2nd International Symposium on Photonic Packaging

Electrical Optical Circuit Board and Optical Backplane | November 13, 2008, Munich

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2. International Symposium on Photonic Packaging

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Electrical Optical Circuit Board and Optical Backplane

organized by Fraunhofer IZM, co-organized by VDI/VDE-IT, IEEE-CMPT, IEEE-LEOS

November 13, 2008, Electronica, Messe München | Hall A1 Conference Room A12, 9:30 am – 5:30 pm

Program

» System Design

09:30-09:40 Welcome
Henning Schröder
Fraunhofer IZM Berlin, Germany

09:40-10:10 Optical Interconnect Applications for Multimode Siloxane Components
Ian H. White
University of Cambridge, Cambridge, UK

10:10-10:40 Design Rules for Polymer Waveguides and Measurement Mechniques
Kai Wang
University College London, London, UK

10:40-11:10 CAD of Board-Level Optical Interconnects
Jürgen Schrage
Siemens C-Lab, Paderborn, Germany

10:40-11:10 Coupling Light to and from Optical Boards
Peter van Daele
University of Gent, Gent, Belgium

11:40-12:30 Lunch break

» Components

12:30-01:00 240 Gbit/s Parallel Optical Transmission Using Double Layer Waveguides in Thin Glass Sheets
Henning Schröder
Fraunhofer IZM Berlin, Germany

01:00-01:30 Flexible Optical Interconnects
Geert van Steenberge
University of Gent, Gent, Belgium

01:30-02:00 Refractive Index Profiling of Polymer Planar Optical Waveguides Using Optical Coherence Tomography
David Ives
National Physical Laboratory, Middlesex, UK

02:00-02:30 Ink Jet Printing of Optical Waveguide Material
John Chappell and David Hutt
Loughborough University, Loughborough, UK

02:30-03:20 Coffee break

» Integration Technologies

03:20-03:50 Transfer of Polymer Waveguide Fabrication Processes to a Commercial PCB Foundry
Dougal Stewart
Stevenage Circuits Limited, Stevenage, UK

03:50-04:20 Board-Level Optical Interconnects for Computing Applications
Bert Offreins
IBM Research Labs, Rüschlikon, Switzerland

04:20-04:50 Pluggable Interconnect Technology for Electro-Optical PCBs
Richard Pitwon
Xyratex, Hampshire, UK

04:50-05:20 Optoelectronic Printed Circuit Board Realised by Two Photon Absorption Structuring
Gregor Langer
AT&S AG, Leoben, Austria

05:20-05:30 Final Remarks
Henning Schröder
Fraunhofer IZM Berlin, Germany

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Coupling Light to and from Optical Boards

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Abstract — **Optical interconnections have proven their value for long distance communications, but the cost of the essential coupling structures becomes more and more important as the distance to bridge goes down. The coupling structures also have a big influence on the performance of board-level optical interconnections. Different approaches are being used and will be presented.**

Keywords - coupling components, laser ablation, optical boards, optical interconnections, polymer waveguides

I. INTRODUCTION

Optical interconnects have gained interest over the last years in view of their ability to offer a solution to the bandwidth problems that are associated with electrical interconnections [1]. Optical interconnections offer a high bandwidth and are immune to electromagnetic interference and compatibility problems, which makes their use interesting at high frequencies. Besides these advantages, optical interconnections also show a clear benefit regarding power consumption, weight reduction, volume and edge density…

At distances in the order of 1 m to 10 cm, interconnections within systems and sub-systems always are integrated in printed circuit boards (PCB). Therefore it should be clear from the beginning that the integration of optical interconnections at this level can only become successful if the technology to introduce these optical interconnections is completely compatible with the existing, mass-production and low cost manufacturing technology of electrical PCBs.

The integration of the optical interconnections at the board-level, covering distances from a couple of centimeters up to one meter, can be done with the use of a polymer optical layer. Optical printed circuit boards (PCBs) contain an optical layer in addition to the traditional electrical interconnections. Although a rather large number of board level optical interconnect technologies have been developed in the recent years [2, 3], optical signaling on PCBs does not yet provide a very cost- effective solution, mainly due to its lack of maturity.

