

Sensor and Sensor Elements Manufacturing: Laser Direct Patterning (LDP) for Reel to Reel Processing to generate High Throughput

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Abstract

The newly developed mask projection process, called Laser Direct Patterning (LDP) is a process for the high volume production of conductive and reflecting structures. Due to its simple process mechanism it combines precision and economic efficiency. Depending on material, sensors and sensor elements with lines and spaces < 15µm for thin metal films and are producible. The principle of laser ablation of thin metal films on polymer substrate materials is represented, the systems engineering is described and the achieved results are discussed. Advantages of this technology are shown and reference is made to selected applications of this technology.

LDP- Laser Direct Patterning

The mechanism of laser direct patterning is shown in fig.1. A thin metal layer, e.g. Cu, Au, Ni, Pd, Al (step 1) is fully penetrated by the UV-laser radiation up to the metal/polymer interface. Then the upper layers of the polymer substrate are ablated. This process is connected with a volume extension and the formation of a plasma plume (step 2). The plume formation results in an explosive removal of the metal layer (step 3).

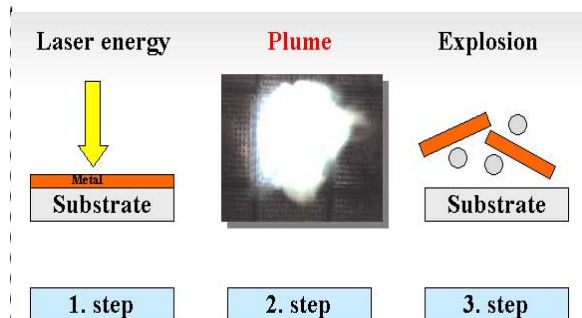


Fig. 1: Laser ablation mechanism (9)

Table 1 shows a choice of flexible substrate materials that have proved themselves so far for sensor production. Flexible materials are advantageous for reel to reel processing.

Property	Polyimide (KAPTON)	Polyimide (APICAL)	Polyimide (UPILEX)	PEN (KALADDEX)	Polyester (MYLAR)	Polycarbonate (MAKROFOL)
Tg, (°C)	385	>500	>500	122	80	153
CTE, (ppm/ °C)	15	12	8	20	20	70
Tensile Strength (Kpsi)	24	15-24	35	32	28-32	20-25
Water Absorpt. (%/ Wt.)	2.9	2.2	1.2	<1	<1	0.35
Dielectric Strength (kV/ mil)	7	9.4	6.8	3.4	3.5	2.8

Tab. 1: selected material characteristics of flexible substrates (1)

(Denominations KAPTON, APICAL, UPILEX, KALADEX, MYLAR and MAKROFOL are trade names from the manufacturers.)

Beside the above mentioned high performance flexible substrates, also substrate materials like polypropylene, polyethylene, polyvinylchloride and so on can be used, depending on the corresponding application.

As was already mentioned, all polymer materials that can be coated with metals, including their alloys (e.g. Cu, Ni, Au, Ag, Al, Cr, Si, Mo, W, Ni/ Cr, Ta, Pt, Pd, Ti/Al, Ti/ W, constantan and so on), can be utilized for the LDP process. The following conditions must be fulfilled:

- thermal stability during the coating process
- defined surface roughness with R_a values of a maximum of $1.5 \mu\text{m}$
- application-oriented bond strength of the bond
- (e.g. Tape-Test according to IPC-TM-650-2.4.1)
- application-oriented adhesiveness after climatic test, life time test, especially for connections
- low pin-hole number ($<10/ \text{cm}^2$)
- small pin-hole sizes ($< 1\mu\text{m}$)

Economical structuring times can only be achieved in single-shot mode (2). For this reason the metal layer thickness should be at $< 100\text{nm}$. This means that chemical processes or the application of compact metal foils are not suited for metallisation of polymer substrates. Coating techniques that proved suitable for such substrate materials are the PVD process, like evaporation, sputtering, chemical vapour deposition, P-CVD, and there are a number of companies that do these coatings. To improve the adhesiveness and to increase climate stability, tiecoat based on chromium, nickel titan molybdenum and so on have proved advantageous (5). Laser ablation of thin metal layers on polymer materials is also determined by the physical parameters of the metal layers, such as reflectivity, absorptivity und thermal conductivity. In table 2 the values for metals Cu, Au and Al are shown (3).

Metal	Reflectivity (248nm)	Thermal Conductivity (W/ $\text{cm}^2\text{Kexp-1}$)	Absorptivity (248nm)
Copper	0.366	3.98	0.62
Gold	0.319	3.15	0.66
Aluminium	0.924	2.37	

Tab. 2: Parameters for certain metals

It is the prerequisite for a metal removal to exceed the ablation threshold of the polymer substrate material and not to exceed the one of the metal layer. The ablation threshold of polymer materials lies within the range of $50\text{-}500 \text{ mJ} / \text{cm}^2$ and depends on the polymer's chemical structure (double or multiple bonds, functional groups etc.)

