Laser-based production of multifunction packages taking innovative rotary encoders for automation and vehicle technology as examples

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Zusammenfassung

Spritzgegossene Schaltungsträger (Moulded Interconnect Devices - MIDs) eröffnen die Chance, Elektronik und Mechanik miteinander zu verbinden. Neben der größeren Gestaltungsfreiheit im Vergleich zu konventionellen Schaltungsträgern bietet die MID-Technologie zudem ein enormes Rationalisierungspotenzial durch die Verkürzung der Prozesskette. Zudem tragen 3D-Leiterplatten durch die Reduzierung der Teileanzahl zur Miniaturisierung elektronischer Baugruppen bei.

Wesentliche Einsatzgebiete für die MID-Technologie sind multifunktionale Packages für die Automobilelektronik und die Telekommunikation, daneben aber z.B. auch Computer-, Induststrieelektronik oder die Medizintechnik.

Mit dem von LPKF entwickelten Laser-Direkt-Strukturierungsverfahren (LDS) ist es möglich, hochauflösende Schaltungslayouts auf komplexen dreidimensionalen Trägerstrukturen zu realisieren und damit die bisher getrennten Einheiten Gehäuse und Leiterplatte funktionell zu integrieren.

Die Grundlage des Verfahrens bilden dotierte Thermoplaste, auf denen die zu realisierenden Leiterbahnen mittels Laser gezielt aktiviert und anschließend im chemischen Bad metallisiert werden können.

Im weiteren werden die technischen, wie wirtschaftlichen Vorteile dieses Verfahrens angesprochen, so wie die Umsetzung anhand von zwei Beispielen aus der Industrieautomatisierungstechnik sowie der Kraftfahrzeugtechnik.

Abstract

Moulded Interconnect Devices – MIDs present the chance to combine electronic and mechanical parts. Compared to conventional circuits, MID technology offers a greater freedom of design and, due to the shortened process chain, a tremendous potential of rationalization. Moreover, by reducing the number of required parts, three-dimensional circuit carriers contribute to the miniaturization of electronic components.

Main application areas of MID technology are multifunctional packages for automobile electronics and telecommunication, but also computer technology, industry electronics, or medical technology.

With LPKF's Laser Direct Structuring process (LDS) it is possible to produce high-resolution circuit layouts on complex three-dimensional carrier structures, thus integrating casings and circuit boards that previously were separate units in one unit.

The process is based on doted thermoplastic materials on which the tracks that are to be realized are activated by means of targeted laser radiation and then metallized in a chemical bath.

Further discussed are technical and economical advantages of this process, as well as using it for specific applications. One from the industry automation and one from the automotive area.

1. Introduction

The are demands today for greater function integration and higher performance levels combined with more miniaturisation, weight savings and lower piece costs: these all place globally active car builders, machine manufacturers, plant constructors, manufacturers of consumer goods and domestic appliances under increasing competitive pressure. This pressure can only be compensated by ongoing and continuous innovations and further developments, of which advancements made at the component level are particularly critical. A critical role is played by sensor technology, as exampled here by rotary encoders for cars, machines and many other appliances. These devices are used in very high numbers to determine the position and rotary speed in many, diverse tasks.

In addition to miniaturisation of sensors and the raising of a device's function density and reliability, a key goal is that of reducing of piece costs. In order to achieve sustainable miniaturisation while opening new cost saving opportunities in the field of micro-rotary encoders for future sensor generations, high performance micro-system chip components are indispensable, for example GMR magnetic field sensors, in conjunction with state-of-the-art casing and assembly technologies.

A research project funded by the German Federal Ministry for Research and Development (BMBF) is looking into the suitability of laser-based production techniques for multifunction packages, taking automation and car industry technologies as examples. IMDAKT (innovative micro-rotary encoders for automation and car technology) is a joint project seeking to implement suitable system concepts based on currently available micro transducer modules and microelectronic circuit chips in conjunction with casing and assembly technologies based on laser MID technology (MID = moulded interconnect device) and flipchips. The industrial production suitability, functionality and basic reliability is investigated on two actual products under the tough conditions prevailing in industrial pneumatics and automotive applications.

This paper presents laser-based production techniques for the production of MIDs together with process-related design rules upon which the concepts for the multifunction packages are based. The paper closes with a discussion of the qualification results of the micro-rotary encoders produced.

2. Current engineering practice

2.1 Rotary encoders in the automotive industry

The majority of active sensors used to date in the car industry are based on either PCB substrates or built using wirebonding on stamped inserts followed by moulding. Both techniques require the sensor carrier to be separately packaged, usually in a thermoplastic injection moulded casing.

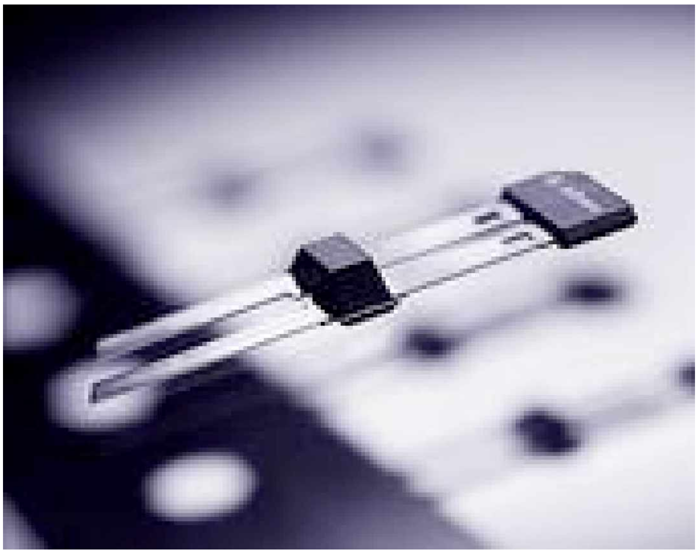

Figure 1: Unpackaged rotary encoder, stamped insert technology (Infineon)

Stamped insert technology has the drawback of not only offering minor miniaturisation potential but also that both technologies described offer no large opportunities for cost savings now or in the future. Bearing this situation in mind, a flexible solution was sought for a substrate with a high miniaturisation potential, e.g. MID technology.

Bare-die assembly was seen as a promising way of optimising the assembly technology of the active sensor element. Adopting bare-die assembly for the structural design and connecting technology appears favourable, particularly in the fine pitch sector, where the objective is to produce both smaller and cheaper rotary encoders.

2.2 Rotary encoders in automation

Miniature sensors for pneumatics are already manufactured as non-contact miniature position sensors on ceramic carriers. These are then fitted in a suitable casing using a very complex production process with subsequent moulding.