The optical layer contains either fibers (both POF and glass fibers are being used) or waveguides (both single mode and multimode waveguides are presented) for in-plane propagation and other passive optical elements (e.g. splitters, combiners, etc) can be integrated if desired.

Independent from the optical layer which is being used, out-of-plane coupling elements are required to come to a working system, where light signals coming from/going to optoelectronic elements or fiber arrays can be coupled out of/into the optical waveguide. To maintain the good performance of the system, efficient coupling structures are needed.

Different solutions for the 90° beam deflection have been presented such as grating couplers [4], optical plugs and micro-mirrors [5]. The most straightforward solution is the use of 45° micro-mirrors. These mirrors are wavelength independent, have a high reproducibility and can be fabricated with a large variety of micro-structuring technologies such as photo-lithography, reactive ion etching and V-shaped diamond blade.

II. SINGLE MODE VERSUS MULTIMODE

When discussing optical interconnections at short distance, one should keep in mind the application one is looking for:

- the situation where optical signals are arriving into the cabinet from optical fibers coming from long haul interconnections, and which signals have to be switched, repeated or decoded. In this case the arriving signal will be on a wavelength of 1.3 or 1.55 um and the fibers will be SM, requiring similar wavelengths and modal structures on the boards, and
- the situation where processors on the same or different boards within the same system have to communicate at high bitrates, but over short distances, which will imply a MM structure and most probably also a less stringent requirement on wavelength dependent losses.

It is clear that the current status of maturity of the technology still prohibits proposing low-cost solutions for single mode on-board optical interconnections, which are also fully compatible with printed circuit board technology. This mainly lies in the cost of the required alignment tolerance.

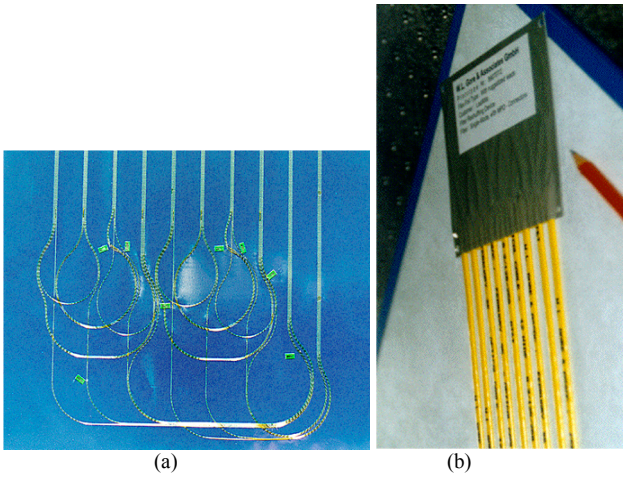
It is therefore our opinion that the introduction of on-board optical interconnections will not take place via the applications such as telecommunications (which require SM solutions), rather than applications which allow the use of 850 nm MM optical interconnections such as data communications, storage systems, computing, sensing, automotive, robotics,… We will therefore focus on the MM solutions in this paper.

III. Coupling Structures for Optical Boards

As explained above, there are currently a wide variety of solutions being used worldwide. This paper does not have the intention to be complete in covering all solutions and all research work in this area, but the listing below is just a snap-shot of possible ways to cope with the crucial issue of coupling light in and out of the boards.

A. Coupling structures for fiber-based optical layers

Optical fibers have been integrated in printed circuit boards for many years already and these optical fiber-based boards have already been implemented as passive optical backplanes (Figure 1), but also integrated in stacks of electrical interconnection layers (Figure 2) [6].



(a) (b)

Figure 1. Optical fibers, embedded in flexible foils for use as passive optical backplane. (a): top view with a clear view of the patterning of the optical fibers, (b): photograph of the final packaged board with fiber lips and connectors

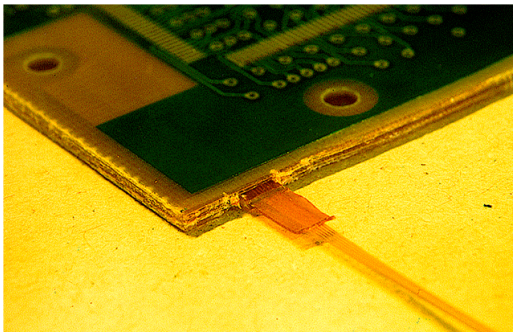


Figure 2. Optical fibers integarted as an optical layer in a standard electrical multi-layer PCB.

