Laser Direct Structurization for the Selective Metallization of MIDs

Nils Heininger, Gerhard Naundorf, LPKF Laser and Electronics AG,
Wolfgang John, I &T 3D Produktions AG,
FriedrichTalgner, Rohm and Haas Electronic Materials, Lauterbourg, France,
John E. McCaskie, Rohm and Haas Electronic Materials, New York, USA

Progressive miniaturization with accompanying complexity of components through function integration as well as ever shorter product lifecycles are the challenges faced by producers of modern, high value functional components particularly in the electro-/electronics, but also increasingly in the automotive, medical and telecommunications industries. Molded interconnect devices (MID) in combination with suitable connection and assembly techniques are ideally suited to allow the number of parts and assembly expenditures to be reduced. MIDs use the large spatial organization possibilities of molded plastics to integrate mechanical and electrical (mechatronic) functionality into a module. With the **L**aser- **D**irect-**S**tructurization Process (LDS) developed by LPKF it is possible to realize highly functional circuit layouts on complex 3 dimensional carriers and to achieve the above mentioned functional unity of housing and circuit board. The basis of the process involves doped thermoplastics/thermosets, which allow the formation of circuit traces by means of laser activation and finally metallization by electroless copper chemistry. The following article shows an example from a user in the automotive industry which demonstrates that it is possible with assistance from I&T AG and Rohm and Haas Electronic Materials, for MID user to go from prototype to production.

For more information, contact:
Dr. Jack McCaskie
Rohm and Haas Electronic Materials
Packaging and Finishing Technologies
272 Buffalo Avenue
Freeport, New York 11520
Phone: (516) 868-8800 ext. 227
Fax: (516) 868-8074
E-mail: jmccaskie@rohmhaas.com

The LDS-Process

For a long time MID products with 3 dimensional structures have been made in 2 component moldings (2K-Technique, Double Shot Molding) followed by surface chemical activation and selective metallization – a process with high initial cost that only made economic sense for high volume of parts. By contrast, introduction of laser structurization, allows the MID – manufacturer the possibility of eliminating the 2K technique and to make MID by means of single component molding. The additive LPKF-LDS-process in comparison to subtractive Laser structurizing is characterized by very short process scheme. The main process steps are shown in Figure 1. LDS, in contrast to conventional processes, offers wider range in forming extremely fine circuit structures. In addition, the process offers high flexibility regarding the circuit patterns, since modifications are easily realized through changes of the structurizing data. In addition, changes in the conductive pattern do not require changes in equipment. This flexibility makes it possible for the user to employ the laser direct structuring for the product development process with the certainty of having a production process available at the same time which avoids a complex transfer from the prototype stage. For the production employment of the LDS procedure the selection and availability of laser activated plastics, which meet demands in the electronic industry, represent important conditions. This is secured by intensive material development and appropriate license agreement with the respective plastic manufacturers. Thus LPKF has made agreements with LANXESS, Degussa, and Ticona.