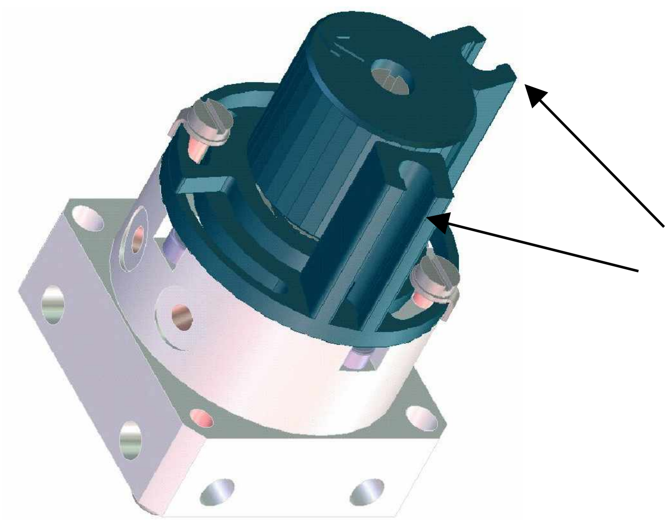

Figure 2: Current version of rotary encoder for pneumatic rotary drives

Figure 2 illustrates a rotary encoder as used today in industrial automation, in this case with two magnetic field sensors. The magnetic field sensors are placed in the vertical grooves, moulded and then wirebonded. In this technology there is presently no alternative for integrating a sensor die in the casing of a position sensor which offers not only a competitive cost framework while also achieving the required degree of integration within the installation geometry. In the pneumatics sector, the incentive is to use dies which can be processed using a combination of MID substrates and flipchip technology to create a novel technology offering benefits both in diverse integration tasks within pneumatics as well as beyond.

The function model demonstrator shown as a schematic in figure 3 prepared in the project represents a novel product series of position sensors for pneumatic rotary drives which will not only solve many problems associated with the handling of bare-sensor chips on a plastic substrate, but also mark the start of a new generation of position sensors.

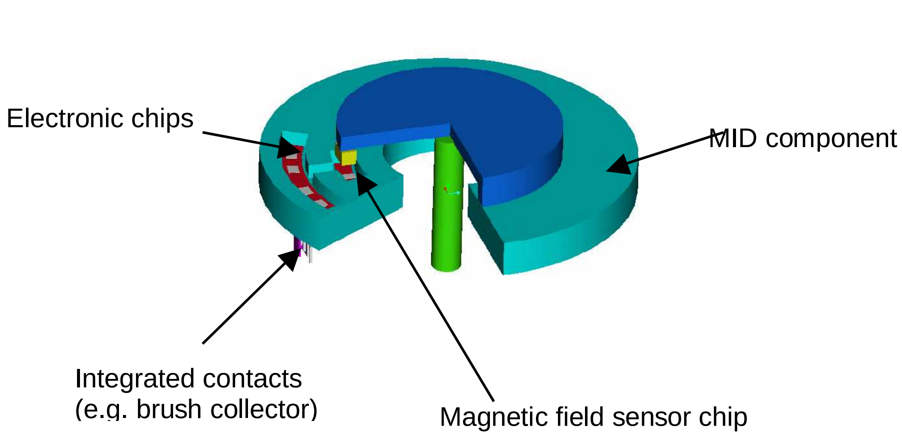

Figure 3: Schematic of novel miniaturised rotary encoder for pneumatic rotary drives with MID component

2.3 flipchip technology on MIDs

The use of MIDs as the assembly and connection technology for microsystems has recently made great advances (1-3), as have flipchip technologies used in the assembly of bare-die chips on flat substrates, i.e. PCB, ceramic substrates and glass substrates (4,5). It therefore was logical, within the framework of the joint project, to consider whether the high demands of future rotary encoders could be met using a combination of micro-moulding techniques, laser-activated selective metallisation of MID casings and flipchip technology - despite flipchip technology not having previously been combined with MID substrates.

In flipchip technology, the structural fineness, the surface quality and the mechanical properties of the substrate are extremely critical, and represent demands not yet state-of-the-art for MIDs. This is indeed the primary reason for selecting the LPKF-LDS process as the laser-based MID technique of choice because it is the only way of realising the correspondingly fine pitches in a short process chain.

3. LPKF-LDS process

To date, MID products with genuine 3D structures have been predominantly manufactured using 2-component injection moulding (2C-process) followed by chemical surface activation and selective metallisation - a process with high lead costs, making it only economically viable for volume production. In contrast, MID production using laser structuring opens up the option of waiving the 2C-process and producing the circuit carrier blank using single component injection moulding.

Compared with subtractive laser structuring, the additive LPKF-LDS process also offers the advantage of a very short process chain. Figure 4 below illustrates the principal steps in the process.

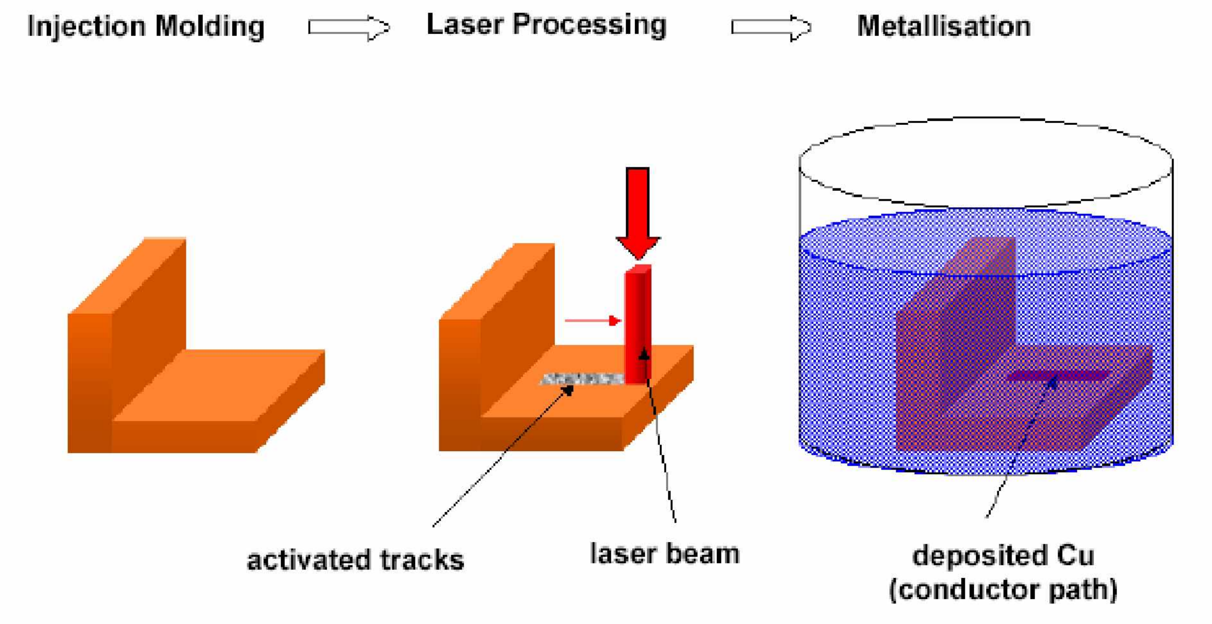

Figure 4: LPKF-LDS process steps

Compared with conventional techniques, laser direct structuring offers the further benefits by producing extremely fine conductor track structures. Over and above this, the process also offers a high degree of flexibility in terms of the circuit image because modifications can be easily introduced by changing the structuring data. In effect, this means later adaptations of the circuit design do not require any tool changes. It is exactly this flexibility which enables users to apply laser direct structuring within the product development process with the security of knowing that they will ultimately have a volume production process at their disposal which does away with complex and expensive transfers from prototype to volume production.

