Sensors and Materials, Vol. 10, No. 6 (1998) 363–373
MYU Tokyo

S & M 0338

LIGA — A Technology for Fabricating Microstructures and Microsystems

Jürgen Mohr

Forschungszentrum Karlsruhe, Institut für Mikrostrukturtechnik
Postfach 3640, 76021 Karlsruhe, Germany

(Received July 12, 1998; accepted July 28, 1998)

Key words: LIGA process, microsystem, micropump, microoptical bench, waveguide, microspectrometer

The LIGA process (LIGA is an abbreviation of the German words "Lithographie, Galvanik and Abformung") is a technique well suited for fabricating microstructures of a wide variety of polymer and metallic materials. By precision molding using mold inserts fabricated by different patterning technologies, complex microcomponents can be fabricated. In combination with assembly technology, microsystems are being developed in the fields of fluids and medicine as well as in the field of optics.

1. Introduction

Microsystem technology is a growing field with increasing importance in various industrial areas. Different market studies are predicting a market share of millions of dollars with an exponential increase in the next few years. Whereas, in former studies, predictions were based exclusively on integrated devices mostly built from silicon technology, the new market study from NEXUS also includes devices fabricated with other technologies, for example printer heads and read/write heads for computer and CD applications.[1] In most cases these devices are based on different materials other than silicon and are built using sophisticated assembly technology.

Thus, other microfabrication technologies had to be developed in the past. Although precision machining has made great advances in highly precise fabrication of small structures, it has the drawback of serial fabrication which therefore has limits in the shortening of the fabrication time and in cost reduction even if automatically driven machines are used. Thus, it has been important to look for batch fabrication methods that can be used with materials other than silicon. Lithography as well as molding techniques are well suited to fulfilling these requirements. These are the domains of the LIGA process (LIGA is an abbreviation of the German words "Lithographie, Galvanik and Abformung") which was developed at the Karlsruhe research center in the early eighties and continuously improved and optimized over the last 15 years. Eight of those years were under the direction of Professor Menz, who thus contributed to the current state of the technology.

In this paper, first the LIGA process will be described. Then different examples will be used to demonstrate the possibilities for application of LIGA technology.

2. The LIGA Process and Its Characteristics

Figure 1 shows the process sequences of the LIGA process as it was introduced by Ehrfeld and Becker to fabricate separation nozzles for uranium enrichment.(2) In the first step, synchrotron radiation is used to pattern a several hundred-micrometer-thick resist layer by proximity printing of an absorber structure on a mask membrane. As the resist material, polymethylmethacrylate (PMMA) is used due to its high contrast in X-ray patterning. Other polymer materials tested in the past do not guarantee the high structural quality achieved using PMMA. After developing the exposed resist areas, deposition of

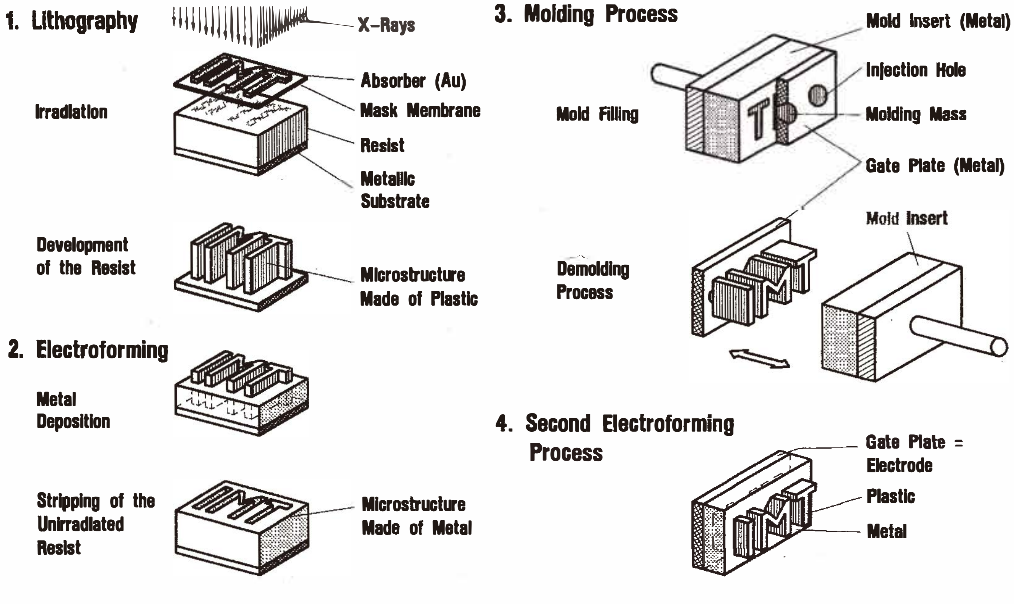

Fig. 1. Steps in the LIGA process.

