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LASER SUPPORTED ACTIVATION AND ADDITIVE METALLIZATION OF THERMOPLAS-TICS FOR 3D-MIDS

M. Hüske[1], J. Kickelhain[1], J. Müller[2], G. Eßer[3]
[1]LPKF Laser & Electronics AG, Germany; [2]Chair of Manufacturing Technology, University of Erlangen-Nuremberg, Germany; [3]Bavarian Laser Centre, Germany

Abstract

The market for 3D-MIDs (three-dimensional Mould-Interconnect-Devices) within the circuit board industry grows rapidly and has high future potentials. Miniaturization of electrical componentry, design flexibility, a more rational production and the reduction of production steps are the main driving forces behind this development. On this background a new technology, the so-called LPKF-LDS (Laser Direct Structuring) process, has been developed for the manufacturing of 3D-MIDs. The surface of a modified thermoplastic is partially activated by a focussed laser beam. In a following electroless plating process copper, nickel and gold are deposited on the activated areas completing the circuit tracks. In addition to being highly flexible, ultra fine line circuits and very small assemblies are possible using this 3D-MID production technology. This paper describes the process and system technology as well as results achieved.

Keywords: Laser Techniques – Surface Treatment, Combined Methods

1 Introduction

A large step towards a significant miniaturization of electronic componentry is the integration of electrical and mechanical functions as implemented in 3D-MID technology (Mould Interconnect Device). Here a housing can serve as a three-dimensional circuit board. A more rational fabrication, design flexibility and shorter process chains are the main advantages of this technology, which is of growing interest to the circuit board industry.

A new production process for 3D-MIDs has been developed by the Fachhochschule Lippe and is currently being further investigated by the LPKF Laser & Electronics AG in cooperation with the Fachhochschule Lippe and the Chair of Manufacturing Technology, University of Erlangen-Nuremberg. The so-called LPKF-LDS (Laser Direct Structuring) process comprises merely three process steps. A thermoplastic part is being injection moulded based on a granule modified with an organometallic complex. The surface of the thermoplastic part is then partially activated by laser irradiation. Finally in an additive electroplating process the circuit tracks are selectively deposited on these activated areas.

In addition to being highly flexible relating to changes in the electrical circuit design, the LPKF-LDS (Laser Direct Structuring) process provides high throughput, lines and spaces down to 20 µm and is above all an environmentally friendly technology. This method is now ready-for-market and is currently being adapted for several materials of interest to the electronics industry.

2 State of the Art

A whole string of different technologies is available for coating a plastic surface with a metallic layer, as for example PVD coating, laminating with metal foils, spray coating or electroplating methods. The latter are especially suited for metallizing three-dimensional pieces. When using an electroplating technique, plastic parts are usually metallized in a multi-stage process where the surface is first cleaned and roughened, then given a catalytical nucleation and finally coated with metal using a chemical and / or electroplating method. In the field of platstics metallization, creating a plastic surface that catalyses a chemical metallization process is called activation.

Selective activation followed by selective metal deposition is an especially promising approach to the problem of metallizing only partial areas of three-dimensional plastic surfaces (e. g. in MID production). When using special substrate materials, laser irradiation can *directly* trigger such a selective activation. *Indirect* activation by a laser is possible as well. Here the catalytic plastic surface is not directly created by laser irradiation but rather by the following deposition of a catalyst in the irradiated areas. In recent years, many papers on laser-assisted activation of plastic surfaces have been published.

2.1 Direct Laser Activation

As early as in the 1970s, Suh et al. [1] performed research work on the manufacturing of electrically conductive structures by directly transforming doped plastic materials. Metallic compounds such as Cu_2O, CuO or $CuCl_2$ were mixed with a polymer matrix material in a very high concentration (60 – 90 % by volume) and locally reduced to the metallic phase by irradiation with a CO_2 laser. Then the thin metallic layers could be selectively reinforced with an electroplating process. Unfortunately, the patent papers do not contain information regarding the achievable writing speeds and the exact conductibility.

Another method, which was developed by Epstein et al. [2] in the 1980s, is based on the thermal transformation of non-conductive polyacrylonitrile fibers in a polymer matrix material (e. g. polyetheremide). Triggered by laser irradiation, the polyacrylonitrile fibers carbonize and form a conductive network that can be converted to the desired metallization thickness by chemical or electroplating reinforcement. The maximum achieved writing speeds, however, were only a few mm/s.

