Optoelectronic Packaging Using Passive Optical Coupling

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Abstract

The commercial market for optical telecommunication components has reached $5 billion for 2001. About 60% to 80% of the manufacturing cost of these components resides in fiber pigtailing and packaging. We discuss the fabrication of an optical PC board (OPCB) made of molded, polymeric material with sub-micron mechanical fiduciaries that will enable passive, pick and place coupling of diverse optical components and single mode fibers. Sub-micron mechanical fiduciaries on the platform and mating fiduciaries on the optical component will have dimensional accuracy such that, when mated, even single mode waveguides on the optical chips will be efficiently coupled to each other. This will replace labor and capital intensive active alignment with passive coupling. The price of arrayed waveguide (AWG) wavelength division multiplexers (WDM) will drop from $400/wavelength to $40/wavelength and the cost of a fiber pigtailed telecommunication grade DFB laser will drop from $1,500/unit to $100/unit. Monolithic integration of optical functionalities is near impossible today because of the absence of a “silicon” of the optical industry. However, the optical PC board proposed here will enable hybrid integration of optical functionalities made with different materials such as silica WDMs, InGaAs lasers, InGaAs detectors, liquid crystal add/drop multiplexers (ADM), and polymeric variable optical attenuators (VOA), cost effectively and with small footprint.

1.0 Introduction

The commercial market for optical telecommunication components has reached $5 billion for 2001. About 60% to 80% of the manufacturing cost of these components resides in fiber pigtailing and packaging (see Figure 1).

A major portion of packaging cost is associated with active alignment and attachment of chip to chip and single mode fibers to chips. Active alignment involves lighting up input fibers and active components and maximizing light throughput before attachment. This is labor and capital intensive. The approach the industry has taken to reduce packaging costs is to automate the active alignment process using machine vision and stepper motors. This is a stopgap measure that is still capital intensive, brings no innovation to packaging and fails to address chip-to-chip packaging. By contrast, in the microprocessor industry when the number of leads in a single package grew rapidly, wire bonding was replaced by innovations such as surface mount technology, flip-chip and solder bump technology.

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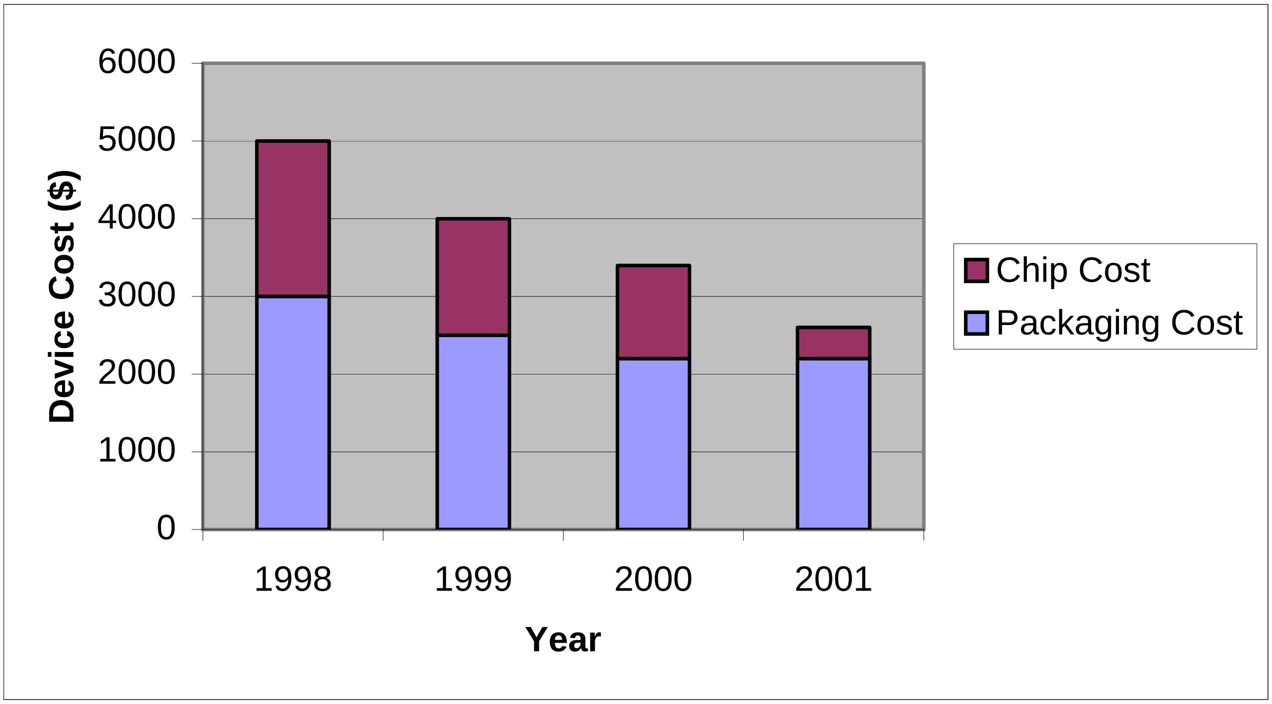
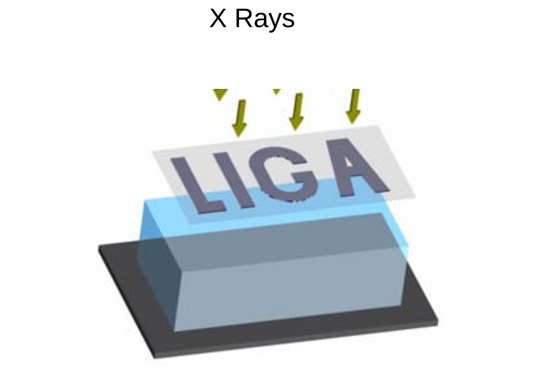


