Laser Ablation as Enabling Technology for the Structuring of Optical Multilayer Structures

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Abstract. In this paper, laser ablation is presented as a versatile technology that can be used for the fabrication of all building blocks and functional elements required for an optical interconnection, integrated in printed circuit boards (PCBs). The integration of optical interconnections in PCBs is an emerging field in which interest worldwide is rapidly growing. The limiting factor is mainly the compatibility of new technologies, used to define and fabricate the optical interconnections, with standard FR4-processing steps, temperatures and lamination pressures. Laser ablation, which is currently frequently used for the drilling of electrical micro-vias in PCBs, has proven to be fully compatible with standard PCB manufacturing. An optical two layer structure is studied that can make full use of the functionalities of 2D elements such as VCSEL or photodiode arrays.

1. Introduction
It is predicted that the increase in microprocessor clock rate will create bandwidth limitations for copper interconnects on printed circuit boards (PCBs) due to signal attenuation, electromagnetic interference/compatibility problems, and crosstalk [1, 2]. Optical interconnections may overcome some of the bandwidth limitation of electrical interconnects on conventional PCBs. In long haul high-speed communication systems, fibre optic links dominate over copper wires due to the superior bandwidth-distance performance of the optical channel. However, as distances become shorter, copper-based interconnects become the dominant solution because they are simpler, cheaper and reliable. Since PCBs will continue to be among the most important components of electronic equipment, compatibility with the standard PCB manufacturing processes is required in order to be able to create a cost-effective solution.

We study the use of a polymer optical layer, which contains waveguides and other passive optical elements, integrated on a PCB [3]. Laser ablation is used for the structuring of multimode waveguides and coupling structures into the optical layer. The technology is compatible with standard PCB manufacturing and is already used for the drilling of micro-vias in high density electrical boards.

2. Laser ablation as micromachining technology
KrF excimer laser ablation is used for the structuring of an acrylate-based highly cross-linked optical polymer, Truemode Backplane™ Polymer (Exxelis Ltd.). The material shows excellent optical and thermal properties and is fully compatible with PCB manufacturing and soldering processes [4]. The KrF laser beam can be tilted (0°-45°), which eases the ablation of angled structures such as 45° micro-
mirrors. During the processing, the sample is placed on a computer-controlled translation stage which has an accuracy of 1µm. The laser beam is send through a rectangular aperture and projected onto the sample with a demagnification of 10. Multimode optical waveguides, which guide the light into the plane of the optical layer, and 45° micro-mirrors, which deflect the light beam over 90°, are ablated into the optical layer.

2.1. Optical multimode waveguides
The waveguides are patterned into the cured core layer by ablation of material on both sides of the waveguide core. The laser beam is send through a rectangular mask with dimension 750µm×3000µm and projected onto the sample, which is moved with respect to the laser beam. The waveguide cores have a cross-section of 50µm×50µm; the pitch is determined by the shift of the laser beam. Arrays on a pitch of 250µm and 125µm have been studied. In the next step, the waveguide core features are covered with cladding material by spincoating and followed with UV curing. The refractive index of respectively core and cladding material is 1.5563 and 1.5266. The pulse energy of the excimer laser has been optimized in order to minimize the surface roughness, and thus scattering loss, of the waveguide core. The best results were obtained for pulse energy of 3mJ and frequency 200Hz. The waveguide cores were ablated at a speed of 360µm/s. The surface roughness of the ablated waveguide core, measured with a non-contact optical profiler (Wyko NT-3300), is shown in figure 1a. The average RMS surface roughness is 26nm ± 4nm.

2.2. 45° micro-mirrors
The excimer laser beam was tilted for the structuring of 45° micro-mirrors. During the ablation, a cavity was formed that has both a facet with a negative and positive slope which can both be used to deflect the light beam over 90°. There is always a certain degree of tapering that can be measured experimentally. The taper angle has to be added or subtracted in order to get a 45° positive or negative facet, respectively. The use of the negative facet as a mirror is based on the total internal reflection (TIR) that occurs at the polymer-air interface. The structuring of this mirror configuration requires only one processing step. The use of the positive facet as a mirror requires the evaporation of a thin Au coating on the 45° facet, to ensure a high reflectivity, and the filling of the ablated cavity with cladding material. The mirrors were ablated with pulse energy of 3mJ and frequency 200Hz. The 45° positive facet ablated with these parameters has an average RMS surface roughness of 62nm ± 6nm, as shown in figure 1b.

Figure 1. Optical profilometer images showing the surface roughness of (a) an ablated waveguide core and (b) laser ablated 45° facet.
3. Two layer optical structure
The interest in multilayer structures is driven by their ability to increase the interconnection density, ease the interconnection scheme and the availability of 2D opto-electronic components. We studied a two layer optical structure, which consists of a stack of two optical layers containing optical waveguides and micro-mirrors, integrated on a PCB. The alignment tolerance between waveguides and micro-mirrors in the top and bottom layer will be studied numerically in the near future.

3.1. Optical multimode waveguides
The alignment between optical waveguides in top and bottom layer was done with alignment marks, placed on the FR4 substrate. The waveguides in the top and bottom layer were ablated with the same ablation parameters (3mJ, 200Hz, 166 pulses). The experimental results are shown in figure 2.

Figure 2. The left picture shows an SEM image of a patterned core layer, waveguide cores have cross-section 50µm×50µm on a pitch of 250µm; the right picture shows a cross-section of a two layer waveguiding structure on a pitch of 125µm.

3.2. Total internal reflection mirror.
In figure 3, a cross-section is shown of a TIR mirror that is defined in a two layer structure. The pitch between the outcoupled spots is determined by the thickness of the cladding layer between the two core layers and can in this way be changed to the desired value.

3.3. Metallized micro-mirror.
Another possibility for out-of-plane coupling is the use of a 45° metallized positive facet. The facet is ablated in top and bottom layer separately. The structuring of the metallized mirror requires three processing steps: ablation of the 45° facet, Au coating of the facet and filling of the ablated area with cladding material. The advantage of these mirrors is the fact that the pitch between the outcoupled spots can be changed to any desired value. In figure 4, a cross-section is shown of a metallized mirror.

Optimization of the metallization process is needed, since the adhesion between the Au-film and the Truemode™ material is not optimal. As can be seen on the microscope image, the Au-film covers the bottom of the ablated area and the lower part of the 45° facet. Some part of the film on the upper
part of the facet is removed with the lift-off process. There is a good filling of the air gap that is created during the ablation with the cladding material.

4. Conclusions
Laser ablation is a very flexible technology that can be used to structure the basic building blocks of an optical interconnection, multimode waveguides and 45° micro-mirrors, into a polymer optical layer, integrated on a PCB. The big advantage of using laser ablation is that it is compatible with the existing processes used in the high-end PCB industry for the drilling of micro-vias. First test results look promising, but need further optimization. The metallization of the 45° positive facet will be studied further and extended to a two layer optical structure. A numerical study will be done to determine the alignment tolerance between waveguides and micro-mirrors in top and bottom optical layer. The experimental results will be compared with the results obtained from the numerical study.

![Figure 4](image)

Figure 4. The left picture shows the cross-section of a TIR mirror in a two layer optical structure; the right picture shows the cross-section of a 45° metallized micro-mirror.

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