metal by electroforming is performed using the plastic microstructure as a template. When the molding process is stopped before reaching the height of the polymer structure, highly precise metallic microstructures are achieved. Thus, from just the first two process steps, PMMA and metallic microstructures are obtained. Nevertheless, in view of mass production and to increase the number of usable polymers, molding must be used. For this reason, the deposition of metal is continued until a thick metal layer has grown over the resist structure. After removing the base plate and the remaining resist, the metallic relief serves as a mold insert in a subsequent micromolding process of either injection molding or relief printing (hot embossing). The achieved polymer structures can also serve as templates in a second electroforming process to produce metallic microstructures in high quantities, as well as a template for ceramic casting. In this case, the polymer is filled with ceramic and burned out after the ceramic is hardened at high temperatures.

There have been numerous modifications of the basic process in the last 15 years to improve its applicability in various fields. Introducing sacrificial layer technologies allows the generation of movable microstructures.(3) It is important to recognize that this is possible not only by aligned exposure, but also by an aligned molding process. Microstructures with shaped sidewalls are fabricated by varying the angle at which the synchrotron radiation hits the resist. To fabricate microstructures with different geometries along the height, prepatterned substrates are used. Light-guiding structures are fabricated using either a three-layer resist material in X-ray lithography or a modified molding process.

X-ray lithography is used to pattern the first PMMA template because of the low divergence of the synchrotron radiation, its high intensity and the high energy, which result in a high penetration depth into the resist material. These characteristics allow the fabrication of microstructures that are very precise along the total height with high aspect ratio (Table 1). Figure 2 shows a 2-mm-high resist wall with a 200 μm width next to a 150-μm-high microturbine with minimum dimensions in the range of 20 μm.

Not every microstructure requires the high quality offered by X-ray lithography. Thus other technologies were also developed and used to fabricate the first template. The most important are optical lithography using thick optical resist layers such as SU8, electron beam lithography for the fabrication of fluid channels or diffractive optical elements and laser ablation. Even precision machining has its place, especially for the fabrication of complex mold inserts, together with the other technologies.(4) Thus the term LIGA now has a broader meaning than initially. Although the mold inserts are fabricated by different technologies, microelectroforming and micromolding are the main elements of the LIGA

Table 1
Limits in aspect ratio in deep X-ray lithography.

Kind of structure	Aspect ratio	Restriction
Self-standing polymer columns	≈50	Mechanical stability of the polymer
Holes in the polymer	≈70	Transport behavior of the developer (diffusion controlled)
Detail of a structure	≈500	Mask distortions

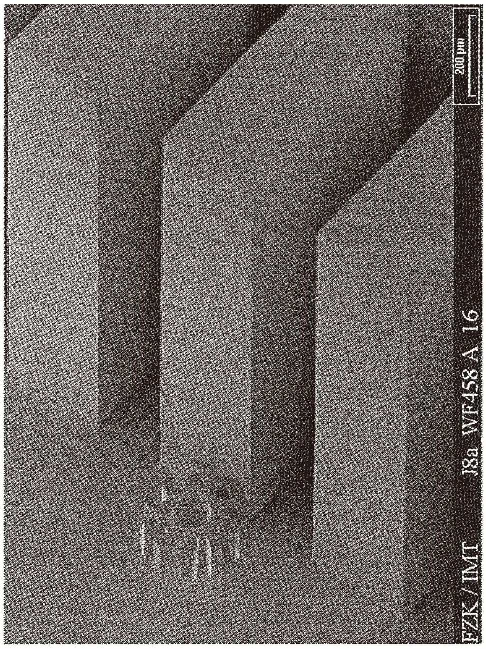

Fig. 2. Two mm-high LIGA structure next to a gear, also fabricated by LIGA, with a height of 150 μm.

process, with the possibility of fabricating microstructures out of a variety of different materials others than silicon.