Figure 1. Packaging as a fraction of total manufacture cost of an optical modulator.

2.0 Introduction to LIGA

The LIGA process was developed in Germany at the Institute for Nuclear Engineering (IMT)). LIGA is an acronym for the main steps of the process, i.e., deep X-ray lithography, electroforming, and plastic molding. These three steps make it possible to mass-produce micro-components with sub-micron features and large aspect ratios at a low-cost. We will only give a brief description here since the process is well documented in the literature (Becker, 1986; Lorenz et al., 1997; Chang and Kim, 2000). Figure 2 shows the main steps in the LIGA process schematically.

Deep X-ray lithography allows structures of any lateral design with high aspect ratios to be produced, i.e., with heights of up to 3 mm and a lateral resolution down to 0.2 µm. The walls of these structures are smooth and parallel to each other. The very sophisticated structures of this type can be produced lithographically only by the highly penetrating, intense, and parallel X-rays supplied by a synchrotron. The structural information is compiled by means of a CAD system and then stored on a mask meeting the special requirements of hard X-radiation. Synchrotron radiation is used to transfer the lateral structural information into a plastics layer, normally polymethylmethacrylate (PMMA), by "shadowing." Exposure to radiation (step 1) modifies the plastic material in such a way that it can be removed with a suitable solvent (step 2), leaving behind the structure of the unirradiated plastic (the "shadowed areas") as the primary structure.

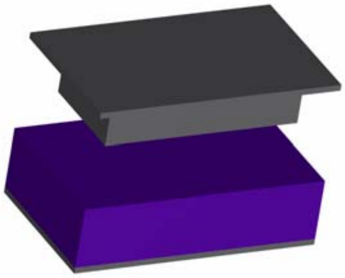


Step 1. Expose Polymer through X ray Mask

Step 2. Develop Exposed Polymer

Step 3. Electroplate through exposed areas

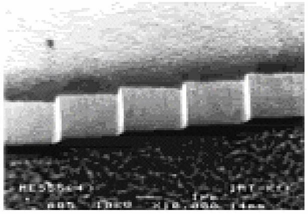
Step 4. Planarize and remove polymer



Step 5. Embossing

Step 6. Molded polymer part

high accuracy



Resist structure of a reflection grating, 0.25 µm step height, 125 µm structural height.

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Figure 2. Schematic depiction of the main steps in the LIGA process and photograph of molded grating (MicroParts, GmBh).

The spaces generated by the removal of the irradiated plastic material can be filled with metal by electroplating processes (step 3). In this way, the negative pattern of the plastics structure is transferred to a hard metal tool (step 4) with excellent replication of the sub-micron features.