Using a laser, it is also possible to modify insulators in such a way that they can trigger a metal deposition in a chemical metallization bath without a conductive (e. g. metallic) phase forming locally [3]. Triggered by the laser irradiation, catalytic centres are created directly on the surface of a string of insulators; these catalytic centres are characterized by a locally changed band structure of the solid body. Successful surface activation can be shown, e. g. for Al_2O_3, SiC, diamond and ZrO_2. A process for excimer laser activation of plastic materials filled with fine ceramics particles developed by Laude et al. is probably based on the same principles [4].

Within a project conducted in co-operation with the 3D-MID e.V. research association, the Chair of Manufacturing Technology in Erlangen also developed a new laser structuring method based on the thermal-physical transformation of catalytic micro-capsule fillers that are added to a thermoplastic material before the injection molding process (ADDIMID procedure). The fillers are uncovered by selective laser irradiation of the substrate material and then serve as seeds for a following metallization process [9].

2.2 Indirect Laser Activation

With indirect laser activation processes, the laser irradiation modifies the plastic surface in a way that catalytic seeds can be deposited in the irradiated areas; these seeds can trigger a selective metal deposition in a following chemical or electroplating metallization process. The Fraunhofer Institute for Laser Technology in Aachen, for example, developed a process where an excimer laser roughens the surface of a 3D-MID substrate and prepares it for the following selective deposition of a palladium catalyst [5]. At present, however, it is hard to say whether the process can be transferred to different substrate materials without problems.

Using excimer laser irradiation (λ = 193 nm) in a reactive N_2H_4 atmosphere, H. Niino and A. Yabe managed to prepare teflon surfaces for a following deposition of a Pd catalyst [6]. In the irradiated areas, a deposition of Sn ions is possible that then catalyze a selective Pd nucleation. The necessary energy densities are around 50-80 mJ/cm^2. Zhao et al. [7] use a similar technique for modifying the surface of a standard polyimide material (Kapton, Du Pont) by irradiation with a KrF excimer laser (248 nm) in a way that a relatively high surface potential forms in the irradiated areas. Using a special palladium solution of negatively charged colloid particles [8], it is possible – after suitable pre-treatment – to deposit Pd seeds in the irradiated areas only. The nucleated substrate areas are then coated with copper in an electroless metallization bath. Thus, it is easily possible to achieve line widths of 50 micrometers.

3 Principle of Laser Supported Activation and Additve Metallization Process

The basic concept of the process developed is to modify an electrically isolating polymer matrix maintaining its non-conductive property and to set free seeds on the surface of the polymer by laser irradiation of a certain energy density level. These seeds enable a selective wet-chemical reductive metal precipitation. The polymer is modified by incorporating dispersive organometallic complexes into the matrix which are designed in a way that they can be activated by the laser irradiation.

Laser irradiation on the one hand induces a physio-chemical reaction in form of cracking chemical bonds. On the other hand it makes a strong adhesion of the forming metal layer possible by ablating polymer material, i. e. roughening the surface and thus providing an effective anchoring for the forming metal layer. Finest cavities are produced, providing a mechanical anchoring for the metal plating (see fig. 1). This effect is supported by incorporating laser irradiation resistant filler particles which protrude on the surface after the laser treatment [10],[11],[12],[13],[14].