Although at the beginning of the LIGA development, sensor elements such as acceleration sensors were being developed, it turned out that mechanical sensors are within the domain of silicon technology in which pressure sensors or acceleration sensors are already commercially available. Thus, the LIGA technology is focusing on structures and systems which take better advantage of the LIGA characteristics. Below, fluidic and medical, as well as optical applications will be discussed.

3. Fluidic and Medical Applications

For fluidic applications, channel structures, together with housing structures for pumps and valves, are easily fabricated by molding using a mold insert fabricated by precision machining and/or lithographic techniques. These parts are used in the AMANDA process together with membrane technology to build the fluidic structures.(5) The membrane itself or thin metal layers are patterned using lithography and etching techniques to form sensor or actuator structures. The membrane is transferred to the fluid structures and glued together. As assembly is done in a batch, several components are fabricated in parallel.

Figure 3 shows the principle of a micropump fabricated by the AMANDA process. The actuator chamber of the pump and the fluid chamber are fabricated of polysulfon by molding. The membrane acts as the actuator by changing the pressure in the fluid chamber as it buckles. The micropump shown in Fig. 4 is only one example in the family of AMANDA products. Pressure and flow sensors, as well as valves are also under develop-

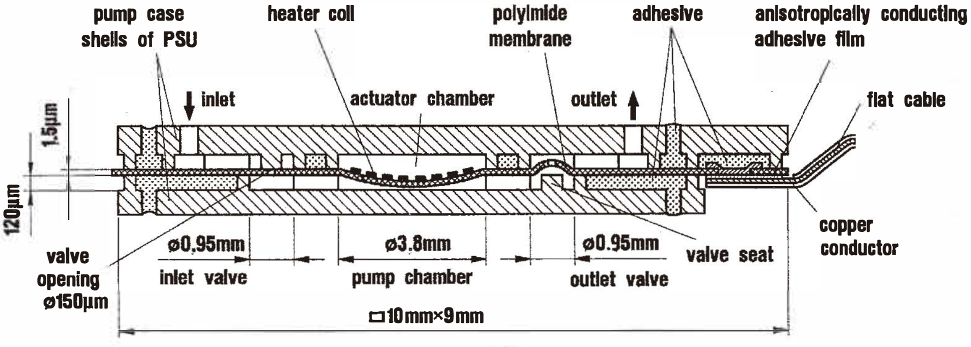

Fig. 3. Principle of the micropump to be fabricated by the AMANDA process (thermoplastic molding, thin layer technique and diaphragm transfer).

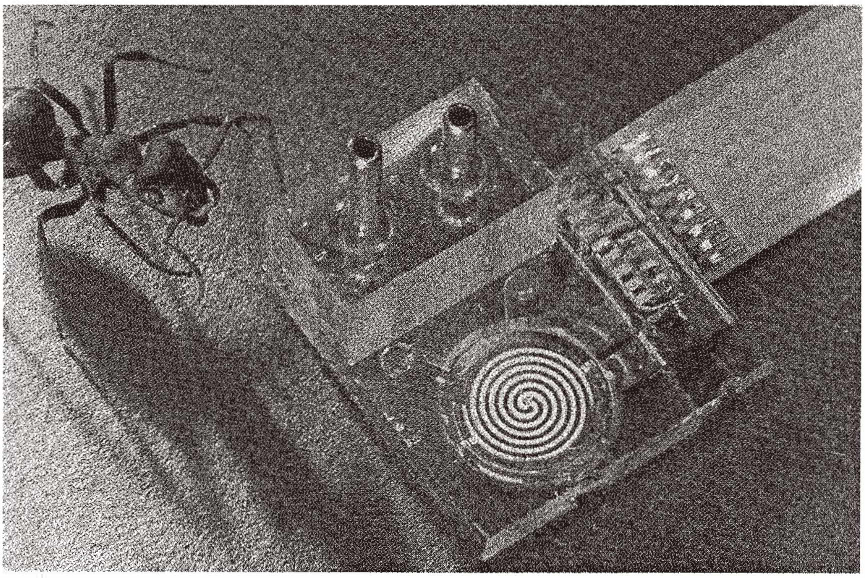

Fig. 4. Micropump fabricated by the AMANDA process.

ment. Even combinations of pumps and flow or pressure sensors are studied to build a closed-loop dosing system.