Coupling light to and from these embedded fibers can not be carried through bending the optical fibers towards the surface, because the limited bending radius of optical fibers. The most common used solution here is to couple light to and from cleaved or etched facets to the fibers in a cleared hole in the optical board. Detectors or light sources can then be mounted in front of the end facet of the optical fiber using special holders and clip-systems. An example of this technology is given in Figure 3 illustrating work carried out by FZK (Forzsungszentrum Karlsruhe, Germany) [7].

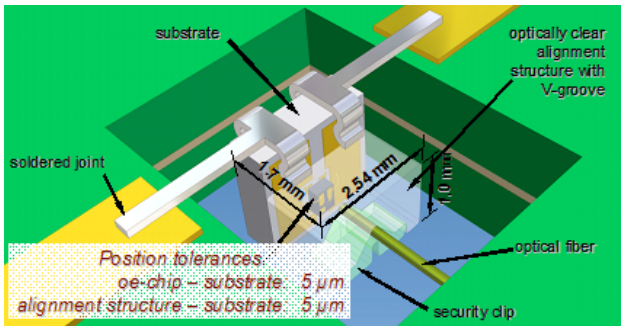


Figure 3. Optoelectronic components (detectors & light sources) mounted a special holder aligned with the embedded optical fibers using a clip-system.

The main advantage of using embedded fibers is the proven high performance and low loss regarding the light propagation through the optical layer. No difference has to be made regarding technology whether SM or MM fibers are being used. Proper design of the clip-systems can also yield low-cost solutions for coupling light to and from SM fibers, but, to our knowledge this has not been shown yet. The technology however also opens ways to use the well-known V-groove technology to align fibers, which has already proven to be capable of alignment tolerances in line with SM-operation.

B. Coupling structures for waveguide-based optical layers

Most of the work on optical boards however makes use of polymeric-based layers applied in or on the stack of the multilayer printed circuit boards. A wide variety of material comes available, but still at high cost and in some cases not completely compatible with all manufacturing processes of standard FR4-based printed Circuit Boards. The combination of high temperature and pressure during lamination or high temperature during solder reflow sometimes excludes materials.

Regarding the coupling structures a classification can be made between either integrated or discrete coupling structures. Some examples will be shown in the next few paragraphs.

1) Integrated coupling structures

a) Total internal reflection mirrors

Using different technologies mirrors can be fabricated integrated in the optical layers themselves. These mirrors can either be metalized or using TIR (Total Internal Reflection). In Figure 4, the TIR mirrors are ablated into the optical layer (Truemode multimode waveguides) with a KrF excimer laser (248nm). The 90° beam deflection is based on the TIR that occurs at the polymer-air interface. The fabrication of these mirrors requires only one processing step: the ablation of the 45° mirror facet. Using laser ablation, there is always a certain degree of tapering during the ablation, which means that the two angled interfaces of the ablated cavity are not parallel. The degree of tapering depends on both the type of laser and the material that is being ablated. The angle of the facets is equal to the tilt angle of the laser beam plus or minus the tapering angle. The tapering angle can be measured experimentally and corrected. The advantage of having the mirrors directly integrated with the waveguides is the excellent alignment of the mirror with respect to the waveguides.

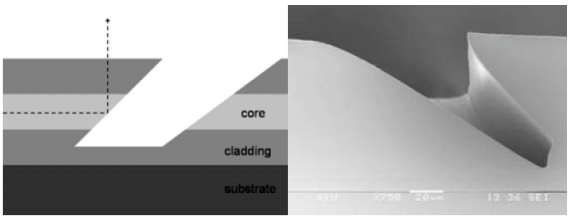


Figure 4. TIR-mirrors ablated into the optical layers (left: schematic view, right: SEM-cross section)

b) Metallized micro-mirrors

The main disadvantage of the solution presented using TIR-mirrors is the difficulty to keep the air-gap clear of dust and materials during subsequent processing steps and during operation. Introduction of material and dust can seriously influence the TIR-characteristics and consequently the performances of the link.