The metal tool is then used for plastic molding using injection molding, thermal compression (step 5) molding or hot embossing (Heckele, 1998; Piotter, 1999; Becker, 2000). This ability to generate a metal tool with submicron features and use it for replication through molding is the key to low-cost mass production by the LIGA process. The materials used in plastics molding range from thermoplastics with very special optical properties (PMMA, polycarbonate) to materials particularly resistant to chemicals (epoxy phenol resins, polyvinylidene fluoride, and other fluoropolymers) to polymers of high temperature resistance (such as polysulfones, polyether ketones).

The embossing technique allows microstructures of metals or plastics to be made directly on top of the appropriate electronic evaluation circuit, i.e., to be integrated in a quasi-monolith without changing their electronic properties. The enormous advantage of this integration technique lies in the combination of the LIGA technique with silicon microelectronics as well as micromechanics in manufacturing industrial products. In this way, microsystems can be produced which avoid, on the one hand, the drawbacks of inflexible monolithic integration and, on the other hand, the high costs of hybrid structures.

The LIGA process allows fabrication of products with the following features:

- Any lateral geometry of structures.
- Structural height above 1 mm.
- Smallest lateral dimensions down to 0.2 µm.
- Aspect ratios of free-standing individual structures and details, above 50 and 500, respectively.
- Surface quality in the sub-micron range with RMS roughness of 30 nm.
- Various materials: polymers (e.g. PMMA, deuterated PMMA, polycarbonate); metals (e.g. Ni, Cu, Au); alloys (e.g. permalloy).
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3. Examples of LIGA packaging

3.1 LIGA enabled monolithic spectrometer

MicroParts GMBH in Germany was the first to introduce a commercial application of exploiting LIGA technology – a monolithic molded spectrometer operating in the visible and UV region of the spectrum. Figure 3 shows a schematic of the spectrometer.