Figure 5 shows the head of a heart catheter with an integrated turbine, and the shaft to drive a drilling tool.(6) To build the driving unit, different components had to be fabricated by the LIGA process, taking advantage of its high precision, and were then assembled afterwards. The rotor of the microturbine which has minimum dimensions of 20 μm is first mounted on a shaft, then stacked into the housing and covered by the nozzle plate. The housing is also a molded part, obtained using a stepped mold insert build by precision machining with minimum dimensions of 20 μm.

There are other fluidic devices fabricated by the assembly of LIGA components, *e.g.*, a positioning system based on a microvalve.(7)

4. Optical Applications

For the fabrication of optical setups, two concepts which take advantage of the characteristics of the LIGA process are being followed:

- microoptical benches with hybrid integrated optical components for free space optical elements,
- waveguide structures with sidewalls having optical functionality for multimode use.

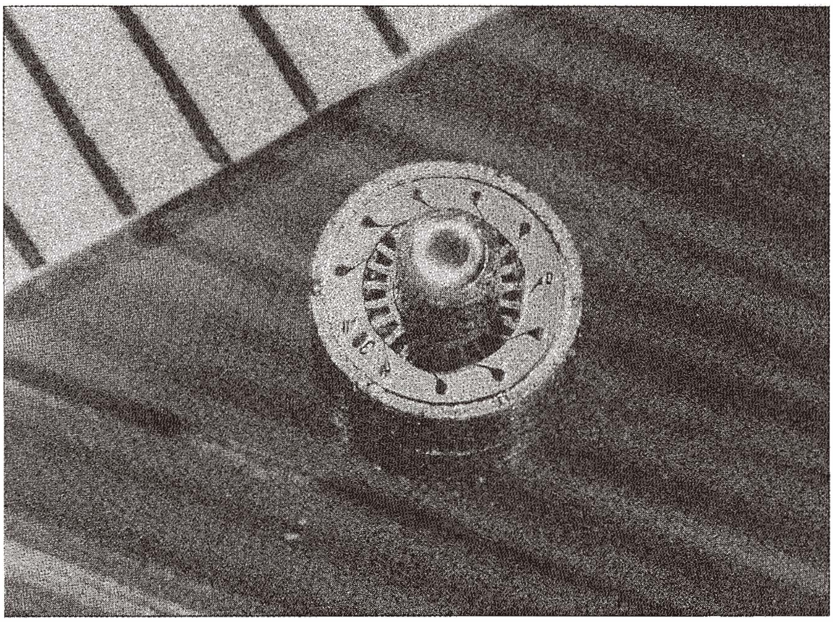

Fig. 5. Microturbine in a housing to be mounted on the tip of a catheter.

4.1 *Microoptical benches*

The optical benches fabricated by the LIGA process combine fixing structures for positioning and passive aligning of mounted optical components, such as fibers, ball lenses and wavelength-selective filters, with simple microoptical structures such as prisms, cylindrical lenses and mirrorlike structures. Together with integrated actuators such as electrostatic linear actuators or micromotors, micro-optoelectromechanical systems (MOEMS) are available. Since all fixed and movable structures in the optical bench are produced in one lithographic or molding step, lateral tolerances are only in the range of 0.1 to 0.2 μm, depending on thermal mask distortion and shrinkage of the polymer. Thus, optical losses due to misalignment are fairly small.

Figure 6 shows a simple optical bench which combines a wavelength-selective filter, two ball lenses and a fiber, all well positioned by the fixing structures. This optical bench is part of a bidirectional transceiver module.(8)

The concept described is also used to integrate unpacked active devices, such as laser or photodiodes into the microoptical bench. For this purpose, the laser chips are equipped with an alignment trench whose position is well defined to the active laser area. As long as