In preparation for LDS process implementation in production it is vital to have a selection of laser activatable plastics as used in the electronics industry available on an industrial scale. This particular aspect is assured by an ongoing material development process backed by license contracts signed with the various plastics manufacturers. For example, LPKF has now entered agreements with companies such as BASF AG, Bayer Material Science AG (since 01.07.04 LANXESS), Degussa AG as well as Ticona GmbH.

3.1 Principles

In order to avoid the disadvantages of conventional MID techniques (6 - 11), the thermoplastic materials are modified by finely dispersing a metal-organic compound in the material. This special chemical compound can be modified by an incident laser beam such that it catalyses selective metal deposition in the irradiated sections during the subsequent metallisation step. This material is preferentially a chelate complex of a precious metal - based on either palladium (Pd^{2+}) or copper (Cu^{2+}) (12). This metal-organic complex must satisfy a number of varied requirements. Thermostability must conform with the handling temperatures of the thermoplastic matrix and the complex must split in a defined way when irradiated by high energy laser light, i.e. dividing into the metal atom and the organic ligand fragments. Further criteria include:

- excellent compatibility with the polymer matrix
- no affect on electrical properties
- sufficient solubility /distribution in the matrix
- no catalytic activity causing degradation of polymer chains
- resistant to extraction
- non-toxic.

A key variable when qualifying electronic components is the adherence of the tracks. In order to be in a position to guarantee that the tracks have sufficient adhesion to the substrate even after a number of environmental cycles, the initial adhesion must be sufficiently high. In the case of PCBs constructed in accordance with DIN IEC 326 this is between 0.6 - 1.1 N/mm. In this connection, a further key property of the laser light also plays a significant role: it is not only able to selectively and homolytically split the metal complex, the exposure also results in ablation of the polymer surface. In this process, the laser energy is absorbed by the polymer molecules. The molecules are excited and start to oscillate. Ideally, as soon as a minimum energy level is reached the bonds between the molecular chains break down. In practise, the laser beam causes not only a purely photochemical ablation but also a certain degree of relaxation, in turn causing thermal vaporisation of the material (figure 5). This sublimation dominates when long-wave laser light is used, e.g. from an Nd:YAG laser (λ = 1064 nm).

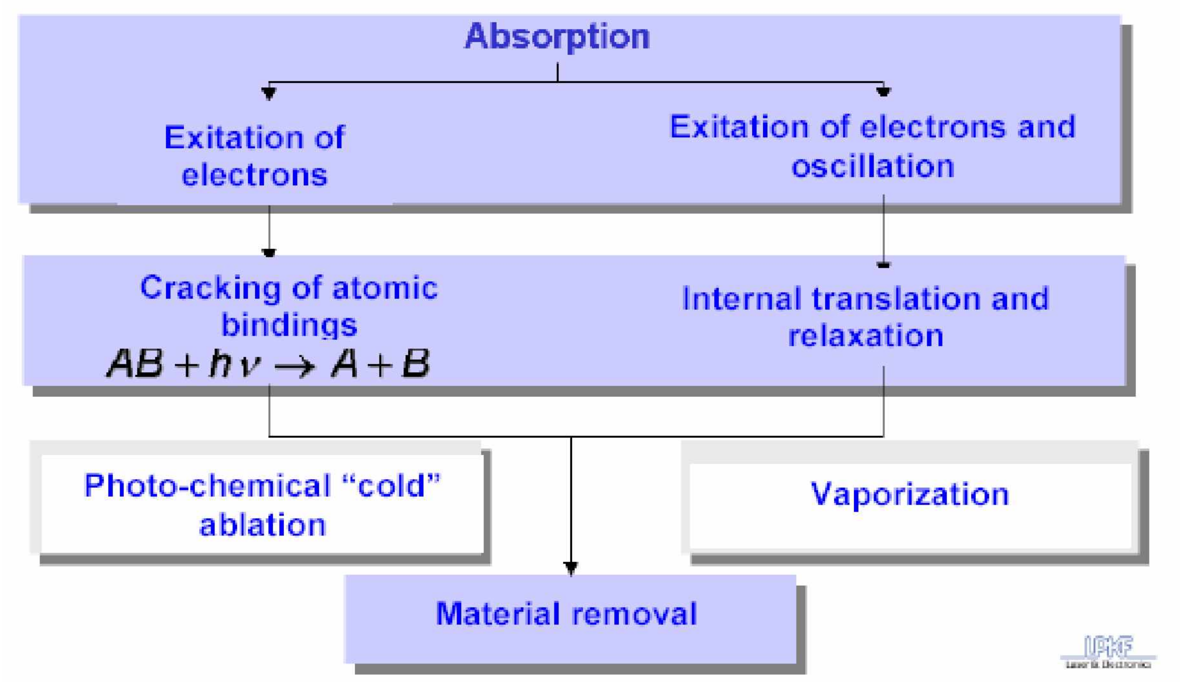

Figure 5: Principal processes of laser ablation

The polymer is carefully modified by adding fillers (generally inorganic substances) which cannot be ablated, or only with great difficulty, so that laser irradiation leaves the surface with microscopically small pitting and undercuts: a surface which allows for excellent adhesion between the plastic and the metal deposit without the need for extra post-conditioning. The schematic in Figure 6 shows the effect of laser radiation on the plastic surface.

