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Multilayer optical interconnections integrated on a printed circuit board

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A two layer optical structure is presented that forms a basic building block of a two layer optical interconnection. The optical layer contains multimode waveguides, that guide the light in the plane of the optical layer, and out-of-plane turning mirrors, that deflect the light beam vertically out of the plane of the optical layer. Laser ablation is used for the definition of both waveguides and micro-mirrors. The interest in multilayer structures is driven by their ability to fully use the functionalities of 2D opto-electronic elements such as VCEL and photodiode arrays.

Introduction

Optical interconnects have gained interest worldwide over the last years in view of their ability to offer a possible solution to the bandwidth problems associated with electrical interconnects. Electrical interconnects suffer from problems such as frequency dependent loss, EMI and crosstalk at high data rates that limit the available bandwidth [1], and become the main bottleneck on the performance of systems. Optical interconnects, which have proven their potential in long-haul high-speed communication systems, transport data faster, consume less power and transfer data more accurately at high data rates.

The integration of optical interconnects to the board-level, covering distances from a few centimeters to a couple of meters, is very challenging. One possible approach that can be followed for the adoption of optical interconnects to the board-level is the integration of optical fibers on top of a printed circuit board (PCB) [2]; boards based on this solution are commercially available but are quite expensive and expendable. Another possible solution that is studied by groups worldwide is the integration of an optical layer inside or on top of a PCB. The optical layer contains optical waveguides and possibly also other passive optical structures. Since PCBs will continue to be the most important components of electronic equipment, compatibility with the existing PCB manufacturing and soldering processes is needed in order to create a cost-effective solution. This implies that the material used for the optical layer has to withstand the increased temperature and pressure that arise during lamination and soldering processes.

The interest in multilayer structures is driven by their ability to fully use the functionalities of 2D opto-electronic elements such as VCEL or photodiode arrays. We study a two layer optical structure that contains optical multimode waveguides, which guide the light in the plane of the optical layer, and micro-mirrors, which deflect the light vertically out of the plane of the optical layer. This two layer optical structure forms the basic building block of a two layer optical interconnection.

Laser ablation

Different technologies are available for the structuring of the optical layer such as embossing, UV-lithography, laser direct writing and laser ablation. Each of these technologies has its own advantages and limitations which make it suitable for specific applications. In

this paper, laser ablation is presented as enabling technology for the structuring of micro-optical elements in the optical layer applied on top of an FR4 substrate. Laser ablation is a flexible, maskless technology that can be used for the structuring of a large variety of materials, depending on the used laser source. It can be used for fast prototyping, as opposed to mask-based technologies where a mask first has to be designed and fabricated. Changes/corrections can be made to the top surface of the sample in a very late phase of processing. Laser ablation is fully compatible with standard PCB manufacturing and is already used for the laser drilling of micro-vias in high density electrical boards. The technology can be used for the definition of all functional elements of an optical interconnect into the optical layer: multimode waveguides, coupling structures, micro-lenses and alignment features [3].

The ablation set-up available at our institute contains three different laser sources: a KrF excimer (248 nm), a frequency tripled Nd YAG (355 nm), and a CO₂ (9.6 μm) laser. The availability of these different sources allows us to structure a large variety of materials such as polymers, metals and ceramics. The excimer laser beam can be tilted, which eases the definition of angled facets considerably. The sample is during the processing placed on a computer-controlled translation stage, which has an accuracy of 1 μm. The three laser sources are available on the same set-up; a high alignment accuracy can be achieved even when different sources are used for the patterning of the optical layer because the sample can stay on the same stage during the processing.

The photon energy emitted by the laser source is absorbed by the material. As soon as the photon density exceeds a certain threshold, the photon energy can be used for material decomposition. An ablation plume is formed, which contains both evaporated and non evaporated particles. The non evaporated fraction will drop back to the surface in or near the ablated area, forming debris. The deposition of debris is highly undesirable viewing the fact that it increases the surface roughness and thus the scattering loss of the optical component. A clean ablation, with a low deposition of debris, is possible when the material efficiently absorbs the wavelength emitted by the laser source. Polymer materials show a high absorption in the UV range and are therefore ideal candidates for UV excimer laser ablation.

Application of the optical layer

The material used for the optical layer, Truemode BackplaneTM Polymer, is a highly crosslinked acrylate based material and is commercially available (Exxelis Ltd.). It shows excellent optical and thermal properties and is fully compatible with existing PCB manufacturing and soldering processes. The material shows a high absorption in the UV, which allows for a clean ablation. The surface roughness of the structured optical components is by preference as low as possible in order to limit the scattering loss. The material is first spincoated on the FR4 substrate; the applied layer is in a next step cured through UV exposure under a nitrogen environment and then postcured in a convection oven. After the described procedure, the material is fully cured and ready to be ablated. The optical layer contains three layers: a lower cladding layer, a core layer and an upper cladding layer. The refractive index of the cladding material has to be smaller than the one of the core material in order to guide the light in the core layer.