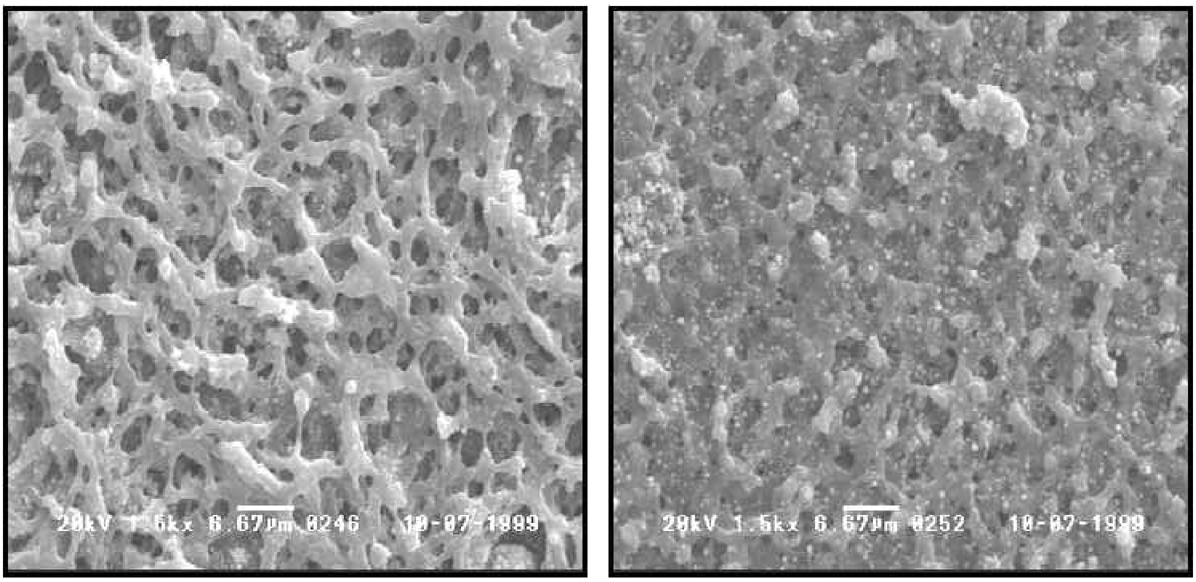

Fig. 1: *Surface after laser structuring and after beginning metallization*

3.1 Organometallic Complex

The basis of this process has been the development of organometallic complexes with the following characteristics:

- electrically non-conducting,
- visual-light-resistant,
- sufficient soluble and/or colloidal dispersible in the polymer matrix,
- good compatibility in the polymer filler material system,
- no catalytic activity,
- separable in metal seeds and organic residuals by laser irradiation,
- high thermal resistance,
- little toxicity and
- low costs.

The organometallic complexes are based on palladium (Pd^{2+}) and/or copper (Cu^{2+}). Due to high palladium prices alternative systems of different transition metals like copper are preferable. The developed organometallic complexes are of an exceptionally high stability.

Within the frame of extensive research work performed by the Fachhochschule Lippe in co-operation with the LPKF AG, a large number of combinations meeting the requirements were found, synthesized and incorporated into different thermoplastics.

3.2 Fabrication of Modified Thermoplastic

Pulverized organometallic complexes, inorganic filler materials, the polymer as well as further additives are processed in a heating-cooling mixer combination (fluid mixer) to a homogeneous agglomerate. The next step is the compounding. In an extruder this agglomerate is molten and transported. The result is a homogenized modified thermoplastic. After cooling the extruded thermoplastic is crushed in a granulator to a conventional granule which can be processed in any injection moulding machine.

Fig. 2: *LPKF system: Heating-cooling mixer combination, extruder, cooler and granulator at FH Lippe (from right to left)*

