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## ABSTRACT

Optical interconnections gradually find their way towards the printed circuit board-level as optoelectronic components become available at affordable costs. To fully exploit the two-dimensional character of these VCSEL- and detector arrays, multilayer optical interconnects have gained interest over the last years. The multilayer approach allows increased integration density and flexible routing schemes. In these multilayer structures light can be coupled either out of the propagation plane or from one layer to another. We present pluggable out-of-plane and inter-plane coupling components that can be readily inserted into pre-defined cavities in the PCB-integrated waveguides.

**Keywords:** coupling structures, deep proton writing, laser ablation, optical interconnects, polymer waveguides

## 1. INTRODUCTION

Coupling structures are critical components in optical interconnections because of their large influence on the overall efficiency of the system. The alignment between coupling elements in the different optical layers however is critical. We present pluggable inter-plane coupling components which can be inserted into pre-defined micro-cavities in the optical layers. The main advantage of these pluggable couplers over waveguide-integrated micro-mirrors, is the accurate alignment between the two mirrors because they are defined in one processing step and the possible monolithical integration of cylindrical micro-lenses for increased coupling efficiency.

## 2. RESULTS

### 1.1 Multilayer waveguides integrated on a Printed Circuit Board (PCB)

The two-layer optical structure consists of two cladding-core-cladding stacks where arrays of  $50\mu\text{m} \times 50\mu\text{m}$  multimode waveguides are patterned in the core layer by laser ablation<sup>1</sup>. A cross-section is shown in Figure 1. The micro-cavities are ablated through the two layers as a final processing step of the PCB.

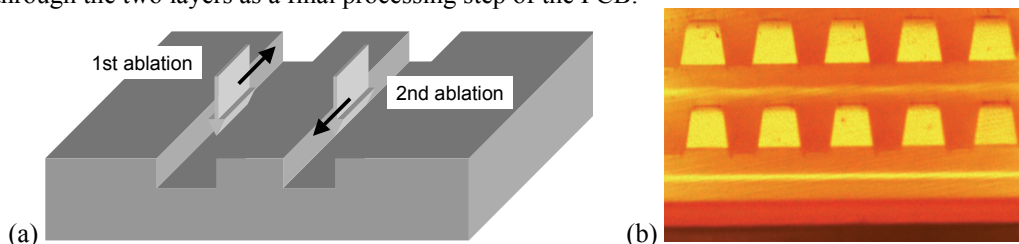


Figure 1: Schematic principle of the laser ablation process for waveguide fabrication (a) and a cross-section of a two-layer optical waveguide structure integrated on a PCB (b).

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The optical material has to be compatible with existing PCB manufacturing and soldering processes and should in addition show very good optical properties such as low propagation loss at the targeted wavelength. We study the use of Truemode Backplane™ Polymer, which is a highly cross-linked acrylate based polymer material with excellent optical, thermal and environmental properties. The main properties are given in Table 1.

### 1.2 Multilayer out-of-plane coupling components

The pluggable inter-plane couplers are fabricated using Deep Proton Writing (DPW)<sup>2</sup>. A 500µm thick PMMA sample is translated perpendicularly to an 8.3MeV proton beam according to a pre-defined pattern in steps of 500nm with an accuracy of 50nm, while depositing  $2.5 \times 10^{12}$  protons/µm<sup>2</sup> per step. This allows the fabrication of high-quality optical surfaces with an average local RMS surface roughness  $R_q$  of  $14.1\text{nm} \pm 2.7\text{nm}$  measured over an area of  $60\mu\text{m}$  by  $46\mu\text{m}$ . Although DPW is not a mass fabrication technique as such, one of its assets is that once the master component has been prototyped, a metal mould can be generated from the master by applying electroplating. After removal of the plastic master, this metal mould can be used as a shim in a final micro-injection moulding or hot embossing step<sup>3</sup>. This way, the component can be mass-produced at low cost in a wide variety of high-tech plastics. The maximum coupling efficiency measured when using the component in a fiber-to-fiber coupling scheme and a source wavelength of 850nm was 70% and 75% for respectively the upper and the lower channel position.