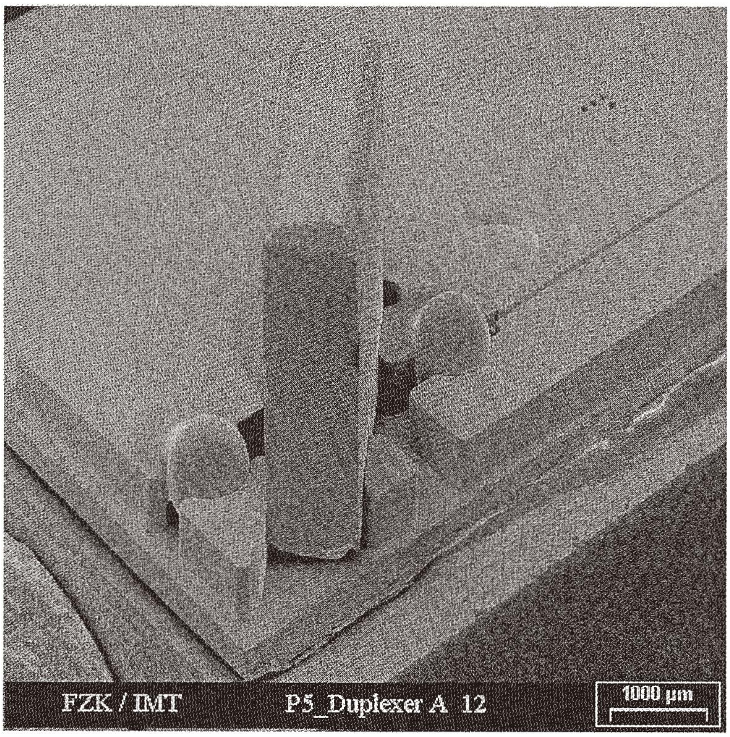

Fig. 6. Microoptical bench with ball lenses, wavelength-selective filter and optical fiber.

an appropriate step relative to the optical beam path is generated in the optical bench, passive assembly of the laser diode can be carried out with the required accuracy.

In the case of the optical bypass element shown in Fig. 7, the microoptical bench not only consists of fixing grooves for passive optical elements, but an electrostatic actuator is integrated into the optical bench, which moves the sidewall of the structure that acts as a mirror. This device is part of an optical network with two fibers connected to the network (lower fibers) and two fibers (upper fibers) connected to a transceiver. The optical setup of the ball lens is used to collimate the light beam between the fibers. When the electrostatic actuator is activated but not placed in the beam, the light from the network fibers is transmitted to the transceiver fibers. In the bypass mode, the mirror surface is moved into the beam path and reflects the light emitted by the first network fiber directly to the second network fiber, bypassing the transceiver.

To move the shutter out of the light beam, displacements of more than 100 μm are necessary, which are achieved with voltages less than 50 V. Using optimized reflective materials, the losses are in the range of 2 to 3 dB. The crosstalk is measured to be more than 40 dB.

The fabrication of active optical setups using the LIGA process is also possible by using substrates whose sizes change due to physical effects (temperature, piezoeffect, magneto-

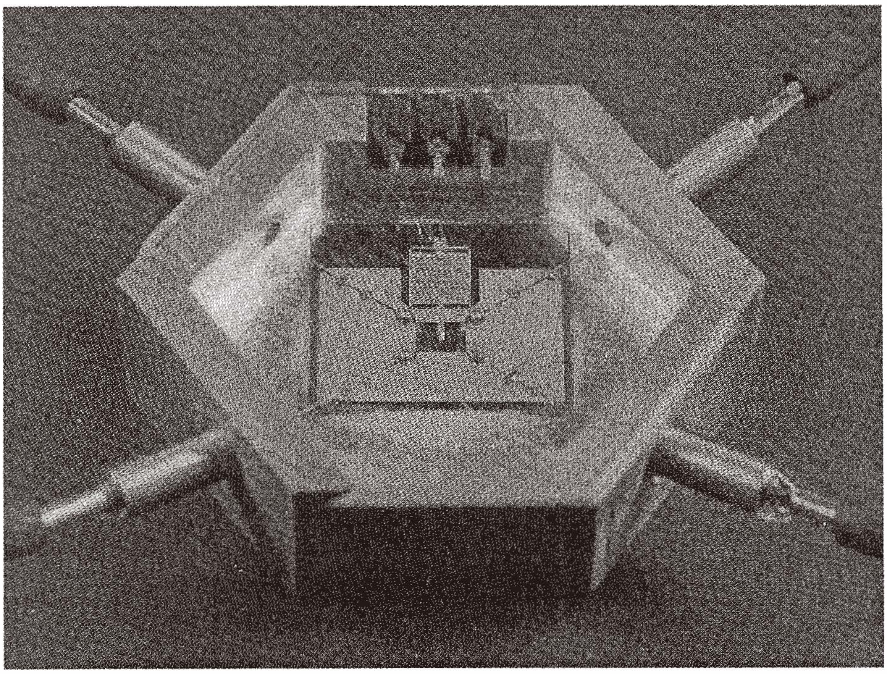

Fig. 7. Optomechanical bypass switch in a housing with fiber pigtails.