The course of the optical beam and the working principle are shown in fig. 2.

By means of optical elements, an excimer laser beam (e.g. 308nm) is expanded, led through a quartz mask, is then scaled down and imaged on the substrate corresponding to the layout. The pulse frequency of the laser is determined by the speed with which the material is handled so that the sensors are projected onto the band in even distances. This work procedure is called "on the fly" and it guarantees highest throughput in "single shot mode".

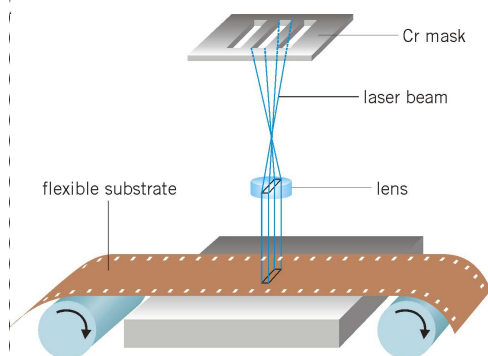


Fig. 2: Optical arrangement

In fig.3 is shown a processing equipment, during the processing of thin Au layers (100nm) on polyester materials developed especially for medical sensor structuring (4, 7)



Fig. 3: LPKF-Laser equipment (reel-to-reel)

Results, Applications and Discussions

To achieve reproducible results, orientating tests were done with uncoated polyimide films (UPILEX- S). At a wavelength of 248nm (KrF- Laser) and with a fluence of 50mJ/cm² the ablation threshold was already reached and an ablation of aprox. 50nm material/ pulse was achieved. This corresponded very well with values in literature (6).

Two different metals were chosen (Au and Cu) as test systems for the ablation of metallised systems:

- a. UPILEX-S /20nm Cr tiecoat/ 32nm Au
- b. UPILEX S /15nm Cr tiecoat/ 50nm Cu

In system a, good ablation results were already achieved at a fluence of approx. 125mJ/cm² while in system b. the optimum ablation was achieved only at a fluence of >180mJ/cm². As the material characteristics are almost the same for Au and Cu (see table 2), it seems that according to Lambert-Beers law the influence of the different layer thicknesses becomes notable.

The appearance of the lasered sensor structures is also in conformity with the fluence. When laser parameters are not optimized, for example, warped edges may occur, as shown in fig. 4.

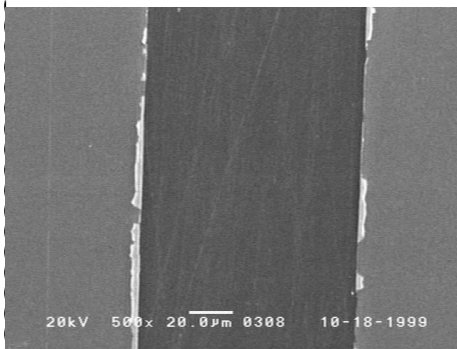


Fig. 4: Fluence not optimized

The adhesive strength of the microstructures is tested using the tape test . If this test is passed, values of the adhesive strength between 4 to 6 N/ cm can be assumed. The corresponding test processes (peeling or pull test) should be used for further measurements. (IPC-TM 650-2.4.9).

There are many applications of LDP structuring for sensors and sensor elements.

Fig. 5 shows the detail of a temperature sensor produced on a reel-to-reel system. Carrier material is a flexible polyimide film metallized with a special resistive film by means of the sputter process. The film thickness is about 80nm. When a frequency of 100kHz is used, approximately 100 sensors/ sec of the size of 30x10mm can be realized.

The reel-to-reel process was also used to produce a special layout for packaging. The substrate material is also polyimide, while the metallization is sputtered Cu with a layer thickness of 60nm.

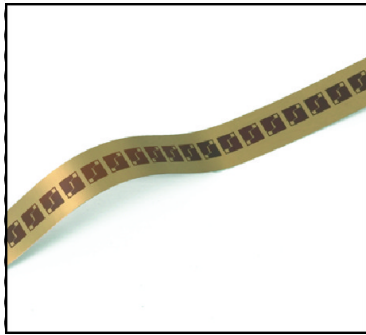


Fig. 5: T-sensor

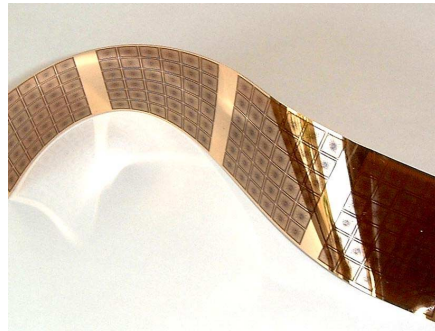


Fig. 6: electronic packaging

Applications are expected in the area of chemical analysis and medical sensors. Electrodes and electrode arrays for test systems can be manufactured economically. A complete sensor, manufactured by laser ablation is shown in fig. 7. It is a fuse element with a sensor placed in its centre with a width of 17.5 μm . The required amount of resistance has been produced by electroless Ni metallization. In fig. 8 is shown a sensor that is capable of detecting changes in capacitance especially developed for security and labelling applications.