3.3 Technology Steps to Manufacture MID-Parts

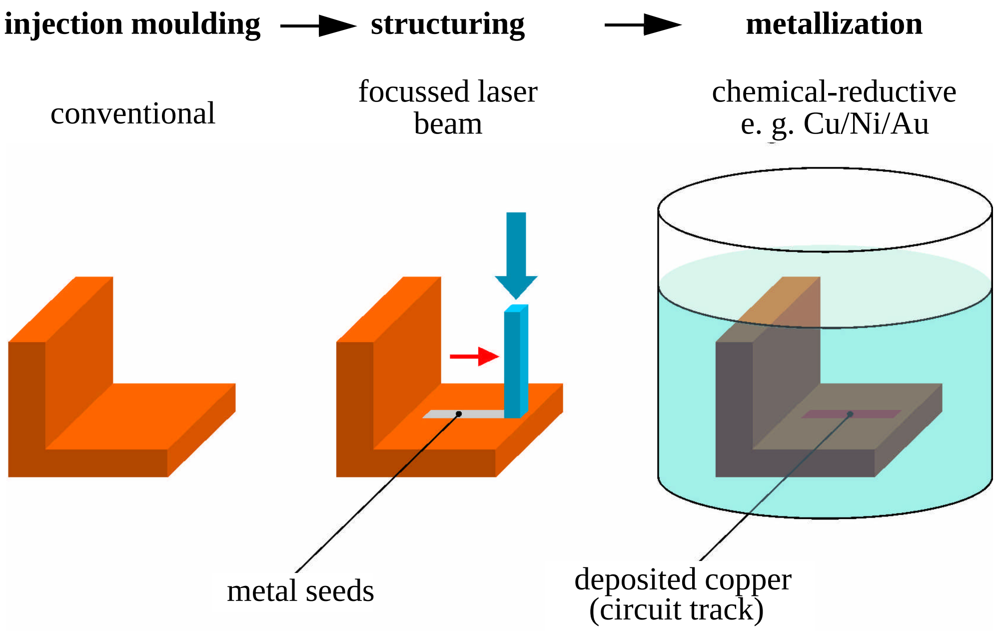

Fig. 3: *Main technology steps*

The granule is outstandingly well suited to be moulded in conventional injection moulding technology to produce three-dimensional parts. The following surface activation and roughening is achieved by using a UV-laser (see fig. 4). The necessary laser radiation shows the following effect with regard to the surface structuring of the thermoplastic:

- high resolution ablation of material, especially applying to organic materials,
- induction of a physio-chemical reaction.

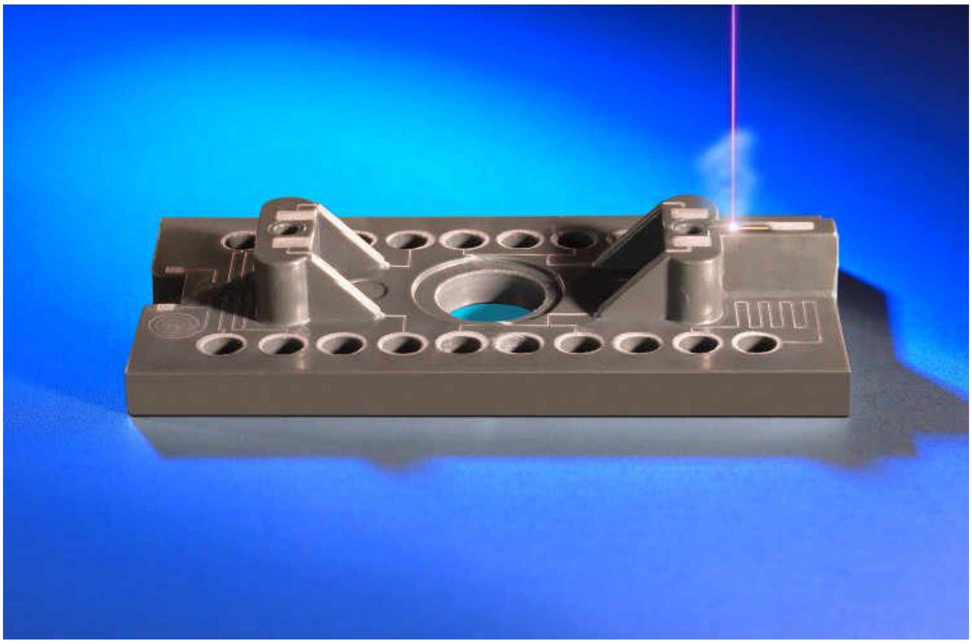

Fig. 4: *PBT surface activation by a focused laser beam*

The conductor lines are selectively built up on the thermoplastic in the areas activated by the laser in a following electroless plating process.