The Truemode material has a low viscosity; a low spinspeed is therefore needed for the application of relatively thick layer (≈50 μm). Some edge bead problems are experienced

Propagation loss	$\leq 0.04\text{dB/cm @ } 850\text{ nm}$
Degradation temperature	350°C
Glass transition temperature	180
Coefficient of thermal expansion	60 ppm/K

Table 1: Most important properties of Truemode BackplaneTM Polymer.

because of this, causing a certain inhomogeneity in the thickness of the layer across the sample, especially at the edges; the exact thickness of a layer is also difficult to reproduce. The material is however an interesting candidate for the optical layer because of the excellent ablation behavior. The most important properties of the Truemode material are given in Table 1.

Multimode optical waveguides

The KrF excimer laser is used for the definition of multimode waveguides, which guide the light in the plane of the optical layer. The excimer laser beam is sent through a rectangular aperture and projected onto the sample with an optical projection system. The waveguides are defined into the core layer by removing material on both sides of the waveguide core. The top cladding layer is then applied and cured. The alignment between the waveguides in top and bottom optical layer is achieved with the help of alignment marks that are ablated into the FR4 substrate. The obtained results are shown in Fig. 1. The alignment between the waveguides in top and bottom optical is ok; the cross-section of the waveguide cores shows a good correspondance. As can be seen in the middle picture, the thickness of the core layer in top and bottom optical layer is not identical. This is a consequence of the low viscosity of the material, which makes it difficult to reproduce the thickness of a layer.

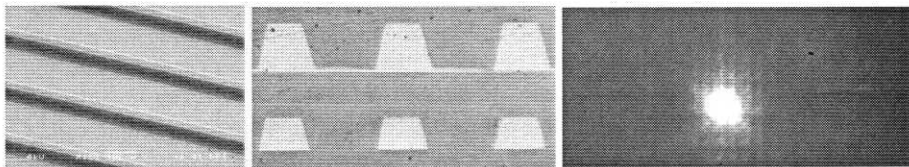


Figure 1: The left picture shows an SEM image of an array of ablated waveguide cores; in the middle picture, the cross-section of a two layer waveguiding structure is shown; in the right picture, a light spot is coupled out of a laser ablated waveguide.

Out-of-plane turning mirrors

The multimode optical waveguides guide the light in the plane of the optical layer. In order to couple the light vertically out of the plane of the optical layer, for instance towards a fiber array or a photodiode array, 45° micro-mirrors are used. Two possible configurations can be used: one that is based on total internal reflection (TIR), and one that makes use of a metallized 45° facet. Both configurations are schematically presented in Fig. 2, a picture of a realized mirror is also shown. The TIR mirror is based on the TIR that occurs

at the polymer-air interface. Only one processing step is required for the definition of the this mirror. Three processing steps are required for the fabrication of the metallized 45° facet: first the 45° facet is ablated into the optical layer, the facet is then metallized and in a next step the ablated area is filled with cladding material. A cross-section of a TIR mirror in a two layer optical structure and of a metallized 45° mirror are shown in Fig. 2. The pitch between the outcoupled spots is in the case of the TIR mirror determined by the thickness of the cladding layers between the core layers. It can be chosen according to wish when the metallized 45° facet is used. As can be seen in the picture, the ablated area is well filled with cladding material.

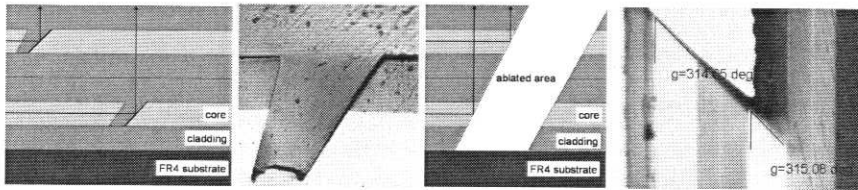


Figure 2: The left picture shows the use of a metallized 45° facet for out-of-plane coupling, in the right picture the outcoupling of the light is done with a TIR mirror.

Conclusions

Multimode waveguides and out-of-plane turning mirrors are defined into a two layer optical structure by means of excimer laser ablation. The fabricated structure forms a basic building block of a two layer optical interconnection. In the future, work will be further carried out on the improvement of the homogeneity and reproducibility of the applied Truemode layers. The alignment between the waveguides in top and bottom optical layer will be further studied and improved.

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