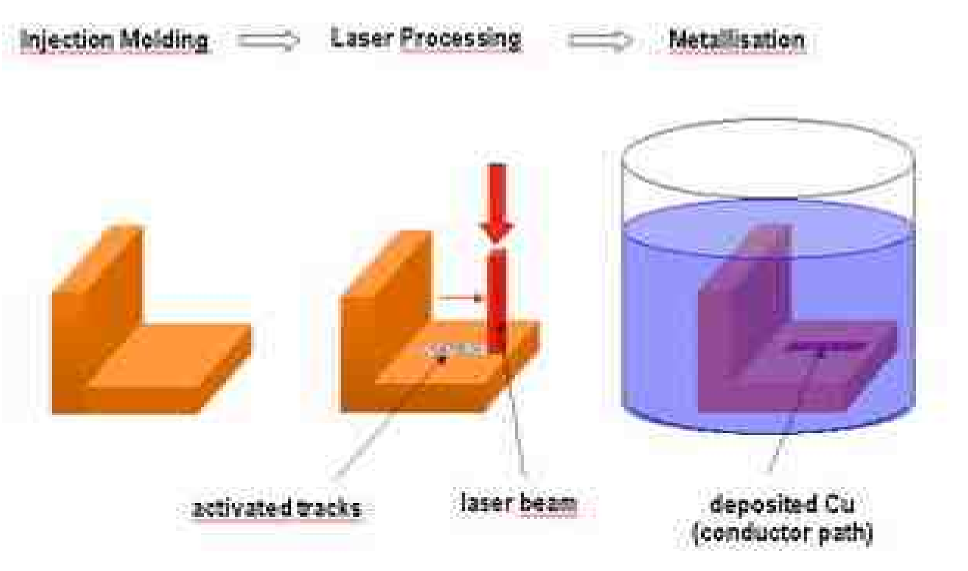

Figure 1: Main Process Steps of LDS

Working Mechanism of Process

The principle means of avoiding the disadvantages of previously known MID-processes [3-8], is the modification of the thermoplastic such that a organometallic complex is dissolved or finely dispersed in the substrate. This special chemical compound is modified by the laser beam in such a manner that it catalyzes selective metal deposition in the irradiated area with a subsequent electroless step. In figure 2 is the structure of the described metal complex.

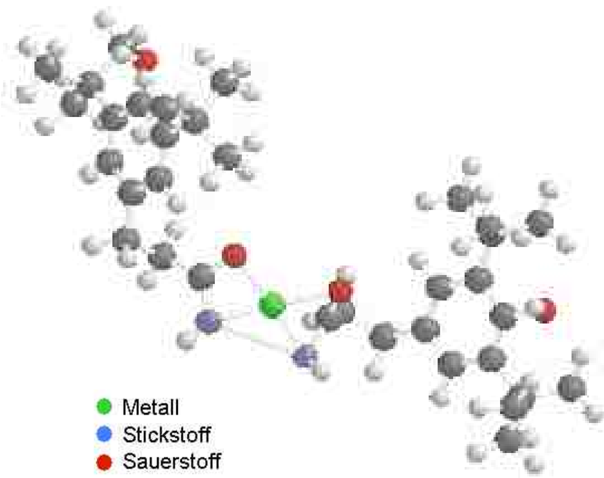

Figure 2: General Structure of Metal Complexes

The preferred compound is a Chelate-Complex of a precious metal either of Palladium (Pd2+)- or copper (Cu2+)-basis [9]. The metal complex has diverse requirements to fulfill. The thermal stability must be sufficiently within the working temperatures of the thermoplastic matrix and it must be fragmented into a metal atom and the organic ligand within defined energy band of the laser. Other criteria are:

- Good compatibility with the Polymer-matrix
- No influence on electrical properties
- A sufficient solubility, specifically for distribution in matrix
- No catalytic activity, which could affect the polymer
- Extraction stability
- No toxicity

A very important qualification of electronic structures is the adhesion of the circuit traces. In order to insure that circuit traces exhibit a sufficient adhesion to the substrate after environmental thermal cycles, a high initial adhesive strength is demanded. Following specification DIN IEC 326 for printed circuit technology this value lay between 0.6 – 1.1 N/mm(6-14 lb/in). In this relation, another important property of the laser beam is to not only selectively and homolytically split the metal complex, but also, the beam leads to ablation of the polymer surface. Thereby, the polymer molecule absorbs the laser beam energy causing excitation and vibration of chemical bonds. Upon reaching a minimum energy, ideally the bonds between polymer chains will be broken. In practice, the working of the laser beam leads to something close to photochemical ablation to a relaxation of the structure and then to a thermal vaporization of the materials (figure 3). This sublimation process is especially important if the laser radiation is long wavelength as for example, that which can be produced from Nd:YAG Lasers (λ = 1064 nm)

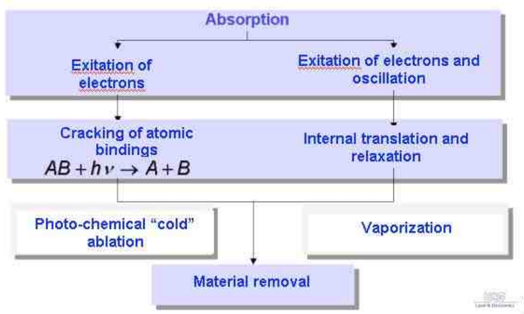

Figure 3: Main Process of the Laser-ablation

Through a specific modification of the polymers with inorganic fillers, which are difficult to ablate, the laser beam makes small cavities and micropores, which without further steps makes possible a good adhesion between plastic and electroless copper deposit. The principle pathway of the laser beam on the plastic surface is clarified in figure 4.