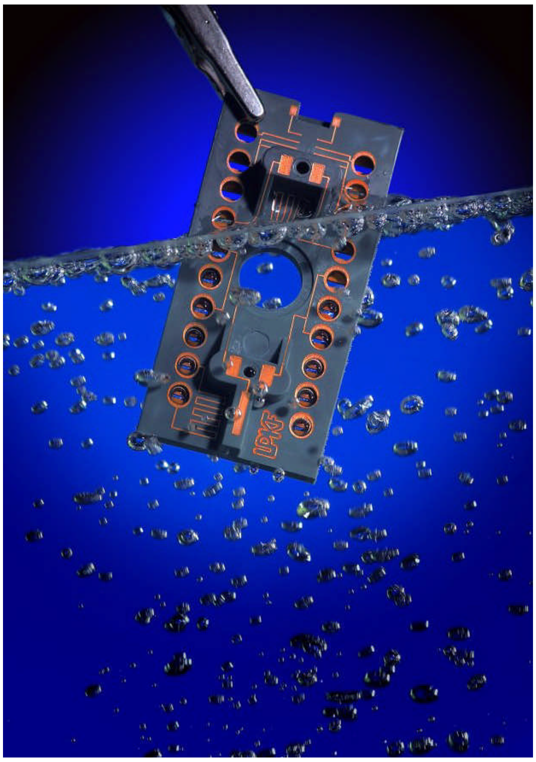

Fig. 5: *PBT MID part in electroless plating process*

Conventional metallization baths (e. g. Shipley, Mac Dermid) can be used. An economical plating thickness lies in the range of 5 µm copper, a succeeding Ni-layer of 5 µm and 0.1 µm gold finish. To achieve a higher copper plating thickness, the part can be placed in an electrolytic bath afterwards.

Basically the described process can be applied to many thermoplastics. In a first step polypropylene (PP) has been chosen to demonstrate the feasibility of the process. PP is a demanding and within the frame of industrial applications a proven thermoplastic with low temperature characteristics. Its extremely difficult metallization behaviour increased the requirement profile for this technology.

The latest developments concentrated on the adaption of the complexes for the incorporation into the high performance thermoplastic polybutylene-terephtalate (PBT) which is well suited for micro injection moulding.

4 Laser Processing Technology

4.1 Laser System

In the frame of the research project MATECH funded by the Bundesministerium für Forschung und Technologie (BMBF); a laser system for the structuring of 3D-MID parts has been developed by LPKF in co-operation with the Chair of Manufacturing Technology (see fig. 6).

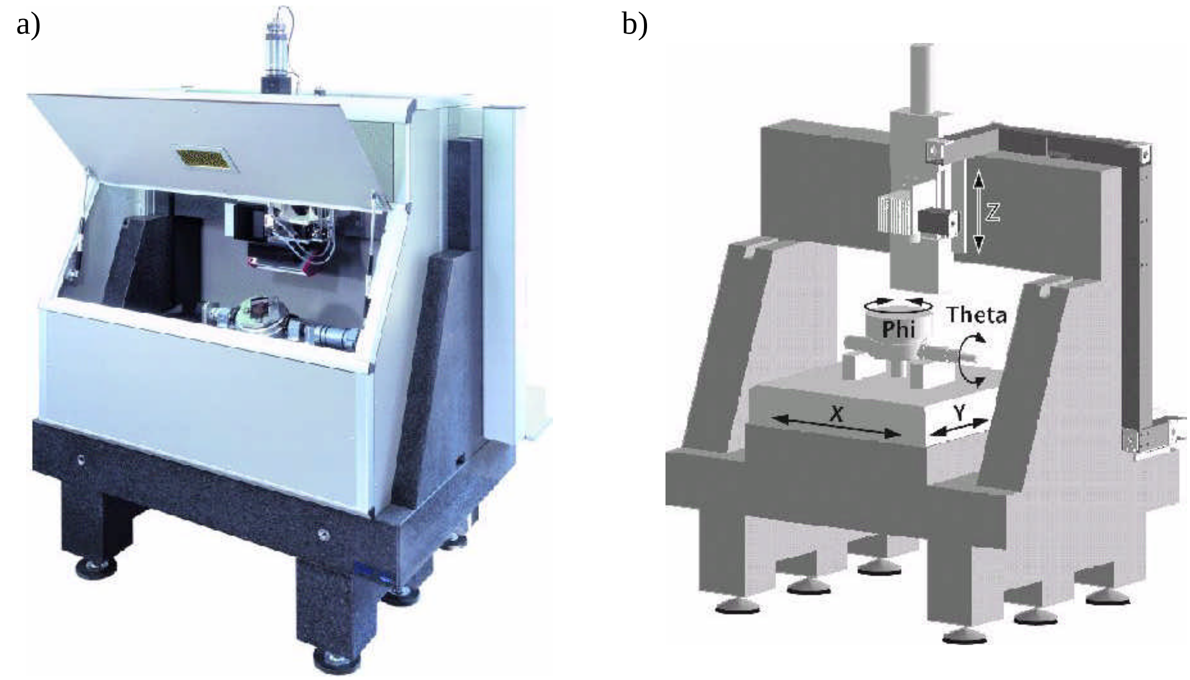

Fig. 6: *a) 3D laser system (LPKF AG) and b) mechanical axis*

The system comprises five mechanical and three optical axis.