striction, etc.). In Fig. 8 the schematic setup of a shutter built on a piezosubstrate is shown. The switching behavior is based on the decrease of the distance between the two fixing blocks, which results in buckling and a perpendicular movement of the attached beam. In the activated position, the beam is blocking the light emitted by the fiber. Measurements give blocking coefficients of more than 60 dB. Since the operation frequencies are in the kHz range, a device like this can be used as a chopper in combination with optical sensor elements (*e.g.*, IR microspectrometers(9)). Together with single-mode fibers the device was tested as an attenuator. Attenuation coefficients between 10 dB and 60 dB were achieved depending on the voltage applied.

4.2 *Optical devices based on waveguide structures*

The second concept for fabricating microoptical devices using LIGA technology is based on patterning planar waveguides to form optical elements at the sidewalls of the waveguides. Light guidance can be performed by either internal reflection (three-layer polymer) or Fresnel reflection at the upper and lower covers of a planar light tube. As neither assembly of optical components nor movable structures are required for those devices, a complex and stable element is formed at low cost.

The microspectrometer is the most famous device based on this concept.(9) Figure 9 shows the two variations of this device. In both cases, perpendicular to the waveguide, the diffraction grating is patterned together with fiber-fixing grooves to hold the incoupling fiber firmly in position relative to the grating. The blazed reflection grating diffracts and focuses the white light to the focal line near the incoupling slit.

Based on this concept, not only microspectrometers but also displacement sensors are under development.

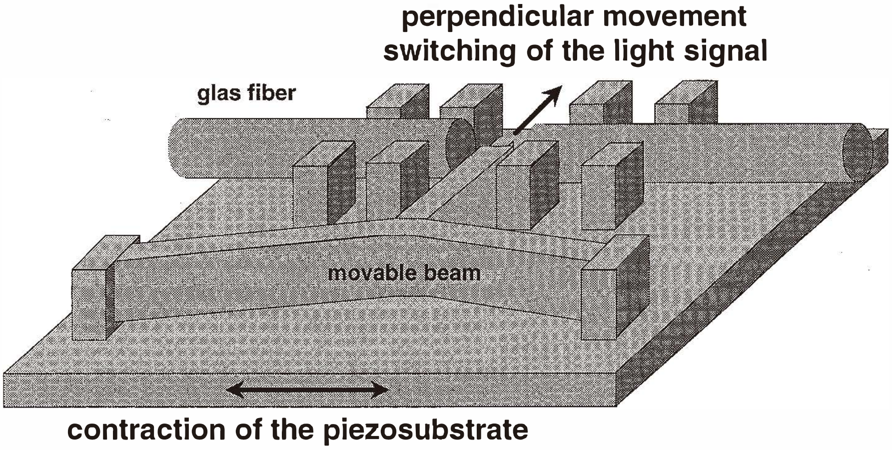

Fig. 8. Scheme of an optical shutter for optical fiber application based on a LIGA optical bench on a piezosubstrate.