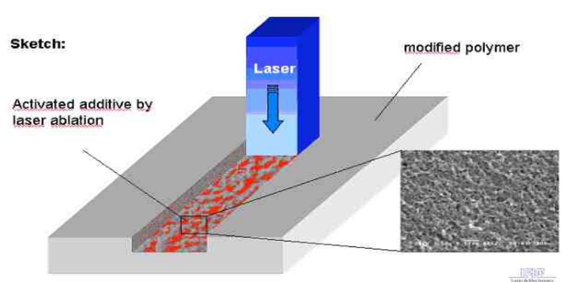

Figure 4. Representation of LDS on Plastic Surface

Modular 3D-Laser System for the Process

MicroLine 3D Industrial is a specially developed laser system for LDS of molded interconnect devices. A major advantage of the laser material processing is the feedback-free effect on the material and high process speed. Beyond that the circuit layout is produced by computer controlled optical head and is not produced through the geometry of a fixed tool (for example as in embossing or 2K molding). This setup results in shorter lead times as well as flexibility and economy. The core of each LPKF Microline 3D Lasersystem is the 3 axis optical head. With a very fast controller and high precision optics, structures as small as 100 micron in a 3 dimensional formed part can be produced. The focused beam of a diode-pumped solid laser of the wavelength 1064 Nm is diverted by mirrors almost without inertia over the surface of the circuit carrier. The beam is focused by an f-Theta-lens onto the working level. A linear translator, a telescope with controllable mobile lens, permits the focus stroke in longitudinal direction by the purposeful de-focusing of the telescope. The combination of telescope and mirror deflecting system makes it possible to lead the laser beam along complex three-dimensional surface topographies with high feed speeds of up to 4000 mm/sec (figure 5).

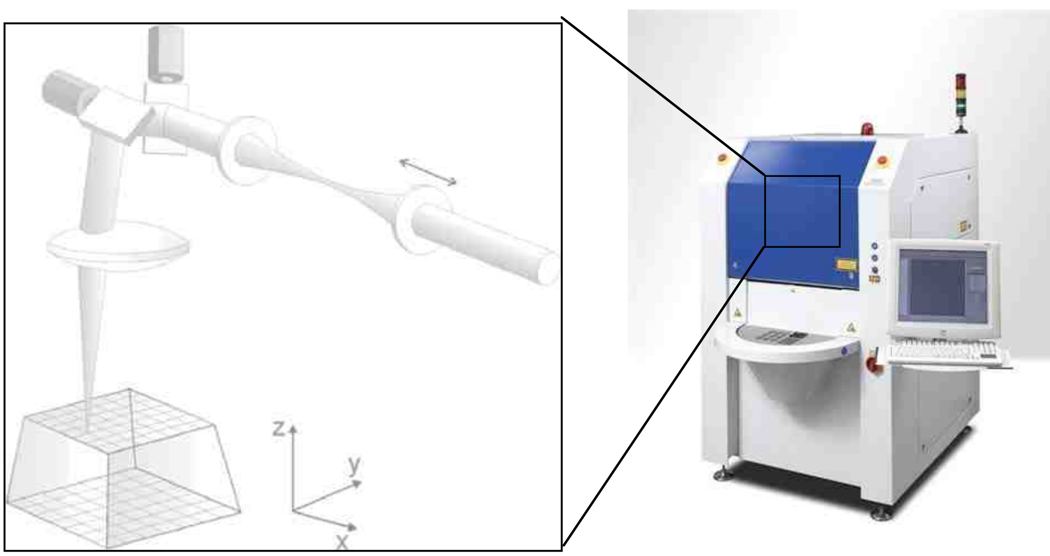

Figure 5: Optical Head with 3 Axis of LDS Laser

In addition to the actual time of the structurizing, the cycle time for parts handling is also important for the throughput of LDS. Since the MIDs have different sizes and shapes the parts handling equipment is adaptable to the geometry of the part. As a basic system, a rotary indexing table with vision system and part handling is available, as well as, a workpiece carrier system (figure 6).