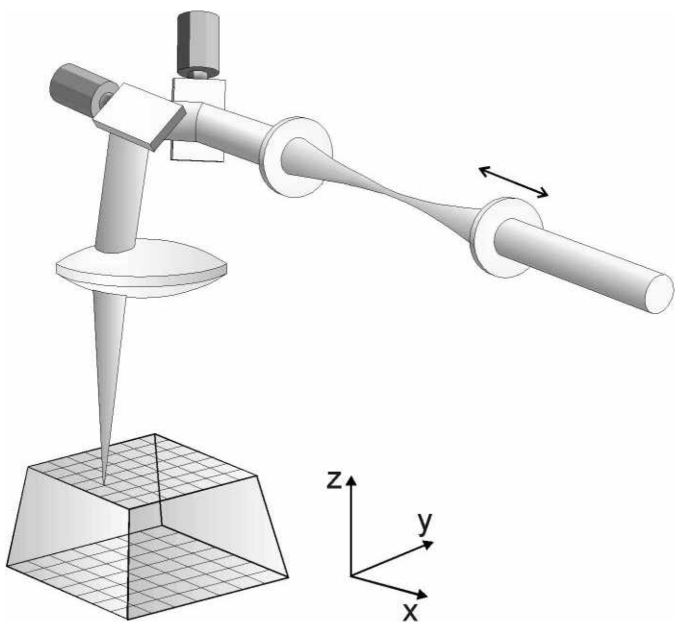

Fig. 7: *Optical axis*

The lateral moving range of the xy-table comprises 200 x 200 mm with an absolut position accuracy of +/- 4 µm. The z-axis has a positioning range of 300 mm with an accuracy of +/- 3 µm. An axis of rotation (360°, accuracy +/- 10’’) is mounted on a swivel axis (+/- 90°, 10 ‘’) to allow an in-feed of parts with multiple planes to be structured.
The initial laser beam is focussed, positioned and deflected within a scanning volume. Three optical axis make it possible to guide the laser focus spot within a plane as well as along complex three dimensional contours. The laser beam is moved relative to the workpiece with two deflecting mirrors in lateral direction (see fig 7).

Moving mirrors are synonymous to low moving masses. The result is an extremely high working speed and thus an economical throughput. The mirrors are mounted on a rotational axis of special motors (galvanometer scanner). In addition to high positioning speeds, high accuracies can be provided.

The third optical (a Kepler telescope) axis provides a shift in longitudinal direction. This shift is achieved by moving one of the lenses mounted on a linear translator. At present a scanning volume of 200 x 200 x 50 mm^3 can be reached.

4.2 Laser Source

Basically the system can be operated with an ultraviolet (λ = 355 nm) or infrared (λ = 1064 nm) laser. Up to now only UV laser radiation has been used for the activation of the thermoplastics.

The laser source that has been used for the laser activation process is a frequency-tripled Nd:YAG laser (λ = 355 nm). Increasing absorption characteristics of polymer materials as well as decreasing spot diameters with smaller wavelengths enable the polymer ablation with the desired characteristics of cracking the organometallic complexes and roughening the surface for a metallization of strong adhesion. This is supported by operating the laser in Q-switch mode producing extremely short pulse durations combined with extremely high pulse powers. The small spot sizes also make it possible to achieve finest lines down to approximately 20 µm.

4.3 Beam Homogenization

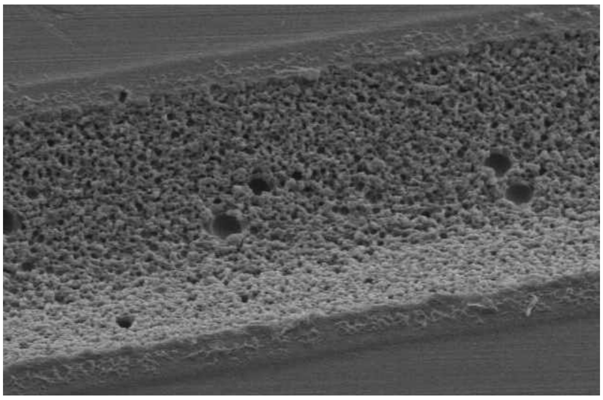

Fig. 8: *Track geometry*

In the context of the BMBF research network project “Ganzheitliche Materialkonzepte und Systemlösungen für Mechatronic-Anwendungen" the laser beam is to be homogenized. The target is to achieve a constant intensity distribution over a defined cross section. On the other hand a typical laser beam intensity profile is gaussian. Therefore less energy is incorporated into the surface of the thermoplastic at the edges of the laser structured track than within its centre. As a result a melting zone is formed at the edges of the track (see fig. 8) which should be avoided in terms of a strong metallization adhesion. Thus a clearly defined beam profile with a homogeneous intensity distribution is required. This kind of "Top Hat" beam can be implemented e. g. using fibers, a pipe with mirror-glass on the inside or an individual diffractive component.