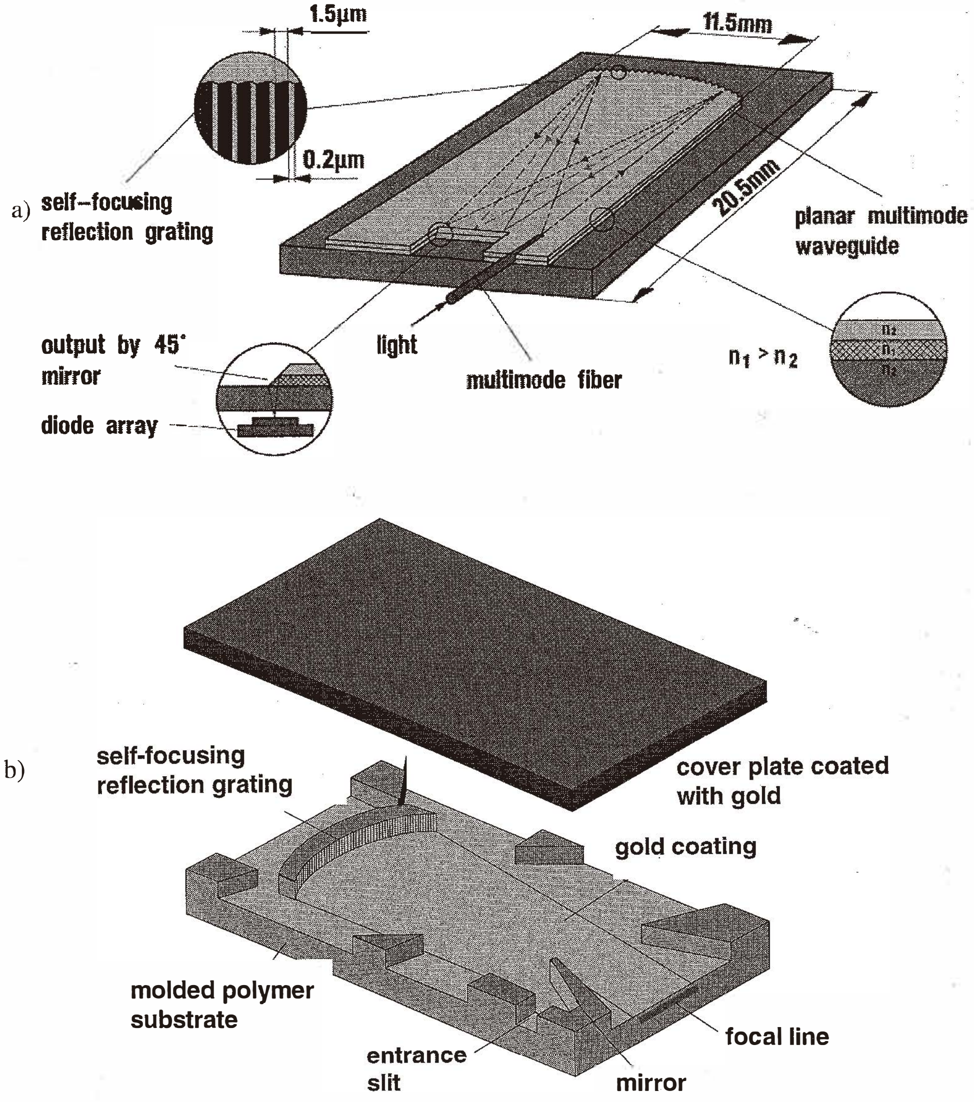

Fig. 9. Principle of the LIGA microspectrometer as an example of a waveguide structure with sidewalls having optical features: a) polymer waveguide structure, b) hollow waveguide structure.

5. Conclusion

The examples shown in this paper demonstrate the possibilities of using LIGA technology to fabricate microsystems out of materials other than silicon. Low-cost fabrication by molding of precise structures and intelligent automated assembly are the main attributes of the fabrication concept. In order to increase the complexity of the systems without increasing the fabrication costs, efforts have to be made to define the interfaces between individual modules which are assembled to form a system. By following this modular concept not only will large companies be able to profit from microsystem technology, but also, small- and medium-sized companies can use such OEM modules to produce their own system either for a niche market or a general consumer market.

References

1 R. Wechsung: First results of NEXUS Market Study, NEXUS Internal Communication (1997).
2 E. W. Becker, W. Ehrfeld, P. Hagmann, A. Maner and D. Münchmeyer: Microelectronic Engineering **4** (1986) 35.
3 J. Mohr, C. Burbaum, P. Bley, W. Menz and U. Wallrabe: Micro System Technologies 90, ed. H. Reichl: (Springer Verlag, Berlin, 1990) p. 529.
4 K. Schubert, W. Bier, G. Linder and D. Seidel: Industrial Diamond Review 50 No. 5 (1990).
5 W. K. Schomburg, W. Bacher, W. Bier, B. Bustgens, J. Fahrenberg, C. Goll: Proc. ASME '95, San Francisco (1995) 951.
6 U. Wallrabe, J. Mohr, I. Tesari and K Wulff: Proc. IEEE MEMS Workshop, San Diego (1996) 462.
7 A. Ruzzu, K. Bade, J. Fahrenberg and D. Maas: accepted for publication in J. Micromech. Microeng.
8 A. Müller, J. Hehmann, A. Rogner, J. Göttert and J. Mohr: Proc. of ECO '95, Brussels (1995).
9 P. Krippner, J. Mohr, C. Müller and C. Van der Sel: SPIE Proc. Series 2783 (1996) 277.