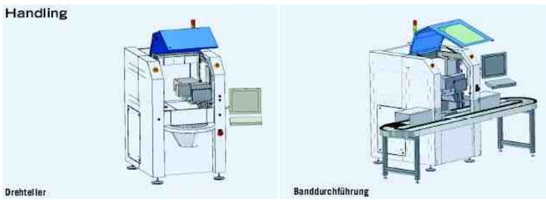

Figure 6: Different handling variants of LPKF MicroLine 3D Industrial

Thermoplastic Materials for Production

There is a range of interesting technical plastics available for use in the electronic industry. For MID the portfolio is reduced significantly. Important criteria are metallizability, metal adhesion, and for SMD application, necessary temperature stability. Often the selection is also reduced further by the MID manufacturing process. For example, only thermoplastics with special rheological properties can be used in 2 component moldings (lower melt viscosity to fill fine cavities).
In principle, the foregoing restrictions do not apply to the materials for LDS. The processing takes place in the single component injection molding and requires therefore no special manufacturing properties. The activation and the adhesion of the metallization are determined by the described surface treatment. Only the temperature resistance demanded for many applications limits the portfolio of the available materials. However, if no soldering is demanded or other reason for increased thermostability, each thermoplastic can be modified in principle for the laser direct structuring. The materials qualified at present are specified in table 1.

Table 1: Comparison of Material Properties for LDS-plastics

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
Polymer type	-	PBT	PBT	PA6/6T	LCP	PBT	PBT	PET/PBT
Processing 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
Shrinkage 2	%	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 Strength	Mpa	95	44	140	116	55	51	110
Tensile modulus	Mpa	10500	4800	9700	9000	5600	5500	120000
Elongation	%	1,2	1,1	2,2	4	2	3,3	1,5
Charpy Impact	kJ/m_	30 C	15 C	33	19	25	40	25
Density	g/cm_	1,77	1,67	1,4	1,79	1,57	-	1,75
Volume flow rate (MVR)	cm_/10 min	28	37	-	-	10	5	16 *
Melt temp. DSC	°C	-	-	295	335	225	225	-
Form Restistance (HDT/A) 1,8MPa	°C	-	-	-	220	115	110	250 *_
Filler level	%	30	30	30	40	25	25	40

* = 280°C/2,16 kg   * _= 0,45MPa

LDS Prototyping

With the LPKF LDS procedure it is possible to insert the same MID manufacturing process already very flexibly used in the product development process into quantity production and avoid a complex transfer from the prototype to quantity production. Further advantages of the use of prototypes during the product development process are:

- ★ market validation by shortening of the development times
- ★ development samples can be prepared within days
- ★ changes of the structure and the circuit layout are discovered earlier in process
- ★ substantial savings of development costs
- ★ early examination of individual functions of the developed MIDs

As with the production thermoplastics, a doping with the described metal complexes is necessary for the prototypes. Since prototyping uses polyurethane (PU) thermoset resin, only one component is preferably modified, the resin.
A particularly suitable procedure involves vacuum forming of PU resins (PURE) , with which on basis of a stereolithographic process a base model of silicone rubber is made and afterwards up to 25 PU prototypes can be produced in the vacuum casting process within days. The vacuum formed prototypes can be activated afterwards, exactly as during the production process with the thermoplastic units, by means of lasers tracing selective pathways which are subsequently metallized.

Table 2: Properties of PUR-vacuum Formed Thermoset Resin

PUR Vacuum Forms			
Property	**Unit**	Value	**Test / ISO**
Bending Strength	N/mm²	108	178
Bending Modulus / E-Modul	N/mm²	2460	178
Tensile Strength	N/mm²	64	R 527
Impact Strength	KJ/m²	5	180
Elongation	%	17	R 527
Heat Resistance	°C	95	75

Metallizing Laser Activated Parts

As described in 2.1 each splitting of the metal complex by the laser produces a metal particle which catalyzes metal deposition in the activated area. For this process electroless copper electrolytes are used, the typical thickness is 4-6 µm. Final finishes, such as electroless nickel immersion gold (Ni/Au) are used after the copper. Table 3 represents a metallization scheme which is a commercial process. It is shorter than conventional plating on plastic process. Ecologically unfriendly steps like , chromic acid etch and catalyst which are used in treating 2 shot molded MIDs are not used with LDS.