The current research focus is a circular Top-Hat intensity profile that is to be generated using diffractive lenses (see fig. 9). At present, diffractive optical elements (DOE) are used in laser technology, fiber technology, communications technology, projection lens technology and sensor technology.

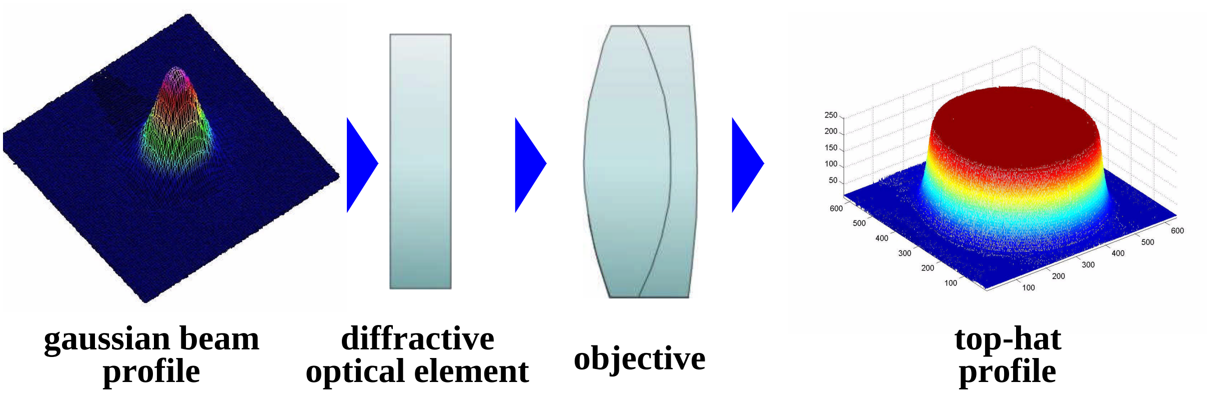

Fig. 9: *Top-Hat profile implemented using a diffractive optical element (DOE)*

5 Material Properties

In connection with the investigations concerning the characteristics of the developed thermoplastics, measurements of the viscosity in dependence on the shear speed are very important (see fig. 10 for PP-MID). The dependence does not show any significant difference to standard polypropylene. This proves that components of high quality can be fabricated in standard injection moulding processes with doped PP. This also applies to polybutyleneterephtalate.