During the ablation a cavity is formed that contains two interfaces that are not parallel because of the tapering under a slightly different angle. The first interface can be used as TIR mirror, whereas the other facet can be used as a metallized micro-mirror. The fabrication of a metallized integrated mirror configuration requires three processing steps: the ablation of the 45° mirror facet, the metallization of the mirror facet and the filling of the ablated cavity with cladding material. The three processing steps are depicted in Figure 5.

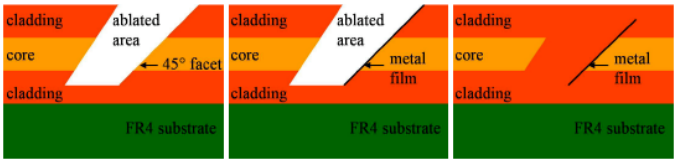


Figure 5. Fabrication process of the metallized micro-mirror: ablation of the mirror facet, metallization of the mirror facet and the filling of the ablated area with cladding material.

2) Discrete coupling structures

Besides integrated mirrors, one can also explore the possibilities of discrete coupling structures. These discrete coupling components are fabricated and optimized separately from the assembly and have to be inserted into cavities formed in the PCB-integrated waveguides [8]. The advantage of discrete coupling components is that they are very versatile since they can be extended towards multilayer structures and can incorporate enhancements to increase the coupling efficiency, such as: integrating cylindrical micro-lenses or using a curved micro-mirror rather than a standard 45° mirror [9]. A distinction can be made between several categories.

a) Optical plugs

Two types of optical plugs are shown here, just as an example without the intention to be complete.

The pluggable out-of-plane couplers presented in Figure 6 are fabricated with the use of deep proton writing (DPW) [10]. The pluggable couplers contain a 45° mirror and can be readily inserted into a laser ablated cavity in the optical layer. Because of the tapering that occurs during the ablation, the cavity has to be ablated with a slightly tilted laser beam. The cavity therefore has one vertical facet and one facet under the double tapering angle. The couplers can be passively aligned by mating the vertical input facet with the vertical edge of the laser ablated cavity. Active alignment can also be used to align the coupler element with respect to the waveguides when using fine-placing equipment. The pluggable couplers can be inserted in a very late stag of processing, which makes the need for compatibility with the full fabrication process not necessary.

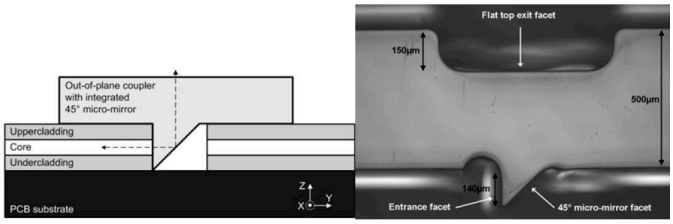


Figure 6. The left picture shows a schematic view of a pluggable coupler inserted in a micro-cavity; the right picture shows the pluggable DPW coupler.

These optical plugs are widely used in very different configurations and materials. Another example is given in Figure 7 [11] where a short piece of an optical fiber with a 45 degree facet is inserted in the through-hole and used to couple light between the optoelectronic component and the optical layer. Also self-written pins are being used.

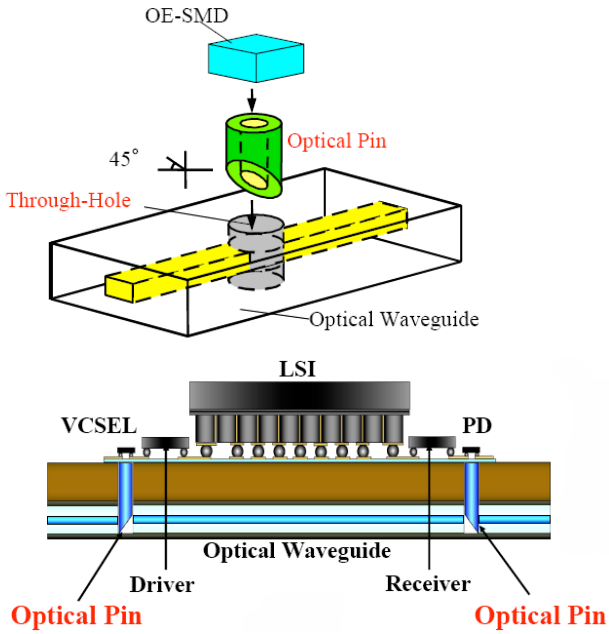


Figure 7. Concept of an optical pin using a short optical fiber with angled facet.