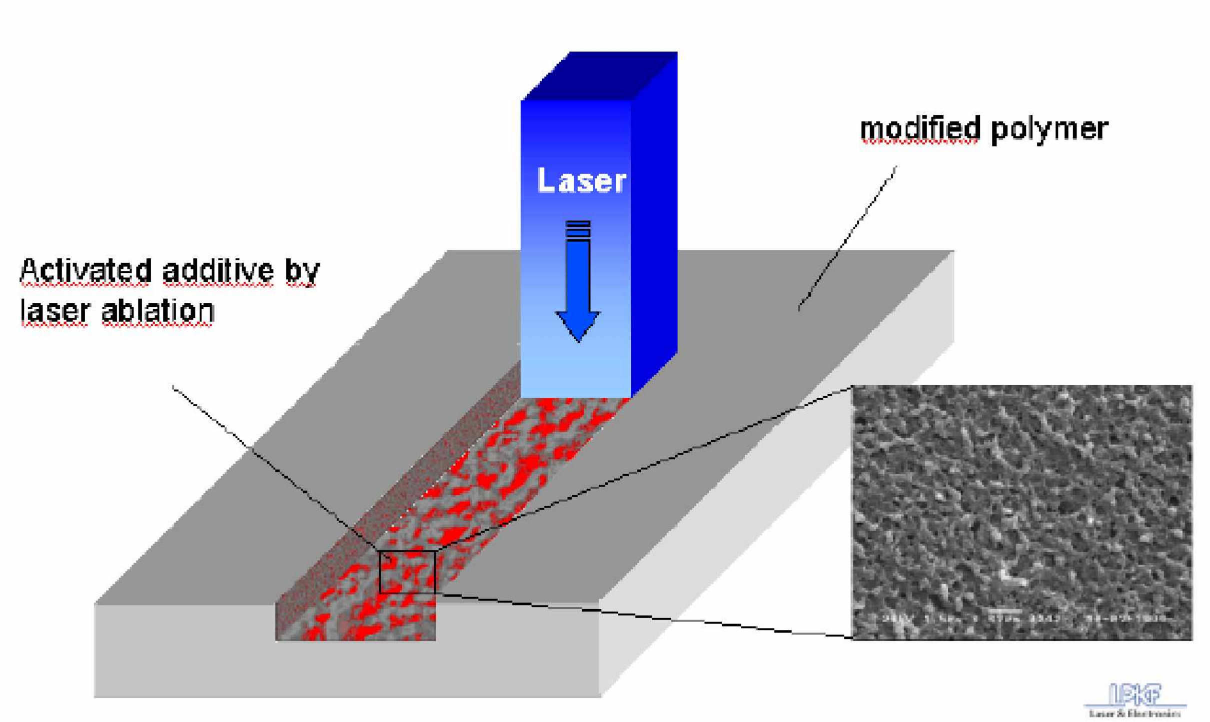

Figure 6: Schematic of laser direct structuring

3.2 Modular 3D laser system for LDS process

MicroLine 3D Industrial is a laser system developed specifically for laser direct structuring of MIDs. One of the key advantages of using laser light to work materials is lack of feedback effects in the material coupled with simultaneously high processing speeds. Furthermore, the circuit layout is generated by binary addressing of an optical processing head and is not dictated by the geometry of a fixed tool (e.g. stamp die, 2D tool). This results in shorter lead times, higher flexibility and improved economics.

The key feature of LPKF MicroLine 3D laser systems is the processing head referred to above, with its three optical axes. This tool has a high-speed control system and high precision optical system and can generate structures of smaller than 100 µm on three-dimensional components. The focused beam of a diode-pumped solid state laser of wavelength 1064 nm is scanned over the surface of the circuit carrier using mirrors of virtually zero momentum. The beam is focused on the target surface using an f-Theta lens. A linear translator, in this case a telescope with an addressable movable lens, can execute a focus stroke in a longitudinal direction by deliberate defocusing of the telescope. The combination of telescope and mirror unit is a configuration which allows the laser beam to be directed along complex three-dimensional surface topographies with high advance speeds of up to 4000 mms^{-1} (figure 7).

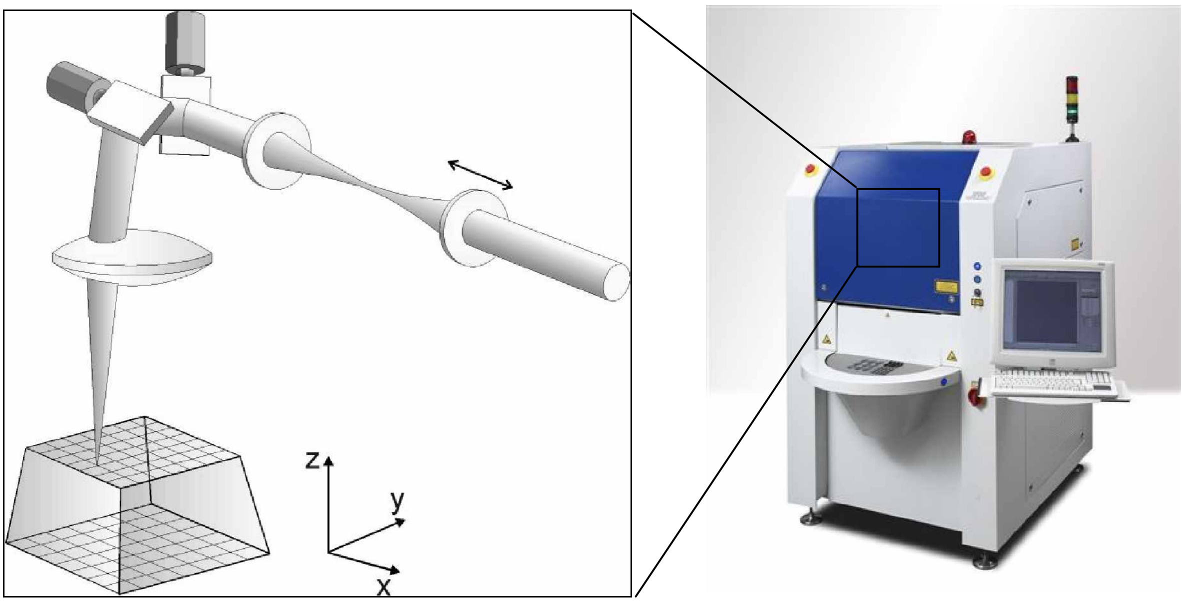

Figure 7: Processing head with three optical axes / LPKF MicroLine 3D Industrial

In addition to the actual structuring time, the "primary time", the time taken to feed and withdraw the components being structured also determines the overall cycle time and so the capacity of laser direct structuring. It is therefore paramount that attention is paid to ensure efficient component handling. Since MIDs come in many different shapes and sizes, the usual procedure is for component handling to be adapted to component geometry. This is achieved by using a circular indexing table with a built-in vision system for scanning the component as well as a model featuring a conveyor combined with a tool carrier system (figure 8).