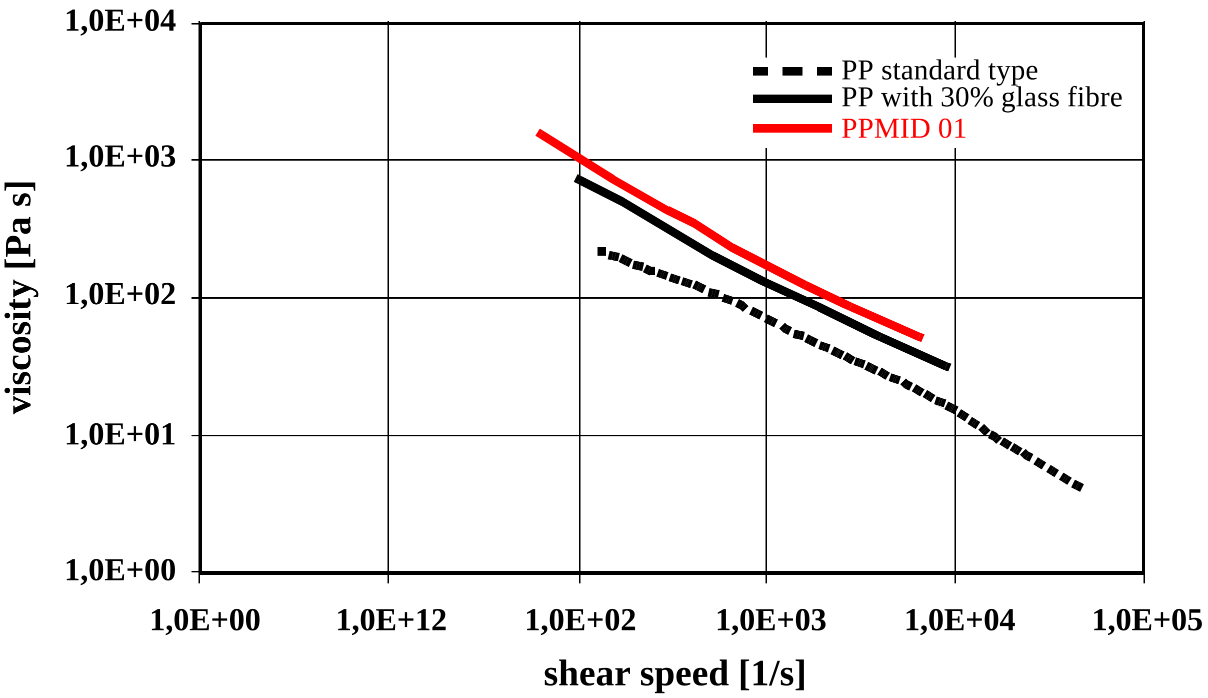

Fig. 10: *Viscosity as a function of shear speed for PPMID*

Characteristics \ Material		PP standard type (Hostalen PPN 1060)	PP with 30 % glass fibre (Hostacom G3 U01)	PPMID	PBT standard type (Pocan B 1305)	PBT standard type (Ultradur B 4520)	PBTMID
Electrical Characteristics							
spec. Surface resistivity	Ω	>1.0E14	>1.0E14	>1.0E14	1.0 E15	1.0 E13	1.0 E13
spec. Volume resistivity	Ω*m	>1.0E14	>1.0E14	>1.0E14	1.0 E13	1.0 E13	1.0 E13
permittivity ε_r	-	4,52	N/A	4,52	3,4	3,4	5,38
dielectrical loss factor tanδ (100 Hz)	-	0,007	N/A	0,009	0,002	0,002	0,0036
Mechanical Characteristics							
breaking elongation	%	140	3	1,4	20	>50	>10
tensile strength	MPa	31	85	29	55	60	53
E-module (tensile)	MPa	1250	6200	2200	2800	2600	3150
density	kg/m^3	907	1140	1170	1300	1300	1380
shore hardness D	-	70	N/A	75	k.A.	k.A.	83
adhesion strength of metallization	N/cm	[<0,5]	N/A	13	-	-	8
Processing Characteristics							
melting temperature	°C	165	N/A	179	225	223	227
melting temperature (injection moulding)	°C	250	230	230	260	265	255

Fig. 11: *Material properties of modified PP and PBT in comparison to standard materials*

The most important material data are listed in fig. 11 for PPMID and PBTMID.

Apart from impressing electrical and mechanical properties of doped PP and PBT the exceptional adhesion strength of the plating with values of 13 N/cm for PPMID and 8 N/cm for PBTMID is important for the circuit board manufacturing industry. Figure 12 shows a complete manufacturing step of a 3D-MID part, from the moulded part to a complete circuit with components.

Fig. 12: *Complete chain for manufacturing a 3D-MID: moulding, activation, plating, component assembly*

6 Conclusion and Outlook

Laser supported additive metallization of different thermoplastic materials for 3D-MIDs is an environmentally friendly technology for structuring finest lines down to approximately 20 µm for microelectronic applications with a high throughput. At present two modified thermoplastic materials are available which can be injection moulded in standard processes with exceptional mechanical and electrical properties.

The research work is being continued within the project “Ganzheitliche Materialkonzepte und Systemlösungen für Mechatronic-Anwendungen” funded by the Bundeministerium für Bildung und Forschung (BMBF). The investigations focus on the adaption and qualification of the organometallic complexes to the plastics ABS, PC/ABS, PA, sPS and PI. In addition other laser sources, e. g. CO_2 and Nd:YAG) will be investigated regarding their effect on the organometallic complexes and thermoplastic.

Applications are foreseen within the areas of telecommunication, sensors and automotive systems.

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