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Free Space Optical Components Based on LIGA Technology

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Abstract

Because of the high aspect ratio and the high precision the LIGA-process is well suited to fabricate micro optical benches with integrated optical elements and fixing structures to mount optical components by passive alignment only. Precisions of better than 1 µm for distances of even more than 10 mm have been demonstrated by a 16-multifiber connector fabricated by molding and also by an optical bench to build a heterodyne receiver. In addition a 2x2 free-space optical matrix switch and a micro optical distance sensor were fabricated and proof the concept to fabricate free space optical components by LIGA technology.

1. Introduction

The LIGA process which is a combination of lithography methods, electroforming and molding is well suited to fabricate micro optical components and systems out of polymers, metals and ceramics /1/. This is because of the special characteristics of this process technique, which is

- the high aspect ratio (more than 50), allowing to fabricate microstructures with dimensions in the micrometer range and heights more than one millimeter,
- the high precision resulting in very parallel sidewalls perpendicular to the substrate (less than 0.4 mrad) and in smallest structure details with dimensions in the sub micrometer range
- very precise lateral position of the structures on the substrate with tolerances of less than 1 µm for distances of several millimeters

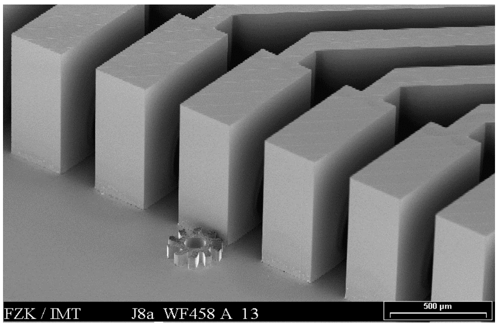


Fig. 1: SEM-photograph of a 1100 µm high polymer structure (PMMA) in comparison to a 200 µm high nickel structure fabricated by LIGA technology

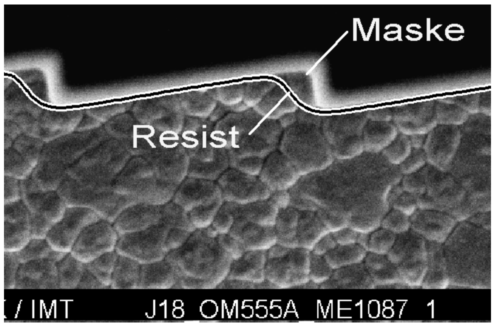


Fig. 2: Absorber structure and resist profile of the grating of a micro spectrometer (grating constant: 6,8 µm, grating height: 0,8 µm)

These characteristics are of advantage for one of the concept to fabricate micro optical systems followed by Forschungszentrum which is "**The fabrication of micro optical benches with exactly positioned fixing structures for passive alignment of optical components".** The possibilities of this concept will be shown by the examples described in this paper.

2. Optical Benches fabricated by the LIGA process

Although the **16-multifiber connector** which is developed at Forschungszentrum Karlsruhe in collaboration with Spinner GmbH, Munich is not really a free space optical component it shows the possibility of the LIGA process and its fabrication features very well /2/.

The layout of the connector is illustrated in fig. 3. It consists of two micro molded plastic parts: one for the alignment of fibers and guide pins with rows of highly precise alignment structures, the other for fixation and protection. The free choice of geometry in the LIGA process allows to pattern elastic ripples in the side walls of the alignment structures (fig. 4) facilitating fiber and pin insertion. The gap between the alignment structures is reduced form 140 µm in the last row to 123 µm in the first row. This enables a very easy assembly and passive alignment of the fibers without the need of micro positioning.