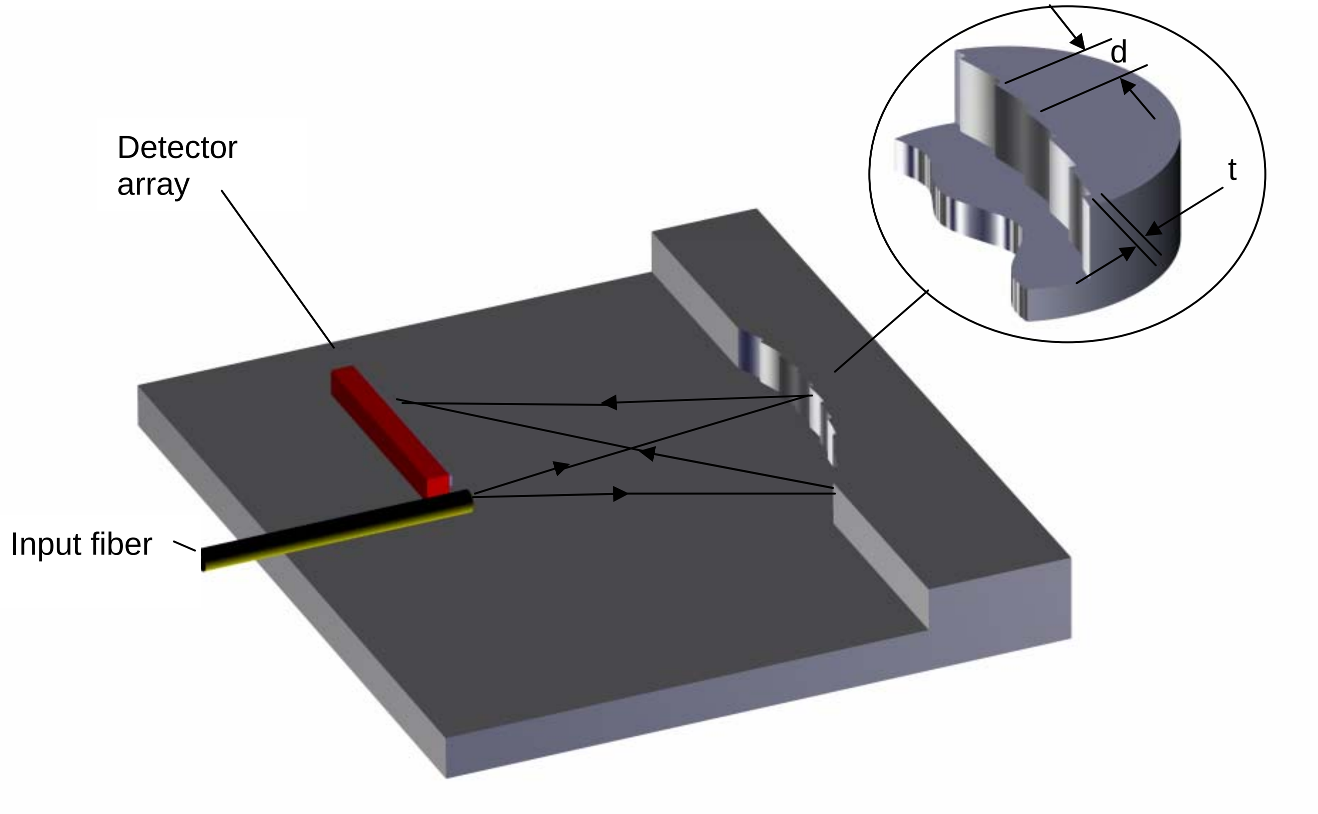


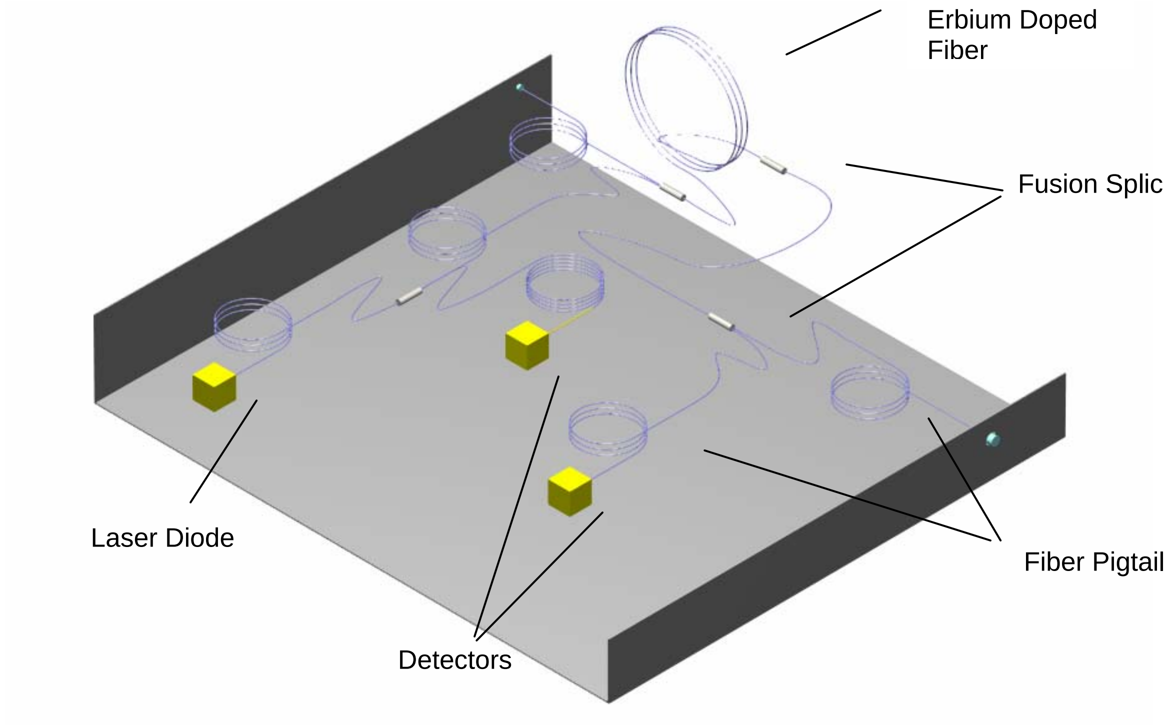
Figure 3. Schematic of LIGA molded spectrometer

Light is introduced via a multimode fiber and is reflected by the blazed molded and metallized echelle grating. A CCD array is placed at the focal plane to detect the diffracted light.