Table 3: Metallization chemistry of Rohm and Haas Electronic Materials

Working Step	Bath Type	Time	Temp./ C
Cleaning	SPOX®-HP SO	5 min.	RT
Chemical Copper	Circuposit™ Copper 4500	45-90 min.	50-55
Microetch	Circuposit™ Etch 3330	0.5-1.0min.	RT
Activation(Pd)	Ronamerse™ SMT Catalyst CF	1.0-3.0min.	RT
Chemical Nickel	Niposit™ LT	20-40min.	60
Immersion Gold	Aurolectroless SMT-G	10-15min.	70
Drying	Dryer	10-20min.	100

Typically the metallization is carried out in barrel or rack operations. The integration of the LDS metallizing process into equipment technology suitable for production requires a comprehensive know-how for adherence to given process windows and technically well controlled line analytics of the bath parameters. Figure 7 shows automatic production equipment of the firm I&T with integrated online-bath analysis for metallizing MID parts as part of the LDS process.

Figure 7: Automatic Metallizing Equipment for MIDs with Online-Analytical Controls (I&T AG, Austria)

MID-Application for the Automotive Division of TRW

In similar way, the use of electronics for function integration is increasing in the auto industry because cost pressures are increasing for electrical and microsystem components. As a automotive supplier, TRW sees itself under continual competitive pressure to provide always higher performance and at the same time higher reliability at lower cost. In order to meet these pressures, TRW has developed a concept for a multi-functional steering wheel in which the MID plays a central role. The Base Line Concept should replace a large number of parts and thereby lower manufacturing cost for mid-range and under mid-range passenger cars.

From the outset, special attention was paid to guarantee production success by the choice of partners with suitable production equipment technology and experience as suppliers to the automotive sector. The task was given to the Austrian firm, Innovation Technology Development and Holding AG (I&TAG).

The core idea of the concept is to reduce the number of necessary individual parts to a minimum and integrate all functionality into a molded part. The name “multifunctional steering wheel“ clarifies the goal since previous model called for a plan for an assembly of an entire range of individual parts, and also routing cables between left and right sides of the steering control.

With the development of the MID concept all the general customer requirements were taken into consideration: such as design (functionality, quality impression), ergonomics (feel of switches, Surface of keys) and environmental quality, (temperature requirements, life span), as well as legal requirements (potential injury from loose parts, glare, minimum turning radius after ECE R12) also stability of the formed part with unusual loads such as putting on a anti-theft lock, panic like honking and air bag deployment.

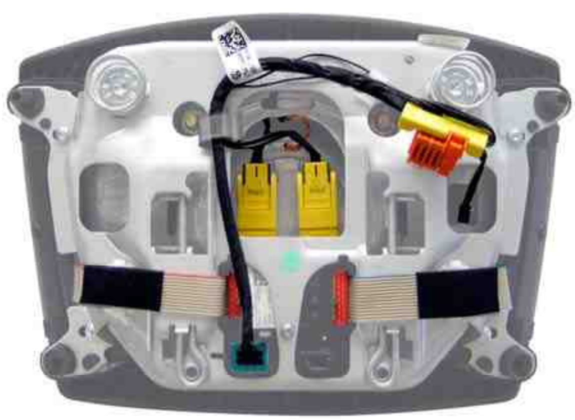

Figure 8: Wiring in Conventional Multifunction Steering Wheel (VW Phaeton)

In order to meet demand to reduce the number of individual parts to a minimum, the Base-Line-Concept integrates together the electrical switches into MIDs and eliminates cables. Also eliminated is a plug connector to the data bus which next leads to a controller and then attaches to the CAR CAN bus. Figure 9 shows such an MID-solution for a multi functional steering wheel with 4 switching MIDs.