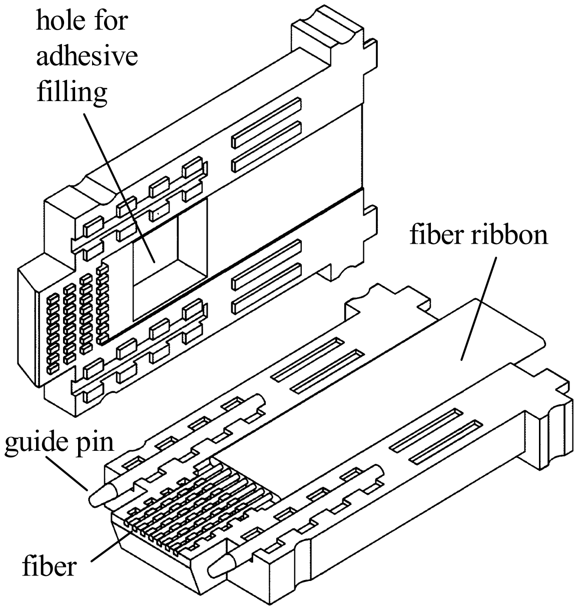


Fig. 3: Design of the fiber connector; for better illustration only 7 of the 16 fibers are shown

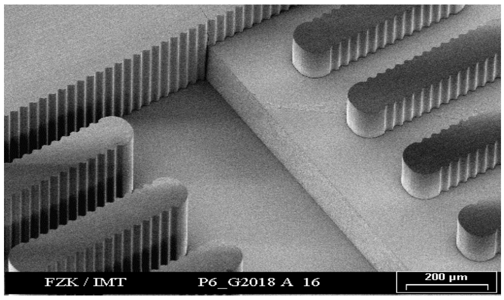


Fig.4: SEM of the lower connector part showing the rippled alignment structures for the fibers

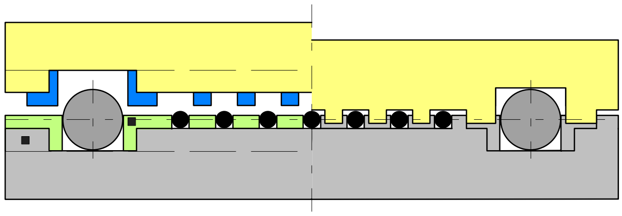


Fig. 5: Cross section of the fiber connector illustrating the vertical and horizontal alignment

Because of the different diameters of fibers and pins the cross section of the connectors features two structural layers (fig. 5). On a substrate a first layer is patterned which aligns the fibers and pins vertically in one line. The height of this level is 287.5 µm. In a second layer the rippled alignment structures are patterned for the horizontal positioning. To fabricate such a stepped molding tool, the first layer is micro milled precise in height into a copper substrate. Afterwards the substrate is covered with a thick layer of PMMA in which the structures responsible for horizontal alignment, e.g. the rippled structures, are patterned by X-ray lithography followed by electroforming of nickel. The nickel block is released from the substrate and the mold inserts are cut to the final shape by wire-EDM.

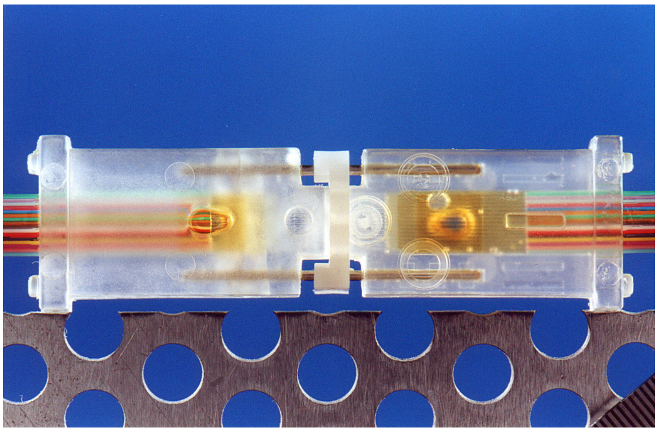
The two parts of the connector are micro injection molded out of polymer and glued together by a simple assembly technique. Fig. 6 shows the coupled hermaphroditic connector.

The loss of the connector depends on the accuracy of the geometric dimensions. Crucial are the level height of the first layer, the pitch of the fiber alignment structures, and the flatness of the molded parts in the grooves of the fibers and of the guide pins. Table 1 lists the mean results of 50 connectors. The observed deviations to the target value are in the range of the measurement resolution and proof the high precision achieved by LIGA technology.

