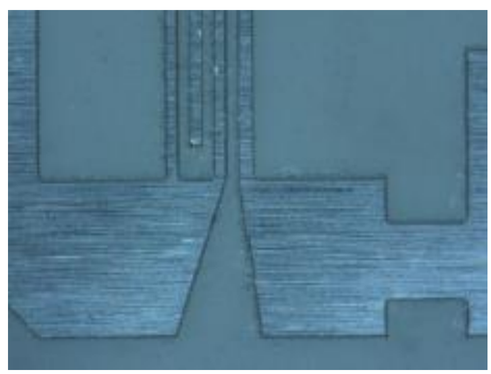


Figure 37: detail Al on PET, ProtoLaser ST

The ProtoLaser S4 (532 nm) can also cut PET material in addition to the ablation, the transparency is unfortunately lost due to thermal stress (figure 38). UV laser systems offer even more processing options, such as fine structuring of different metals, drilling holes and cutting shapes. Absorption of light into foils also influence transparency.

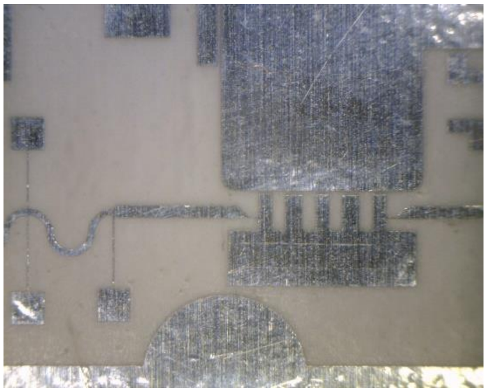


Figure 38: TiPt on PET, ProtoLaser U4

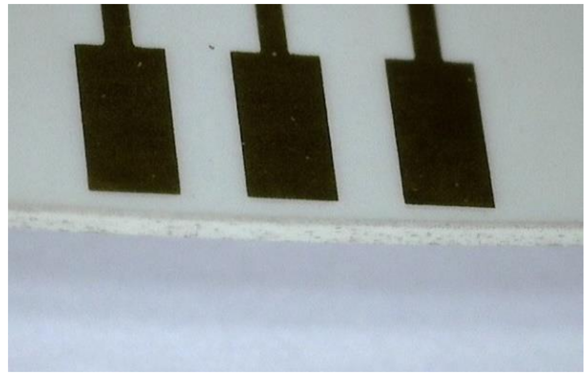


Figure 39: Cu on SiPET, ProtoLaser U4

Removing metals from very thin foils have been tested with ProtoLaser R (picosecond IR source), even with thick metal layer works (30-50 um gold) on PET.

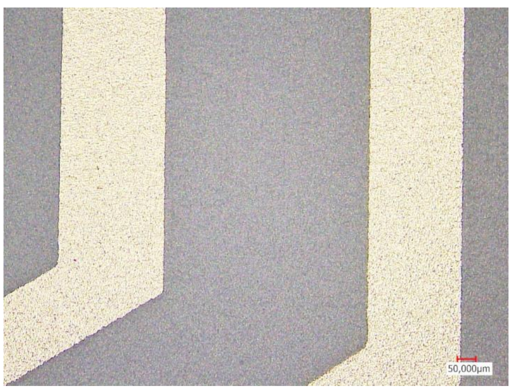


Figure 40: detail thick gold on PET, ProtoLaser R

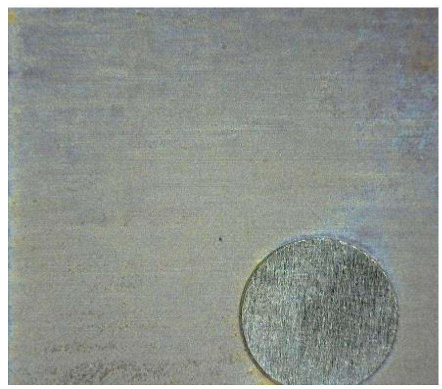


Figure 41: detail Al on PET, ProtoLaser R

35 µm thick Cu layer had been ablated from 100 µm PET foil with ProtoLaser R4, while maintaining high transparency (figure 42, 43). Cold ablation with green picosecond laser source offers wide range of applications on flexible material.