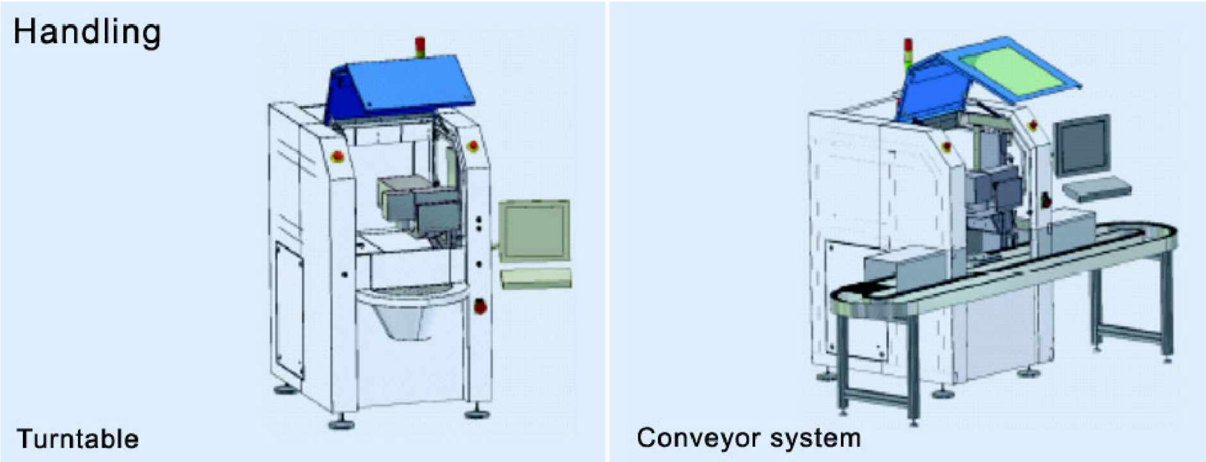

Figure 8: Different handling systems, LPKF MicroLine 3D Industrial

3.3 Thermoplastic materials for production purposes

The electronics industry can now draw on a number of interesting technical plastics. In the case of MIDs, the portfolio is, however, somewhat limited. The key criteria in this application are metallisation capacity, adhesion and also the temperature-resistance required for SMD component placing.

In reality, the choice of thermoplastic material is also further restricted by the MID production process. For example, in the case of 2-component injection moulding, it is only possible to use thermoplastics with special rheological properties (e.g. low melt viscosity) in order to fill fine cavities. These restrictions do not apply to materials for laser direct structuring per se. Single component injection moulding is used and therefore no special processing property demands exist. The activation and subsequent adhesion of the metallisation is created by the surface treatment described in section 2.1 (interaction: material/laser).

In practice, many applications requiring a certain degree of thermostability which limits the portfolio of materials. Wherever soldering is not required, and assuming higher thermal dimensional stability is not demanded for other reasons, it is in principle possible for any thermoplastic to be modified for laser direct structuring. The table below summarises the materials currently available and qualified.

Property	Unit	Vestodur CL2230	Vestodur CL3230	Ultramid®T 4380 LS	Vectra® E820i LDS	Pocan DP7102	Pocan TP710-003	Pocan TP710-004
Manufacturer	-	Degussa	Degussa	BASF	Ticona	Lanxess	Lanxess	Lanxess
Polymertype	-	PBT	PBT	PA6/6T	LCP	PBT	PBT	PET/PBT
Mold shrinkage	%	parallel 0,2	parallel 1,3	constrained 0,5	parallel/normal 0,3 / 0,4	parallel/normal 1,3/1,3	parallel/normal 1,4 / 1,4	parallel/normal 0,24 / 0,98
Post-shrinkage	%	parallel 0,1	parallel 0,4	-	-	parallel/normal 0,1 / 0,3	parallel/normal 0,3 / 0,3	parallel/normal 0,05 / 0,22
Tensile strengh	Mpa	95	44	140	116	55	51	110
Tensile modulus	Mpa	10500	4800	9700	9000	5600	5500	120000
Strain at break	%	1,2	1,1	2,2	4	2	3,3	1,5
Charpy impact strength	kJ/m²	30 C	15 C	33	19	25	40	25
Density	g/cm³	1,77	1,67	1,4	1,79	1,57	-	1,75
Melt volume-flow rate (MVR)	cm³/10min	28	37	-	-	10	5	16 *
Melting temp. DSC	°C	-	-	295	335	225	225	-
Deflection temp. (HDT/A) 1,8MPa	°C	-	-	-	220	115	110	250 *²
Content of material/filler	%	30	30	30	40	25	25	40

* = 280°C/2,16 kg   *² = 0,45MPa

Table 1: Comparison of material characteristic values

3.4 Metallisation of laser-activated components

The split of metal complexes using laser light as described in 3.1 leaves seeds which catalyse metal deposition in only these areas activated by the laser. This process generally uses chemical copper electrolytes which typically generate copper coats of 5 ... 8 µm thickness. A suitable surface finish can be applied later. Table 2 summarises a typical metallisation operation as is standard in many industrial processes. A point worthy of mention is the short process chain compared with standard plastic metallisation techniques. A further benefit is having no environmentally deleterious pickling and seeding steps as are required in full-area plastic metallisation and also in 2-component moulding.

	Operation	Process	Temperature	Time (minutes)
1	Ultrasonic	*Ronashed NT-10	60°C	7
2	Rinse	Running deionised water	Cold	1
3	Rinse	Running water (city)	Cold	1
4	Electroless	Circuposit 3D-MID	55°C	30
5	Rinse	Running water (city)	Cold	1
6	Rinse	Running deionised water	Cold	1
7	Pd Catalyst	Ronamerse MID Catalyst	RT	1
8	Electroless	Ronamax MID	88°C	14
9	Rinse	Running water (city)	Cold	1
10	Rinse	Running deionised water	Cold	1
11	Electroless	Aurolectroless MID	85°C	10
12	Rinse	Running water (city)	Cold	1
13	Rinse	Running deionised water	Cold	1
14	Dry			

Table 2: Metallisation sequence (Rohm & Haase GmbH)

In a typical process, the metallisation is performed using a frame or a drum process. The integration of the LDS metallisation process in production plant demands comprehensive know-how in order to maintain the specific process window while a fully functioning technical online analysis system must be in place to monitor metallisation bath parameters. Figure 9 illustrates an automatic production plant used by Schaal MID Technology GmbH for the metallisation of MID components which integrates all metallisation process steps required for the LDS process.

Figure 9: Automatic galvanisation plant (Schaal)

4. Process compliant concept for micro-rotary encoders

4.1 Component design

The LPKF LDS technique enables structuring along arbitrary surface topographies provided no beam shadowing takes place and all surfaces can be reached within the projection. The laser beam structures the circuit layout within a matter of seconds, directly from the computer image onto the surface of the 3D injection moulded component. The laser actually performs two of the tasks described in section 3.1. On the one hand the area of the circuit layout of the doped LDS plastic is activated, and on the other the laser leaves behind a surface with micro-roughness which in turn ensures sufficient adhesion of the tracks. For its part, 3D laser structuring as per the LPKF-LDS process requires precision focussing along the component's surface topography and also that the design of this plastic component is compliant with the process, as must be the circuit layout being structured.

The goal of cost-efficient laser structuring using the LPKF LDS process requires minimisation of the cycle time per component. This aspect is dictated primarily by the handling time and the structuring time; the structuring time is in turn dependent upon the layout area. The handling time is mainly dependent upon the number of positions into which a component needs to be moved. These two aspects, layout area and number of positions, can be optimised/minimised by appropriate component design.