	Level of 1st layer [µm]	Fiber pitch [µm]	Flatness in pin groove [µm]	Flatness in fiber groove [µm]
Target value	287,5	250	< 5	<5
Measured value	287,3 ± 1,0	249,5± 0,5	< 2	< 1.7

Tab. 1: Target dimensions and achieved dimensions for the geometrical data of the fiber ferrule

To measure insertion loss the connectors have been equipped either with 16-fiber singlemode ribbon or with 12-fiber multimode ribbon (62.5/125 graded index). The insertion loss has been measured using an LED emitting at 850 nm in case of multimode and at 1300 nm in case of singlemode. The results for 5 singlemode connectors and a statistical number of multimode connectors are plotted in Fig. 7. The mean insertion losses for the single-/multimode fibers are 1.16 dB/0.35 dB with a standard deviation of 0.52 dB/0.2 dB.



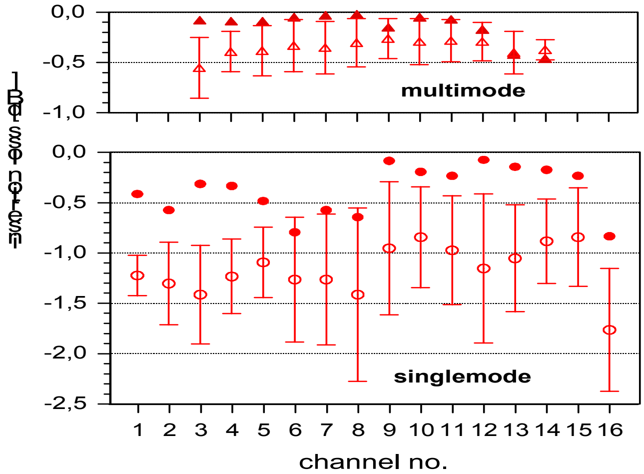
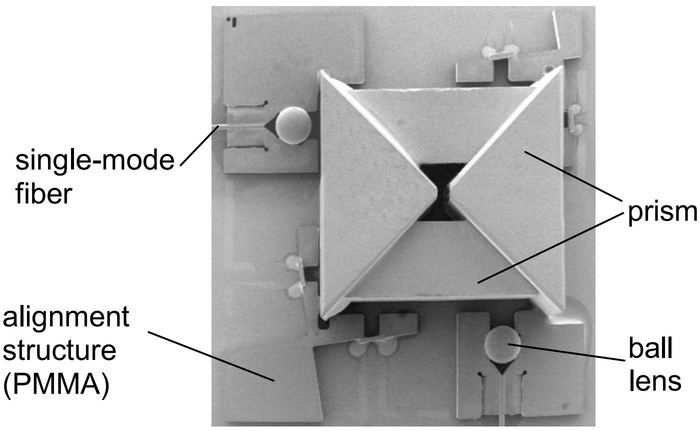


Fig. 6: Two connectors coupled to each other: The pins are inserted into the coupling element

Fig 7: Insertion loss for singlemode and multimode connectors (the open symbols represent the mean values for each channel, the solid symbols the best connection)

The optical bench concept is also very useful to build a **heterodyne receiver** for telecommunication application /3/. In a heterodyne receiver the optical signal is superposed with the light of a local laser source in a free space optical configuration. The beat signal is detected with a photodiode. The amplitude of the signal depends on the spot overlay as well as on the polarization states of both superposed beams. To get good signals high precision of the optical elements is necessary. Fig. 8 shows the assembled bench of such a receiver. The signal and local oscillator light emerging from an optical single mode fiber is coupled into a free-space micro-optical system with ball microlenses to collimate the beams. A polarization beam splitter separates the collimated beam into the perpendicular and parallel polarization state. The polarized light is superposed with a 3-dB splitter. Each beam splitter is optimized for the particular polarization state. The detection of the light signals is done in a balanced receiver with two photodiodes for each polarization state.