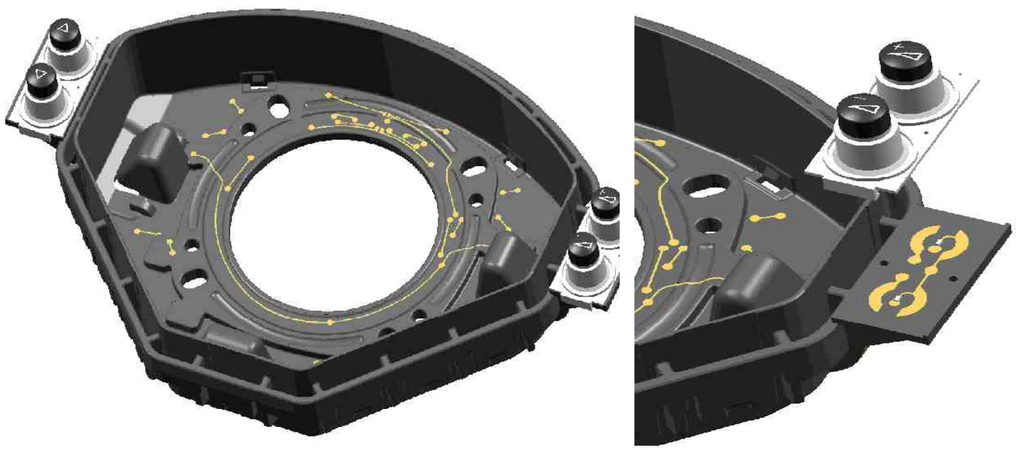

Figure 9: Base-Line-Concept

Process for Construction of MID

The LDS procedure makes the structuring possible along arbitrary surface topographies, as long as no beam shading is present and the surfaces in the projection are reached. Within seconds the laser beam structures the conductive pattern directed by the computer on the surface of the three-dimensional molded part. The laser fulfills the two tasks already described: on the one hand producing the conductive pattern in the doped LDS plastic and on the other hand the laser activation produces a micro-roughened surface, which ensures sufficient adhesion of the conductive circuit traces. The three-dimensional laser structuring in the LPKF LDS procedure pre-supposes that the focusing is accurate along the surface topography of the unit, and that the controlled procedure leads to the uniform structurization of the circuit layouts.

Circuit Layout Organization

The electrical conductive strip layout is arranged in such a way that it does not exceed the maximum work area of 200 mm x 200 mm in the XY level, as well as a focus stroke in z-direction of maximally 25 mm. Fine structures with up to 150 micron width can be produced with the LPKF LDS procedure. For most applications, however, only 300 µm conductive traces are necessary with 500µm pitch. This is to insure current load-carrying capacity by using broader conductive traces because of the large unit size and the comparatively low circuit density. On the other hand minimum current carrying capacity is demanded which is known from printed circuit board technology in which the copper thickness is typically in the range 5- 8 µm. Also copper layer thicknesses can be produced > for 8 µm by electrolytic deposition. This presupposes that the circuit pattern is continuous and a sacrificial path in the layout is planned, which must be isolated after the metallization.

Molding Organization

Since thermoplastics at present available for the LPKF LDS procedure are higher price compared with un-doped thermoplastics, the injection weight with each application was minimized. For MID application the MID unit should be considered as a framework which is later incorporated into the actual housing.
In order to arrange the laser structuring as cost efficient in the context of the LDS procedure the cycle time per construction unit must be minimized. This is essentially determined by the handling time and the structuring time, which are proportional to the layout surface. The handling time is determined mostly by the number of positions in the process. Both layout surface and number of positions for handling are minimized by appropriate design of the unit. With the LDS procedure bevels, and/or flanges can be structured by maximally 75° (fig. 10). Also larger angles are possible. However, it must be ensured that all surfaces in the projection are reached, otherwise one must allow for more positions for laser-structuring, which negatively affects the cycle time and thus economy.

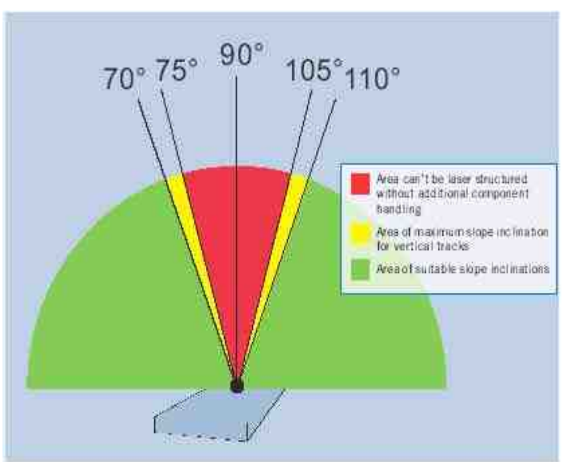

Figure 10: The Permissible Angles of Exposure with the Laser Direct Structuring

Registration Marks / Fiducials

The use of the LPKF MicroLine 3D Industrial with integrated vision system allows for making an automatic correction of the structuring data relative to the construction unit being structured. The Vision system recognizes the position of the plastic part over freely definable Fiducials (ticks) and makes an on-line data correction and turns, shifts or scales the structuring data accordingly. The maximum size of the Fiducials can amount to 7 mm x 6 mm. In application these are ideally drilled holes.