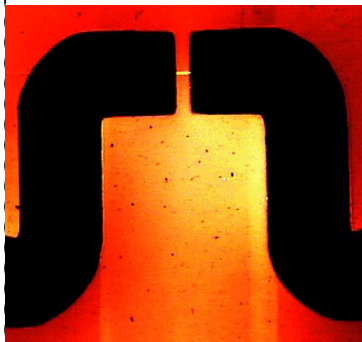


Fig.7: R-sensor (μ -fuse)

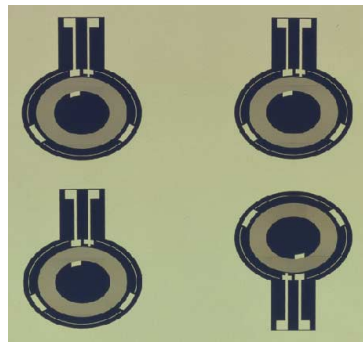


Fig. 8: capacitance sensor

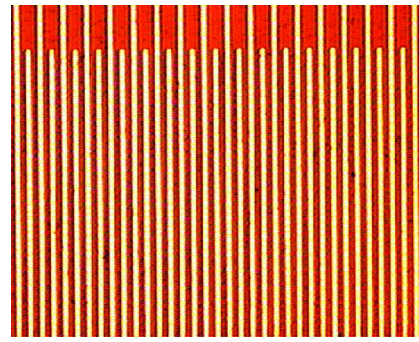


Fig. 9: R-Sensor

Fig. 9 shows a cutout of a resistance sensor. Polyimide foil (UPILEX-S) has been used as a substrate. The laser-structured metal layer is copper with a thickness of 45 nm. The smallest line widths are 30 μm . Laser-structured resistive coatings can be used in micro heaters and thermo elements.

Fig. 10 also shows a resistance sensor. The structured material is constantan. Fields of application are micro-heatings and thermo elements.

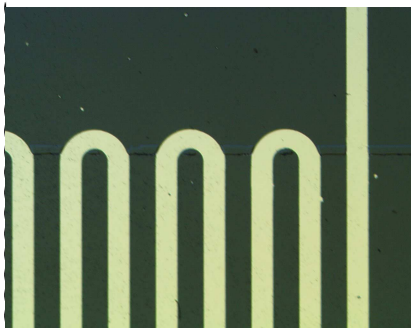


Fig. 10: R-sensor (heater)

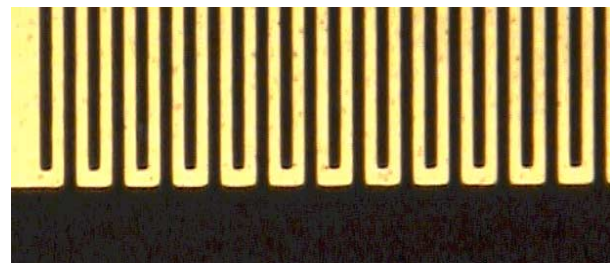


Fig. 11: Al on PET/ PC- sensor

Laser-structured Al layers on polyester or polycarbonate substrates are used for security systems as shown in fig. 11. The lines and tracks are here 30µm.

This technology can also be used for the following applications fields:

- Semiconductor technology (e.g. OLED, polymer electronics)
- Security technology (e.g. inductive/ capacitive elements for labelling/ protection)
- Electronic packaging (e.g. CSP, BGA)
- Telecommunications (e.g. mobile phones)
- Consumer electronics (e.g. digital portable equipment)

Advantages of the LDP- process

So far, the traditional way to produce finest structures for sensors and sensor elements has been photolithography. The material to be structured is coated with photoresist, then exposed, developed and etched. Improved quality and a reduction of production steps is achieved using Laser Direct Imaging (LDI). The newly developed LDP process allows a further reduction of production steps. According to (7), there are 23 steps when conventional structuring is used. For LDI, 11 steps are stated, and the developed LDP process only needs 9 process steps. This means both a reduction in cost and an improvement of quality.. This structuring method seems to be especially interesting for flexible substrate materials for reel-to-reel production plants. A cost reduction of up to 20% is assumed.

In summary the advantages the LDP- process for the mass production of microstructures for sensor applications are:

- high throughput (reel-to-reel processing)
- no etching process
- no photo-imaging process
- patterning of microstructures without chemicals
- capable of producing $\geq 15 \mu\text{m}$ geometries
- process suitable for integration in production lines
- fast layout change by simply exchanging the mask
- reduction of chemicals and waste = cost reduction
- environmentally friendly process
- simple process

Summary

It is proved that thin metal or alloy layers maximum thickness of approx. 100 nm which are applied to flex or rigid polymer substrates by PVD processes can be economically patterned with a UV-laser system. Lines and spaces $\geq 15 \mu\text{m}$ can be created. Both batch or reel-to-reel processes are suited for the mask projection method to economically pattern substrates. Due to its simple process mechanism it combines precision and economic efficiency.

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