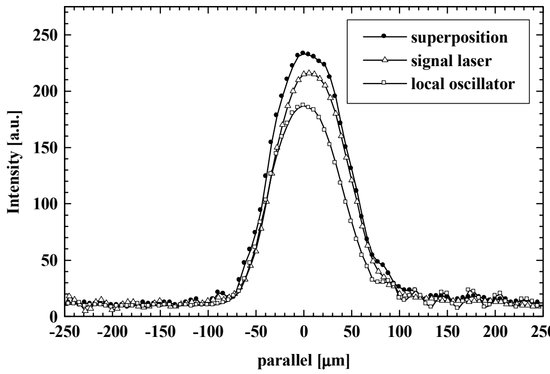


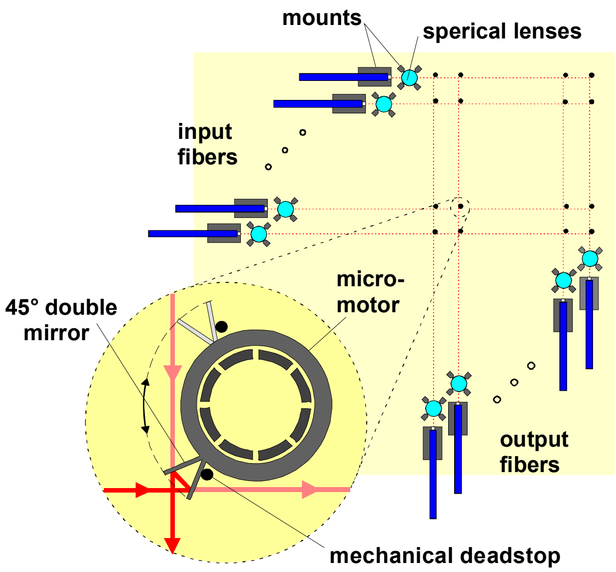
Fig. 8: Optical bench of a heterodyne receiver with passive aligned optical components

Fig. 9: Intenisty distribution of the individual signals and the overlay signal

The precision of the assembly determines the quality of the superposed signal at the position of the photodiodes. Thus, the overlap of the beams is a good indicator for the achieved assembly precision. The intensity distribution at the position of a photodiode is shown in Fig. 9. The two beam centres show a lateral beam misalignment of 5.1 µm. Theoretically a lateral misalignment between both single mode fibers of ± 1 µm would cause a lateral beam misalignment of ± 6.4 µm at the position of the photodiode. This proofs a precision of less than ± 1 µm with direct lithographically produced alignment structures.

The concept of a scalable **2 x 2 free-space optical matrix switch** bases on a 2-dimensional mirror array (fig. 10) /4/. The optical signals are delivered by glass fibers and detoured inside a microoptical bench by means of periodically arranged moveable micro-mirrors. In order to achieve uniform insertion losses in all channels the in- and output ports are displaced by the length of a single switching cell. Thus, all the optical path lengths are of equal length. Double mirrors deflect the light ensuring a 90° reflection. These mirrors are part of an electrostatic micro motor and swiveled into the beam path by the rotation of the micro motor. Defined end positions are realized by the use of dead stops.

The motor consists of a rotor and a static part i.e. bearing ring and stator electrodes (see cross section in fig. 11). A glass plate, placed above the motor serves as a vertical guide to confine the rotor's movement to the optical plane. Thus, a reliable function of the switching mechanism can be guaranteed. Introducing a PMMA column inside the motor structure ensures a defined distance between the rotor and the plate.



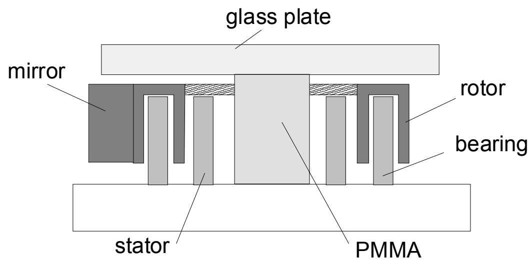


Fig. 11: Cross section of the electrostatic motor with PMMA support of a top glass plate as vertical guide