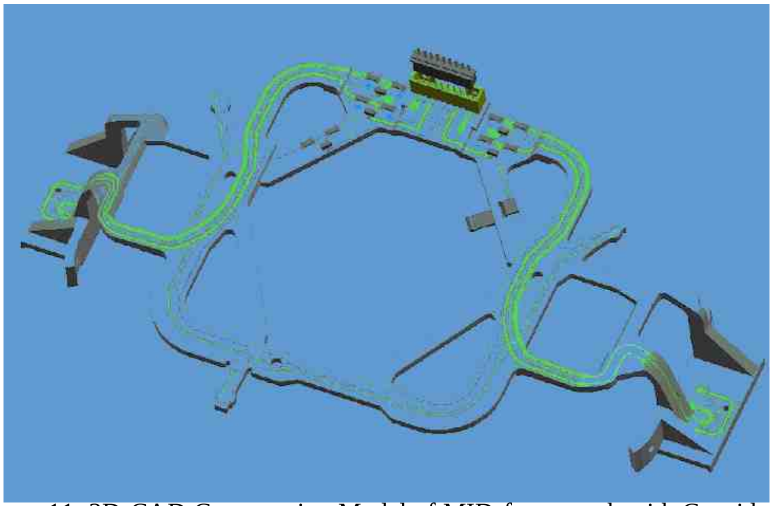

Figure 11: 3D-CAD Construction Model of MID-framework with Consideration of the Construction Lines

Structure of Protoypes

As already described, the LDS procedure makes first samples by well-known Rapid Prototyping Technologies, e.g. the vacuum form manufacturing. For function and installation tests, defining the entire process chain, and the determination of manufacturing costs, MID prototypes are necessary. They are also useful as a basis for discussion with the OEMs. As described above, a base model is produced from 3D-CAD data. In addition, a stereolithographic process (SL) is used to form the unit in layers, as a UV sensitive lacquer is hardened layer for layer.

The respective thickness of the layers determines the geometric accuracy in producing the part. This base model is used afterwards in order to provide a silicone form, in which repeatedly several prototypes can be cast. Before finishing takes place, leveling is done around layer edges/steps.

For the production of the silicone form the finished base model is placed within a casting framework mock up and the dead heads, risers, as well as the interface levels of the two tool halves are specified. Finally the casting framework is filled with silicone. After hardening the form is cut open along the dividing line and the base model is released from the form. In such a way the silicone tool is useful in casting up to 25 specially doped polyurethane prototypes in vacuum form.
The polyurethane prototype is finally laser structured and metallized exactly as in the production process. Since the PU exhibits only a limited thermostability, the assembly of the sample construction units takes place manually.