The LPKF LDS process is capable of structuring angled surfaces/flanks with a maximum incline of 75° (figure 10). While flanks with larger angles can be processed, such cases require that all areas can be reached within the projection (whilst continuing to maintain the maximum possible flank angle), otherwise it is necessary to repeat the laser structuring step after moving the component into several positions, which impacts negatively on the cycle time and hence impacts the economics.

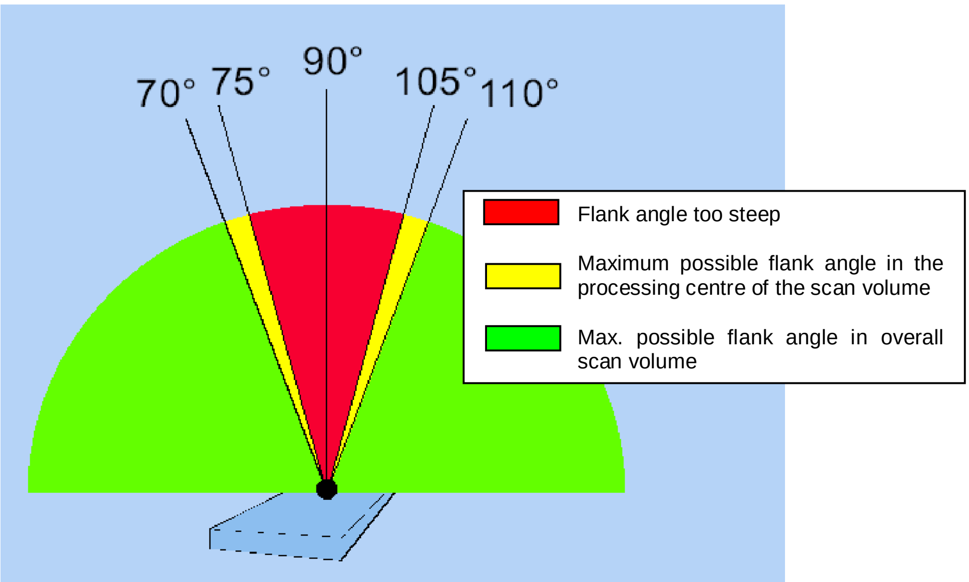

Figure 10: permitted flank angles for laser direct structuring

4.2 Circuit design

The electrical circuit layout should be designed such that it has its maximum area of 200 mm x 200 mm in the XY plane and a focus stroke in the Z-axis of maximum 24 mm.

In principle, the LPKF LDS process is capable of generating ultra-fine structures with a width of up to 150 µm. In the two application examples presented here, the minimum track widths are 200 µm, with a pitch of approx. 400 µm in their finest sectors. During layout design it is therefore important to bear in mind that the typical copper coat thickness is in the range 5 ... 8 µm. It is also possible for copper coat thicknesses to exceed 8 µm. This is, however, only possible electrolytically, i.e. under current. This in turn assumes that the track layout is contiguous, or that sacrificial current tracks are included in the layout which can be removed after metallisation.

4.3 Position marks / fiducials

When operating the LPKF MicroLine 3D Industrial with integrated vision system a further option is to include automatic correction of structuring data relative to the component being structured. The vision system detects the position of the plastic component using freely definable fiducials (register marks) based upon which it performs an online data correction and then rotates, shifts or scales the structuring data accordingly. The maximum size of the fiducials is 7 mm x 6 mm. In the application discussed here the fiducials would ideally be boreholes.

Rotary encoder casing   Position sensor

Figure 13: 3D-CAD design models for rotary encoders reflecting the design guidelines referred to above (HSG-IMAT, Festo).

5 Structure of micro-rotary encoder taking a position sensor as example

5.1 Material selection

In principle, all materials listed in table 1 of section 3.1 are suitable for the laser direct structuring process. Bearing in mind that the position sensor casing is to be fitted not only with the active component, but also a number of passive SMD components, and taking the consequent soldering temperature profile into account, the required level of thermostability results in the selection of a partial aromatic polyamide (PA6/6T) manufactured by BASF, LCP from Ticona, as well as a PET/PBT blend produced by LANXESS as production materials (see table 1).

5.2 Laser structuring and subsequent metallisation

The injection moulded substrate made of the material selected is then structured, as described in section 3.2, with the specified circuit layout using the LPKF MicroLine 3D Industrial laser system. Metallisation of the laser activated sectors is then as per the processes described in section 3.4. The layers were selected as follows:

Chemical copper:	5 µm
Chemical nickel:	3 µm
Flash gold:	0.1 µm

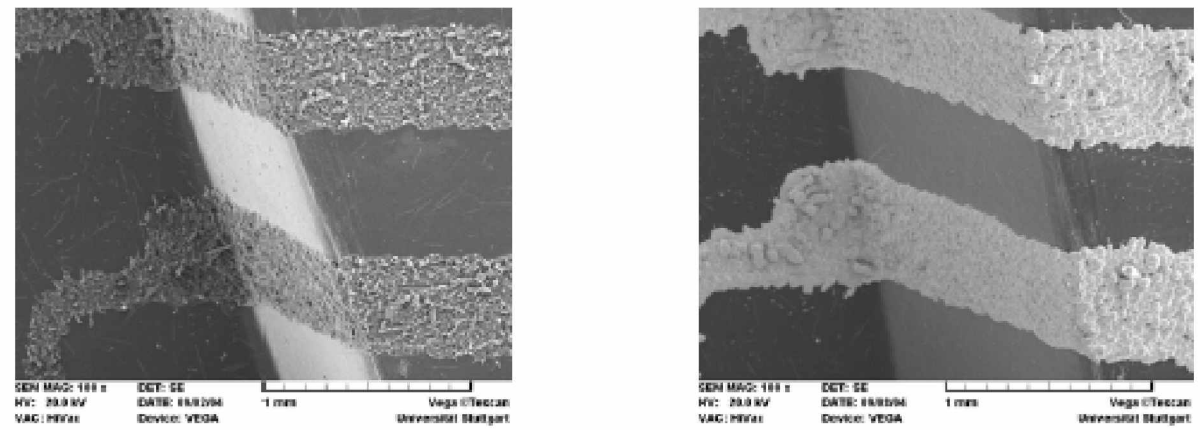

Figure 12: REM image after laser structuring /metallisation (HSG-IMAT)

5.2 Assembly and connecting technology

In addition to the ASIC itself, the position sensor also comprises a diode (Mmelf), two transistors (SOT23), 2 condensers (both 0603). and a resistor. Reflecting the specifications for load and reliability, the soldering process selected is that of lead-free vapour-phase soldering with a low temperature gradient. Figure 13 illustrates the temperature profile for an SnAg/Cu) solder, as selected for this application.