Fig. 10: Concept of a switch matrix with a micro-optical bench and moveable micro-mirrors; the inset shows the reflection of the beam at the double mirror which is moved by a micromotor

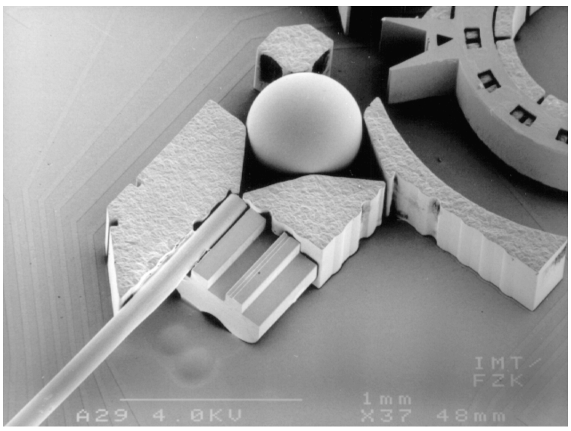


Fig. 12: Assembled micro optical bench with lens, fiber and fiber mount; a rotor with moveable double mirror can be seen in the back

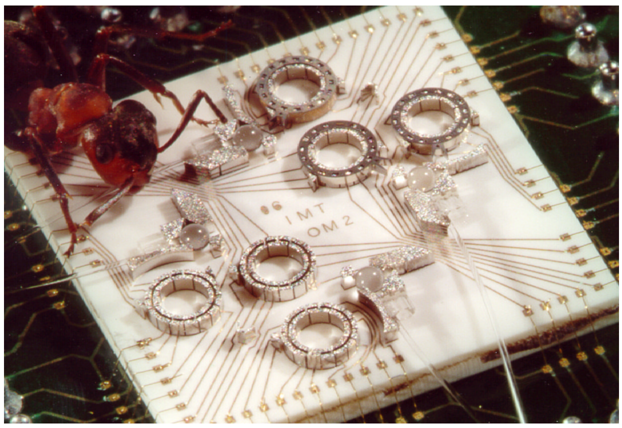


Fig. 13: Assembled and electrically contacted switch matrix system; the matrix in the upper corner features three assembled

The light beams are collimated onto the mirrors and then refocused into the output fibers with the help of spherical lenses. Fibers and lenses are passively aligned inside the optical bench with a modular concept using mounts and stops. The separately fabricated fiber mounts define the fiber's height position. The optical benches, the static motor parts and the mirror stops are fabricated simultaneously on a ceramic substrate using the LIGA-technique. Fig. 12 shows a SEM-picture of an assembled optical bench. A first prototype has been realized by integrating two 2x2 switch matrices on a 10x10 mm² ceramic substrate with six motors of 1.7 mm diameter (fig. 13).

For the electromechanical performance switching times down to 30 ms at voltages up to 300 V have been achieved. For lower voltages the switching time increases up to 0.7 sec for a voltage of 70 V. Measurements of the optical characteristics of the 2x2 switch matrix yielded an average cross talk of 90 dB and a minimum insertion loss of 3 dB in each channel with a repeatability below 0.3 dB The insertion loss includes 1 dB due to reflection losses at the glass-air interfaces of fibers and lenses. The remaining 2 dB demonstrate the high accuracy of passive alignment of fibers and lenses and the excellent performance of the moving mirrors.

If the micro optical system includes not only optical elements but also electro-optical components it is necessary to think about simplified assembly techniques. This goal is followed for the **micro optical distance sensor**, which is developed at Forschungszentrum Karlsruhe in close cooperation with Mitsubishi Electric, Amagsaki, Japan /5/. The sensor is based on the triangulation principle and consists of an electro optical base plate which carries all the electro optical components like laser diodes and photo detectors and an optical base plate (fig. 14, 15). This micro optical base plate is fabricated by molding the optical structures on top of a ceramic substrate and consists of cylindrical lenses and mirrors which form the illuminating and the detection beam. They are optimized in geometry to achieve high linearity of the beam to be measured on the detector array. Both base plates are clamped together passively aligned by balls, which are, glued high precisely to the laser diodes position. The balls fit into tubes fabricated together with the optical structure. Thus, with this assembly technique the laser diode will be positioned into the optical structure with a tolerance of less than 5 µm. Fig. 16 shows the assembled subsystem in a test housing.