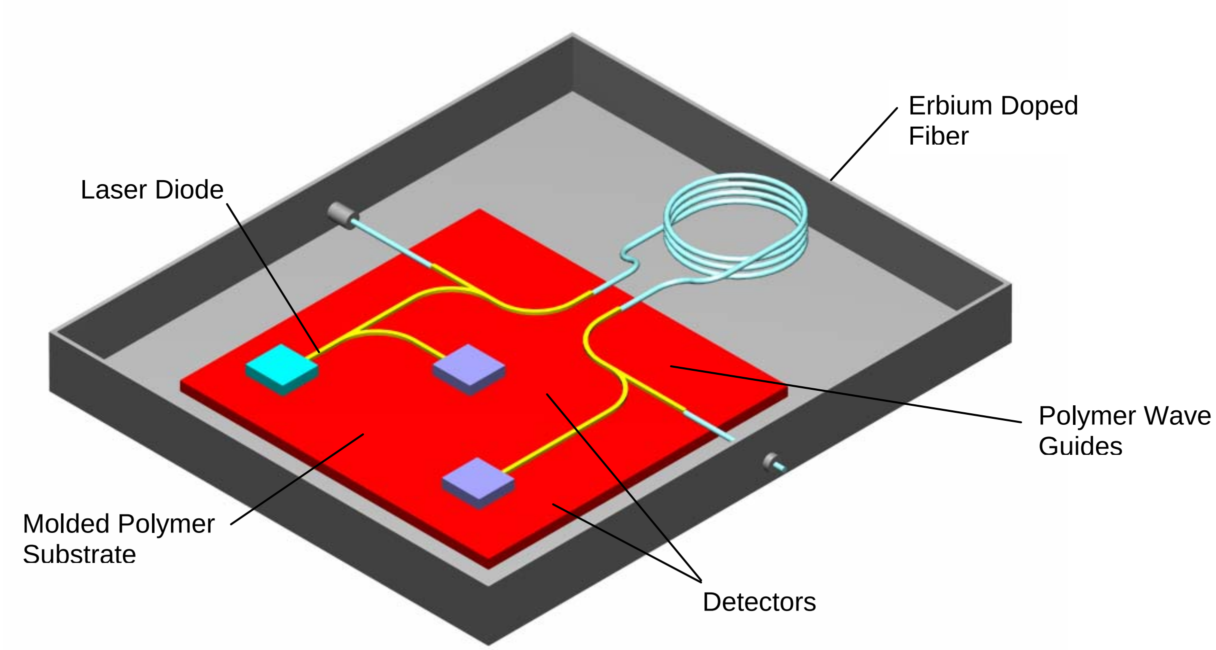
3.2 LIGA enabled optical amplifier

Many integration applications can be addressed with this approach. Figure 4 shows two in line optical amplifiers using erbium doped active core fibers. The current packaging technology (a) requires that each of the various components be fitted with fiber pigtails. that are then fusion spliced together. This is very tedious, and the entire assembly is cumbersome and difficult to handle. By contrast, the molded polymer OPCB (b) is compact , robust and easily assembled. Components such as optical taps are fabricated into the waveguides. Laser diodes and detectors are placed in high accuracy receptacles for passive coupling. Fibers are only used for input and output and are also coupled passively.

The main challenge is to fabricate a molded OPCB with mechanical fiduciaries whose location and dimensions are accurate to fractions of a micron, both in the plane of the OPCB and in depth.



(a)



(b)

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Figure 4. Optical amplifier module (a) as fabricated now (b) as fabricated with polymeric PC board.

REFERENCES

Becker, E. W., W. Ehrfeld, P. Hagmann, A. Maner, and D. Munchmeyer, 1986. Microelectron. Eng. V4, p. 35.

Becker, H., 2000. “Hot embossing as a method for the fabrication of polymer high aspect ratio structures.” Sensors and Actuators, V83, p. 130-135

Chang, H. K.; and Y. K. Kim, 2000. “UV LIGA process for high aspect ratio structure using stress barrier and C-shaped etch hole.” Sensors and Actuators, V84, No. 3, p. 342-350

Heckele, M, K. D. Muller, and W. Bacher, 1998. Microsys. Technol., V4, p.122

Lorenz, H., M. Despont, N. Fahrni, N. LaBianca, P. Reanud, and P. Vettiger, 1997. J. Micromech. Microeng. V7, p.121.

Piotter, V., T. Benzler, T. Hanemann, H. Woellmer, R. Ruprecht, and J. Hausselt, 1999. In *Proc. SPIE Design, Test and Microfabrication of MEMS and MOEMS*, V. 3680, p. 456