b) Embedded Discrete Micro-Mirrors

The discrete coupler can also be embedded into the optical layer, combining the advantages of both configurations [12]. The design of the pluggable coupler is in this case slightly adapted. The insert is Au-coated prior to the insertion in the cavity. This is necessary because of the gap that exists between the output facet of the waveguides and the mirror facet. The insert is then placed into the laser ablated cavity and aligned with respect to the output facet of the waveguides. This can be done with the use of fine placement equipment. After fixing the

insert in the cavity with UV-curing glue, the ablated cavity is filled with cladding material, filling the gap between the output facet of the waveguides and the Au-coated mirror and covering the insert. The process is schematically depicted in Figure 8. The embedded discrete coupler can be used for out-of-plane coupling in single layer structures and for inter- and out-of-plane coupling in multilayer structures. The alignment between the couplers in a multilayer structure can be arranged with the use of alignment features.

Figure 8. Left: the insert is plugged into the ablated cavity and aligned with respect to the output facet of the waveguides; Right: after insertion and attachment of the coupler, the ablated cavity is filled with cladding material.

To guarantee the flatness of the bottom surface of the ablated cavity a Cu island is defined on the FR4 substrate and is used as a stopping layer for the laser ablation. The optical layer is applied onto the substrate and multimode waveguides are ablated into the core layer. The cavity is ablated with tilted KrF excimer laser beam. The excimer laser will selectively ablate the optical layer; the Cu-island is used as a stop layer. The ablation of the cavity is up to the Cu surface, which has the same flatness as the FR4 substrate. After the ablation of the cavity, the coupler can be inserted onto the Cu surface as close as possible to the output facet of the waveguides and fixed.

The insert has a length of 1000_m and a width of 500_m and contains a 45° micro-mirror which has a height of 130_m and is fabricated by means of DPW. In view of the build-up of the structure, the mirror facet has to be Au-coated to deflect the light beam that is coupled out at the output facet of the waveguides. The excimer laser beam is tilted under a suitable angle for the ablation of the cavity in order to have a vertical interface at the output of the waveguides. Loss measurements have been carried out on waveguides which are ablated over the entire sample, running over the Cu-island.

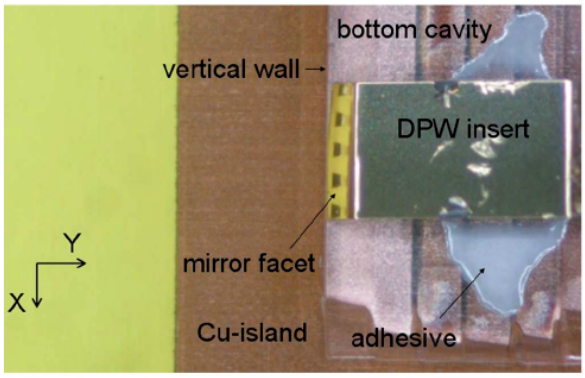


Figure 9. Top view of the metallized micromirror glued to the bottom of the ablated cavity, before filling with cladding material.

The presence of the Cu-island has no influence on the performance of the waveguides, which indicates that the planarization of the optical layer is sufficient.

IV. Conclusions

In this paper, different coupling approaches are presented that can be used for the 90° beam deflection in optical PCBs. Integrated micro-mirrors, which are patterned into the optical layer with use of laser ablation, have high achievable alignment accuracy but have to be compatible with the following processing steps. The discrete coupling structures contain a 45° micro-mirror to deflect the light beam over 90° and can be plugged into a laser ablated cavity in the optical layer. Both configurations can be combined with use of an embedded micro-mirror insert.

Acknowledgment

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