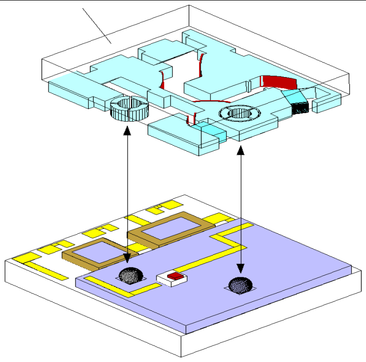


Fig. 14: The modular concept to fabricate an micro optical distance sensor

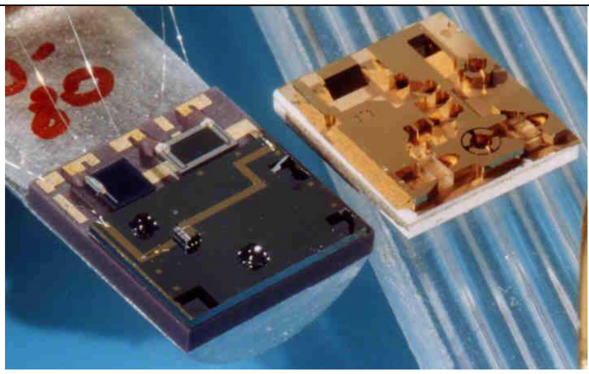


Fig. 15: The two base plates, which will form the micro optical subsystem

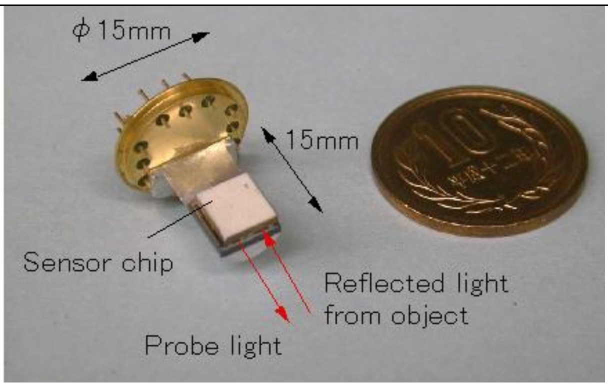


Fig. 16: Assembled micro optical subsystem of the distance sensor in a test housing

3. Modular fabrication concept for complex optical systems

The use of micro optical systems in commercial applications (as sensors or in telecommunication) is not only depending on the performance but also on the price of the system. It is highly dominated by fabrication and assembly costs because the equipment is specialized to the individual optical system. Investment in new equipment would be only reasonable if the numbers of devices to be fabricated are very high. Thus, the barrier to use micro optical systems is rather high. To overcome this problem, the modular concept to build micro optical systems as it has been developed with the optical distance sensor has to be transferred to other systems.

Thus, it is necessary to define the interfaces between micro optical and electro-optical base plate. In this case companies who are specialized in the fabrication technique can fabricate both components separately. For the electro optical base plate it is a mounting technology which is well-known form electronic fabrication and which has to be adopted to the need for higher precision (in the range of less than 5 µm) and to the handling of unhoused active optical devices. The optical base plate can be fabricated by different microstructure technologies like silicon bulk micro machining, surface micro machining or LIGA technology.

As the specialized manufacturers will use their equipment not only for one component, which goes into one subsystem or one system, the equipment costs are shared among different applications, which makes the component for each application cheaper.

4. Conclusion

The shown example demonstrate the possibilities of LIGA technology to fabricate free space micro optical components and systems. Due to the optical bench concept complex systems can be build up with precision in positioning of optical components of less than 1 µm by passive alignment strategies. Although this technique works very well in laboratory scale additional effort is necessary to make industrial use of the technique and the concept. In this case not only the optical performance but also the manufacturing costs have to be taken in mind. Thus, new fabrication concepts have to be used which have to be developed also under quality management control systems.

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