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Pluggable inter-plane couplers for multilayer optical interconnections

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Abstract We present pluggable inter-plane coupling components which can be used to route signals in board-level multilayer optical interconnections. The components are prototyped using Deep Proton Writing, but are compatible with low-cost mass fabrication.

Introduction

Coupling structures are critical components in optical interconnections because of their large influence on the overall efficiency of the system. Nowadays, the interest is shifting towards multilayer structures allowing higher interconnection densities and flexible routing schemes. 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.

Inter-plane coupling structures

A schematic overview of the proposed structures and a picture of the realized components are given in Figure 1. As can be seen, there are two possible configurations, where the propagation direction is either preserved or reversed. These two components can be used as cornerstones for flexible routing schemes in two-layer optical interconnections since they can be readily inserted into micro-cavities which are pre-defined in the polymer optical layer integrated on top of a Printed Circuit Board (PCB). The couplers contain two 45° micro-mirrors to deflect the light beam over 90° by Total Internal Reflection (TIR). The two-layer optical structure consists of two cladding-core-cladding stacks where arrays of 50µm x 50µm multimode waveguides are patterned in the core layer by laser ablation¹. A cross-section is shown in Figure 2. The micro-cavities are ablated through the two layers as a final processing step of the PCB.

The pluggable inter-plane couplers are fabricated using Deep Proton Writing (DPW)². This rapid prototyping technology consists of the following processing steps. First a collimated 8.3MeV proton beam is used to irradiate an optical grade 500µm thick PMMA sample according to a pre-defined pattern by translating the PMMA sample, changing the physical and chemical properties of the material in the irradiated zones. As a next step, a selective etching solvent is applied for the development of the irradiated regions. This allows for the fabrication of (2D arrays of) micro-holes, optically flat micro-mirrors

and micro-prisms, as well as alignment features and mechanical support structures. On the other hand, an organic monomer vapor can be used to expand the volume of the bombarded zones through an in-diffusion process. This enables the fabrication of spherical (or cylindrical) micro-lenses with well-defined heights. If necessary, both processes can be applied to different regions of the same sample. The sample is translated perpendicularly to the proton beam in steps of 500nm with an accuracy of 50nm, while depositing $2.5 \times 10^{12} / \mu\text{m}^2$ protons per step to achieve the highest quality optical surfaces. Typical proton currents for the used 125µm beam diameter are 160pA. Due to the finite beam size of 125µm, there is some rounding at the corners of the component but this does not affect its functionality.

Figure 1: Schematic working principle and fabricated inter-plane coupling components with preservation of propagation direction (a,b) and with inversion of propagation direction (c,d).

Figure 2: Polished output facet of a two-layer optical waveguide structure integrated on a PCB.

Although DPW is not a mass fabrication technique as

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 step³. This way, the component can be mass-produced at low cost in a wide variety of high-tech plastics.

Experimental characterization

For the characterization of the critical optical surfaces of the component, namely the entrance and exit facet, we use a WYKO NT-2000 non-contact optical surface profiler (Veeco). Since the micro-mirrors themselves are not accessible with the microscope objective, these surfaces were not measured, but their surface roughness will be analogous to the two others. The surface profile analysis reveals 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 $46\mu\text{m}$. We averaged at least 5 measurements of randomly chosen positions. The flatness R_t or peak-to-valley difference along the depth of $500\mu\text{m}$ of the component is measured to be smaller than $2.5\mu\text{m}$. This R_t is due to the scattering of the protons during the interaction with the PMMA. In summary, we can say that our developed DPW surfaces have a very good and reproducible optical quality: almost flat and featuring a very low RMS roughness.

Loss measurements have been carried out on the inter-plane coupler with preservation of propagation direction. A multimode fiber (MMF) with a $50\mu\text{m}$ core and a numerical aperture (NA) of 0.2 was used at the input side, whereas a $100\mu\text{m}$ 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 first prototype DPW inter-plane coupler in between, as shown in Figure 3, 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 2-D scan of the output fiber is shown in Figure 4. The resulting -1dB tolerance range is $\pm 25\mu\text{m}$.

Conclusions

We have presented two complementary configurations of pluggable inter-plane couplers 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. The first loss measurements are very promising, especially in view of the possible enhancement by applying a metal reflection coating or by integrating micro-lenses.

Figure 3: Experimental characterization set-up for coupling efficiency measurements

Figure 4: 2-D tolerance scan for mechanical misalignments of the output fiber

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