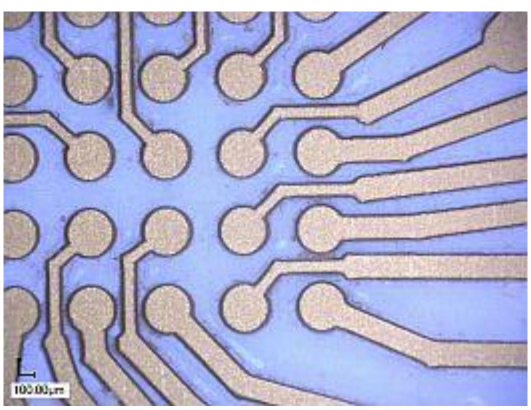


Figure 42: Cu on PET, ProtoLaser R4

Figure 43: Cu on PET, ProtoLaser R4

Krempel Group AKAFLEX KCL 2-9/25polyimide

Another polyimide tested with IR and UV lasers comes from Krempel Group. Processing with UV laser has advantages in drilling and cutting.

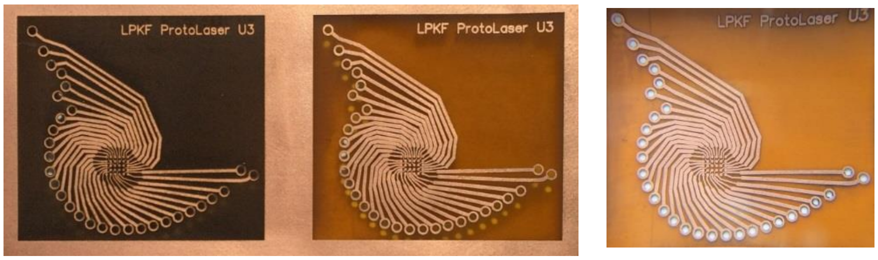


Figure 44: Ablation method to adhesive (left); cleaned with acetone (right), 9µm Cu removal

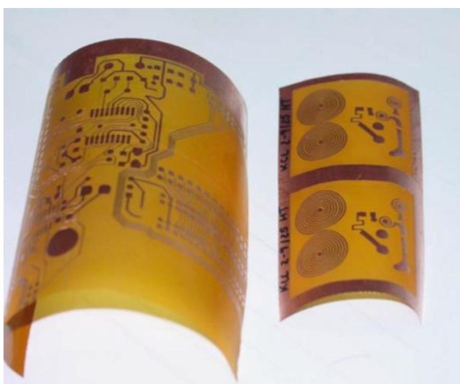


Figure 45: Structured Krempel Group AKAFLEX KCL 2-9/25 polyimide Cu with ProtoLaser S (1064 nm IR laser)

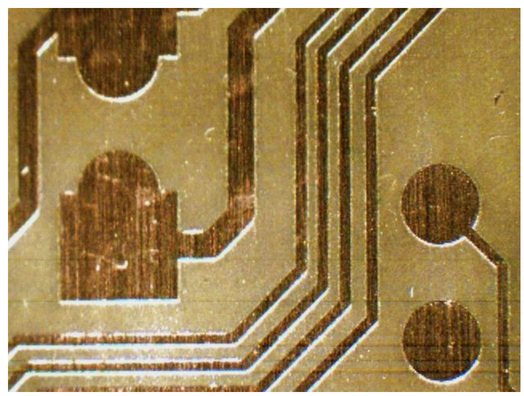


Figure 46: lose look-up to structured AKAFLEX KCL 2-9/25

Conclusion

The material to be processed is decisive in the question of the best suitable laser system to be used. Not every laser can process every material – at least not efficiently. In addition, however, the respective application still must be checked with regard to precision, processing time and economic efficiency. The selection of a laser system is complex and requires the support of a specialist.

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