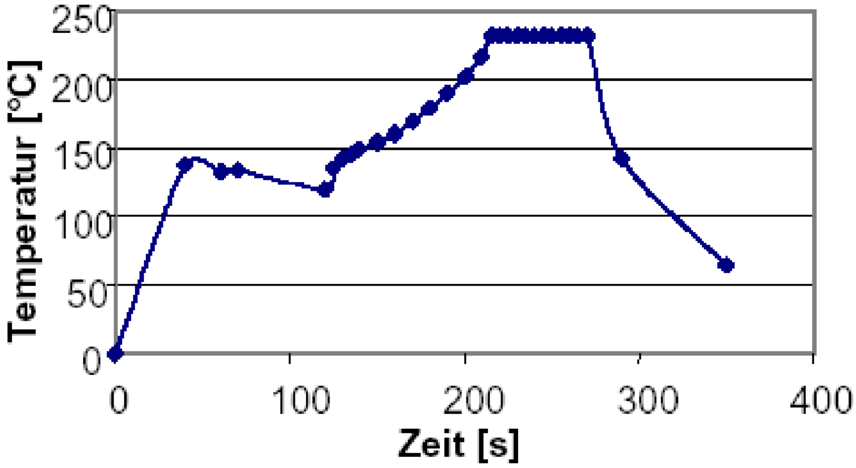

Figure 13: Temperature profile of lead-free vapour-phase soldering process (HSG-IMAT)

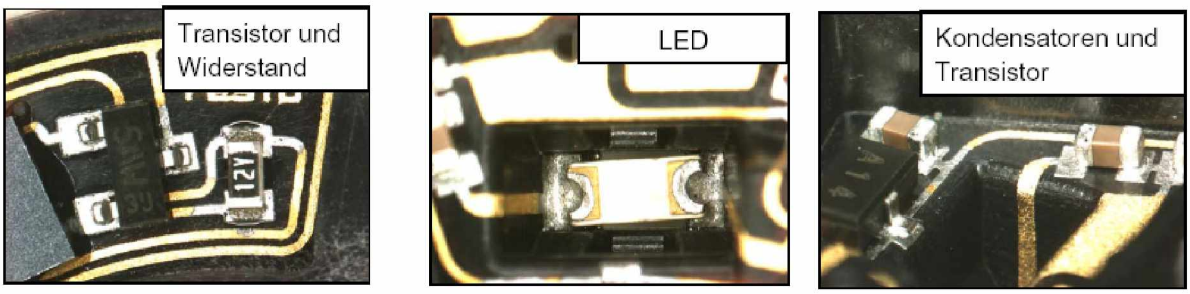

Figure 14: Vapour-phase soldered SMD components (HSG-IMAT)

The assembly of the flipchip components is undertaken with the standard SMD soldering process using a conductive adhesive and a subsequent underfill process if necessary. In addition to the adhesive system itself, adhesive dosing is also a challenge, bearing in mind: the fine spacings in particular of 3D geometries, the fact that template pressure can no longer be applied; the need for high precision placement of the bare-die chip when employing adhesive technologies. The bare-die chip is put together using both isotropic conductive adhesives (ICA) as well as non-conducting adhesives (NCA).

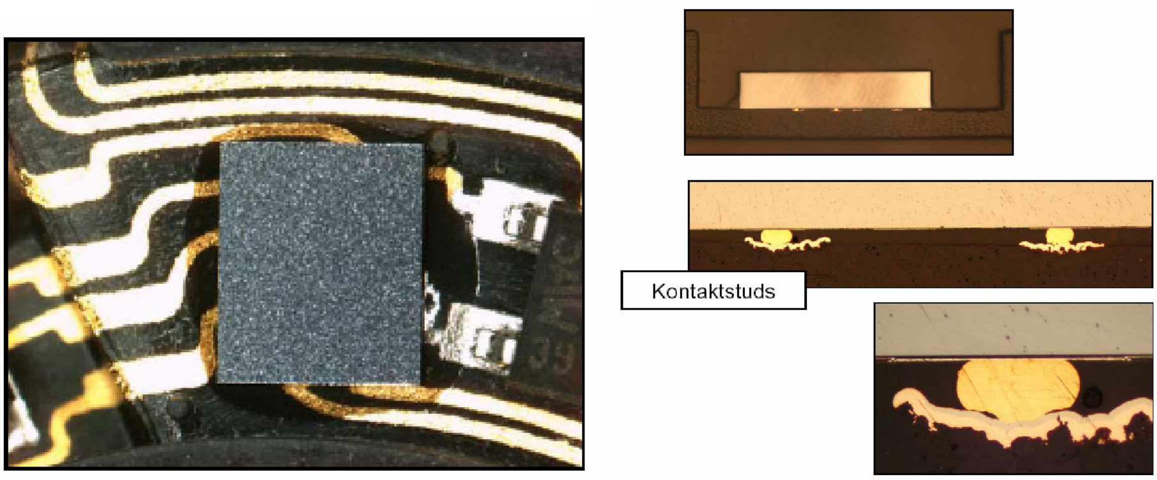

Figure 14: Flipchip glued into place, finish of adhesive connection (HSG-IMAT)

The chips as used are fitted with Au studs. When assembling the sample model, the specific chip layout, i.e. all four pads located along the edges of the chip's lower side, requires an ICA with defined filler fractions to act as spacer to the carrier. This choice of adhesive prevents the chip from skewing during assembly and avoids incorrect hardening of the adhesive. This would not be necessary with NCA, since the component's setting head has a vacuum which prevents the chip skewing during hardening.

6. Qualification results for the rotary encoder

The extreme requirements in terms of temperature loads mean the materials chosen for a rotary encoder application in the automotive industry must have very low coefficients of temperature expansion. In the flipchip case in particular, the behaviour of the material under fluctuating temperatures plays a decisive role. The differing heat expansion behaviour of the substrate and the chip can result in weakening of the contacting, and is therefore a criterion which requires intensive testing. The quality demands of automotive applications, which require full functioning of the module throughout their lifetime under all ambient load conditions, were used to derive the following test requirements for the MID concept:

- Temperature shock storage
  1000 cycles at + 40 °C / 150 °C (double-chamber paternoster enclosure)

- High temperature storage
  1000 hours at 150 °C

- humid storage
  1000 hours at 85 % relative humidity / 85 %

Following these tests, the "end of life" tests were then performed in order to determine the time period/number of cycles up until failure of the component.
No failures were recorded either during the high temperature storage or during the humid storage test. However, the results of the temperature shock storage did give clear indications of the effect of heat expansion. As a result there is a high probability of failure depending on the orientation of the flipchip in relation to the injection moulding orientation/direction of the substrate (see also figure 15).