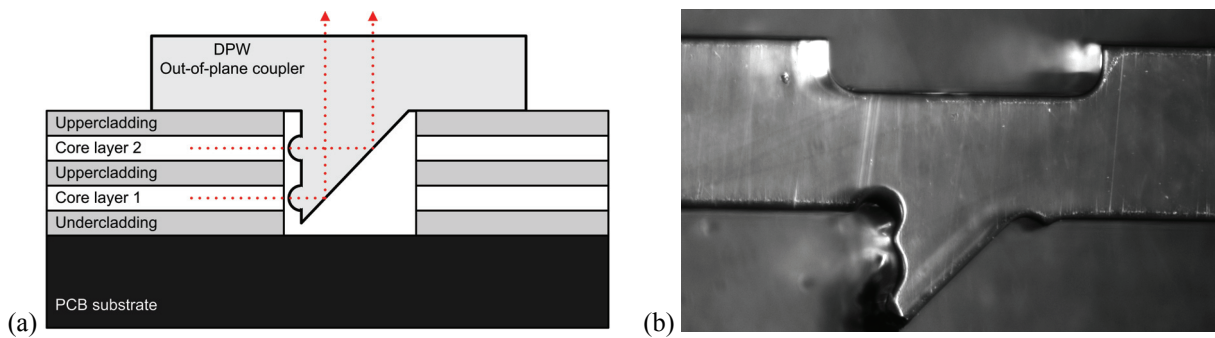


Figure 2: Schematic working principle of a multilayer out-of-plane coupling component inserted in a cavity in PCB-integrated waveguides (a) and fabricated DPW multilayer out-of-plane coupling component (b)

### 1.3 Multilayer inter-plane coupling components

A schematic overview of the proposed structures and a picture of the realized components are given in Figure 3. As can be seen, there are two possible configurations, where the propagation direction is either preserved or reversed. Loss measurements have been carried out on the inter-plane coupler with preservation of propagation direction. A multimode fiber (MMF) with a 50µm core and a numerical aperture (NA) of 0.2 was used at the input side, whereas a 100µm core, 0.29 NA MMF was used as detector. The reference measurement was performed by in-line butt-coupling of the input and output MMF. When inserting the DPW inter-plane coupler in between, as shown in Figure 3(b), a fiber-to-fiber coupling efficiency up to 70% (-1.6dB) was measured. This can be further increased by applying a metal reflection coating on the micro-mirror facets and/or by monolithically integrating (cylindrical) micro-lenses at the entrance and exit facets of the inter-plane coupler. The detector MMF was mounted on a PI F-206 six-axis parallel motion kinematics Hexapod system. This allows us not only to position the detector with an accuracy of 300nm, but also to perform a two-axis scan to check the tolerance for mechanical misalignments of the output fiber. The resulting -1dB tolerance range is  $\pm 25\mu\text{m}$ .

## 3. CONCLUSIONS

We have presented two complementary configurations of pluggable inter-plane couplers and a two-layer out-of-plane coupler as a versatile alternative to waveguide-integrated micro-mirrors. These couplers are compatible with low-cost mass fabrication and can be used as building blocks for flexible routing schemes in multilayer PCB-integrated optical interconnections.

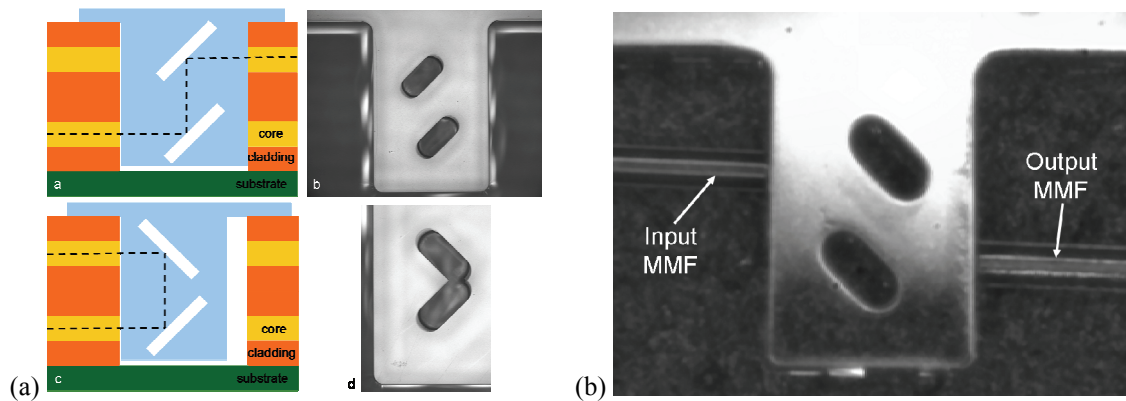


Figure 3: Schematic working principle and fabricated inter-plane coupling components (a) and experimental characterization set-up for coupling efficiency measurements in a fiber-to-fiber coupling scheme (b)

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