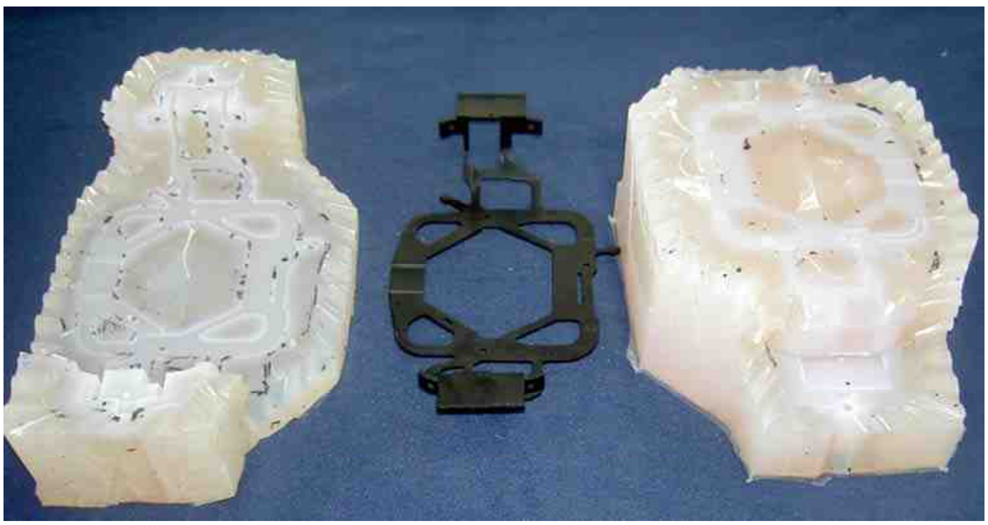

Figure 12: Vacuum Form with Prototype of Doped PU (KLM GmbH)

Material Selection

On the circuit carrier approximately 11 resistors and 5 transistors, as well as an SMD compatible plug housing are employed (see figure 13). In accordance with the requirements of the load resistance and reliability, a lead free solder paste of SnAg or SnAgCu composition was selected and is reflowed during the process. Due to minimum thermostability, as well as requirements of the Base-Line concept, resulting from the reflow profile, a part-aromatic nylon (PA6/6T) from BASF, as well as PET/PBT from Bayer/LANXESS were selected as suitable materials for production. (see Table 1). During the prototype phase, and/or before beginning of tool engineering first soldering attempts to select suitable sample test specimens were accomplished which allowed decision for the material to be used in production. After the successful conclusion of soldering test plates, a set of environmental tests were accomplished, which although not insuring later qualification of the production parts, can show tendencies to be expected for the behavior of the later construction unit.

Figure 13: A Base-Line-MID Prototype out of Polyurethane

Results of the Concept Evaluation

In the LDS procedure manufactured MIDs as high-quality functional devices integrating mechanical and electrical functionality, result in a set of design and cost advantages:

- ★ saving of construction units (tooling expenses)
- ★ saving of assembly -, logistics -, and development costs
- ★ signal tracks over several levels - new possibilities
- ★ space optimization
- ★ no laying of cables (no "cable salad“) higher reliability of operation by fewer interfaces
- ★ flexibility - different circuit variants possible
- ★ simpler manufacture of parts
- ★ existing electrical contact system can be used

Apart from the general advantages above, MID prototyping allows for fairly exact calculation at an early stage of the costs of production runs.
Present calculations estimate about 20% cost savings using the BASE-LINE concept compared to existing conventional solutions.

Summary

With the LPKF-LDS-Process it is possible to have a suitable technology for efficient and flexible manufacture of 3D-MIDs. In contrast to other manufacturing processes LDS allows thermoplastic MIDs to be made in just 3 steps (molding, laser structuring, metallization) without layout specific tools, for example, injection molds and embossing tools. As the example from TRW demonstrates the Base-Line-Concept’s gain in flexibility is ideal for use in the product development process.

TRW is responsible as a system supplier to the automotive- sector for the entire assembly “steering wheel“ including the necessary electronic modules(controller, data bus, airbag activator). The MID, the core of the innovative concept, was developed and manufactured by I&T of Austria. The company, I&T, with many years of experience in automotive wiring systems, is now capable of delivering complete MID structuring and metallization packages with the suitable laser equipment technology of the company LPKF using LDS protocol. A special challenge is represented by the gradual "upscaling" of the metallizing processes of the laboratory into the commercial mass production with quality and process stability to meet automotive requirements. Here, I&T AG, with a highly developed equipment technology, and its process chemical supply partner Rohm and Haas Electronic Materials offers very good conditions.

The Base Line concept of TRW on the basis the prototypes is the beginning production project with a group of OEMs. At present further MID prototypes with concrete customer designs from OEMs are in the planning stage.

References

[1] „Aufbau und Verbindungstechnik für Mechatronik-Anwendungen im Automobil“

[2] „Chancen und Grenzen für den Einsatz der Technologie MID“, Studie des Heinz Nixdorf Institut, Universität Paderborn, Rechnerintegrierte Produktion,
Prof. Dr.-Ing. Jürgen Gausemeier, Paderborn, 2003

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

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

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

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

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

[8] Forschungsvereinigung Räumlich Elektroni scher 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

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