The results presented in figure 15 show for example that the longitudinal orientation of the naked chip and the selection of a suitable conductive adhesive/underfill combination (C) is able to guarantee reliable flipchip contacting even after 1000 cycles.
In contrast the flipchip I/Os with transverse orientation show a very clear failure probability when subjected to alternating temperature loads.

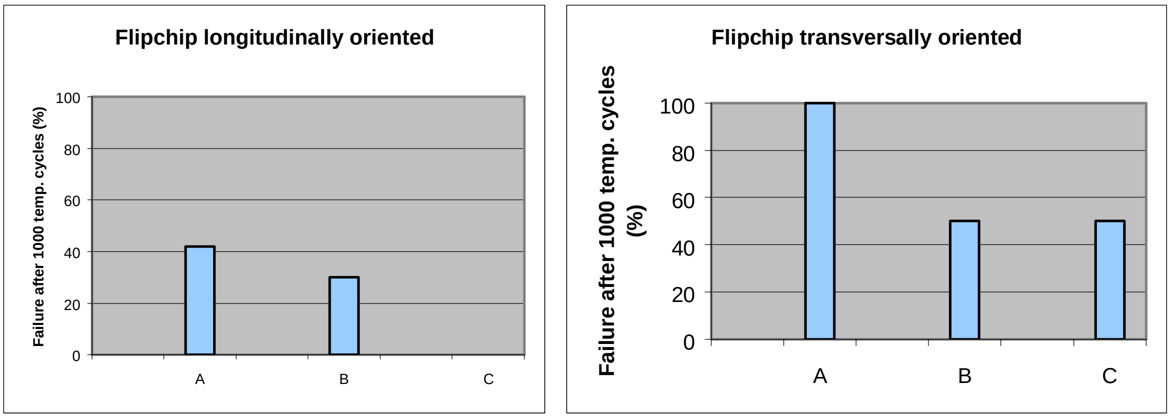

Figure 15: Failure after temperature shock storage, comparison of longitudinal/transversal

These results correlate well with the measured coefficients of heat expansion of the respective materials, i.e. the higher the coefficient of heat expansion, the greater the probability of failure after temperature shock. Since the coefficient of heat expansion is primarily influenced by the selection of the filler of the thermoplastic material, an attempt was made to minimise expansion by optimising the choice of materials. A pure mineral-filled LCP (E820i LDS) has a high rate of temperature expansion, and therefore an LCP filler with 40 % glass fibres was selected for the rotary encoders (LCP MID GF30). By orienting the glass fibres one can induce a very low level of material expansion in the direction of injection when heated, which explains the good results of "zero" percent failure with a longitudinally oriented flipchip.
In order to arrive at a similarly reliable result transversely to the injection direction/to the bare-die chip, a new type of LCP was developed with other fillers which has much better isotropic expansion behaviour. Table 2 summarises the comparison of various types of LCP.

Property	Unit	LCP-MID GF40	Vectra E820iLDS	Vectra LP1223
Polymer base	-	E130i	E820i	E540i
Tensile strength	Mpa	150	116	75
Tensile E-modulus	Mpa	15000	9000	8300
Breaking strain	%	1,6	4	2,3
Thermal dimensional stability	°C	280	220	k.A.
Thermal expansion	10-6K-1	k.A.	parallel/normal 23 / 55	parallel/normal 12 / 10
Thermal expansion	10-6K-1		parallel/normal 23 / 52	parallel/normal 10 / 9
Thermal expansion	10-6K-1	k.A.	parallel/normal 23 / 90	parallel/normal 21 / 41
Thermal expansion	10-6K-1	k.A.	k.A.	parallel/normal 8 / 27

Table 3: Material properties of various LCP types

7. Summary

The IMDAKT project was able to successfully demonstrate that the combination of MID substrate and flipchip assembly and connecting technology is able to achieve high levels of integration in conjunction with a very short process chain and as a result can offer economic advantages. The project used two micro-rotary encoder concepts as examples. In particular, the production technique of laser direct structuring proved almost ideal for the MID substrate since the technology - a laser-based process - can produce both ultra-fine pitches while also offering comparatively short, and hence economical, process chains. The reliability tests demonstrated that thermoplastic substrates are also able to satisfy even highest demands. The results also illustrate that material selection, in particular in terms of flipchip contacting and the heat expansion of materials, plays a decisive role

8. Thanks

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6. References

[1] U. Kessler, H. Kück, W. Eberhardt: Adhesive Technology For Flipchip Assembly on Moulded Interconnect Devices (MID); Proceedings of The Sixth IEEE CPMT Conference on High Density Microsystem Design and Packaging and Failure Analysis (HDP'04) June 30-July03 2004; Baolong Hotel, Shanghai; p.242-247

[2] U. Scholz, W. Eberhardt, U. Keßler, H. Kück, "Flip Chip Assembly on Laser Patterned Molded Interconnect Devices (MID)", MICRO SYSTEM Technologies 2003, München, 08.10.2003

[3] Y. Yagi et al.: Micro Camera Module with MID Using Flip-Chip Mounting Technology ; Proceedings MID 2002, Erlangen, 25.-26.09.2002

[4] W. Eberhardt, T. Gerhäußer, M. Giousouf, H. Kück, R. Mohr. D. Warkentin: Innovative concept for the fabrication of micromechanical sensor and actuator devices using selectively metalized polymers; Sensors and Actuators A 97-98 (2002), 473-477

[5] W. Eberhardt, H. Kück, M. Münch, P. Schilling, M. Ashauer, R. Briegel, "MID-Gehäuse für ein Durchfluss-Sensorsystem", Kunststoffe 3/2003, S. 51ff.

[6] Scheel, W. (Hrsg.): Baugruppentechnologie der Elektronik, 2. erweiterte Ausg., Verlag Leuze, Saulgau, 1999

[7] Kunststoff-Metallisierung – Handbuch für Theorie und Praxis, Saulgau, 1991

[8] Ebneth, H.: Metallisieren von Kunststoffen, expert-Verlag, Renningen-Malmsheim, 1995

[9] Steffen, H.: Kupfer in der Leiterplattentechnik. In: Kanani, N. (Hrsg.): Kupferschichten, 1. Aufl., Leuze Verlag, Saulgau, 2000

[10] Jehn, H. A.: Galvanische Schichten, expert-Verlag, Ehningen, 1993

[11] Forschungsvereinigung Räumlich Elektronischer Baugruppen 3-D MID e.V. (Hrsg.): „Herstellungsverfahren, Gebrauchsanforderungen und Materialkennwerte Räumlicher Elektronischer Baugruppen 3-D MID“, Handbuch für Anwender und Hersteller, 1. gebundene Ausg., Erlangen, 2004

[12] „Laserunterstützte, volladditive Metallisierung hochtemperaturbeständiger Kunststoffe für 3D-MIDs“, R. Schlüter, J. Kickelhain, M. Hüske, Ulmer Gespräche, 05/2002