Laser Ablated Micromirrors for Optical Printed Circuit Boards

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In this paper we present laser ablation as a versatile technology for the fabrication of high quality 45° micromirrors for optical printed circuit boards. These 45° total internal reflection micromirrors fabricated within the waveguides provide surface normal light coupling between waveguide and optoelectronic device. This opens the way towards a fully embedded three-dimensional optoelectronic interconnection. The mirrors are defined using a KrF Excimer laser or a CO_2 laser depending on the material, i.e. whether the waveguides are defined in polymer layers or in glass sheets. We analyze surface roughness and demonstrate the reproducibility of the fabrication process.

Introduction

In recent years a continuous increase of the microprocessor clock rate could be observed. This performance can be totally used only if the off-chip interconnection technology provides an appropriate bandwidth. As known from long haul telecommunication technology optical data transmission provides a lot of advantages over electrical solutions. Apart from data rates in the Gb/s-range also a significantly improved EMC behavior belongs to the main advantages of optical interconnects. The integration of optical interconnects on the PCB and backplane level requires compatibility with the established manufacturing and assembly processes of the conventional electrical board technology. In spite of repeated predictions that the optical interconnect is soon going to replace the electrical interconnect on the board level, this turned out not to be yet the case.

Fiber based interconnections are already available, but the fiber-in-board approach cannot lead to a practical solution as it results in expendable assembly processes being unsuitable for high volume production at reasonable costs. A better solution is the realization of optical layers containing the optical waveguides as well as all passive optical structures [1]. Since printed circuit boards will continue to be among the most important components of electronic equipment, there are a lot of research activities on developing low-cost and robust manufacturing technologies for implementing optical waveguides on PCB and backplane level.

One of the most critical problems is coupling the light in and out of the optical plane, using 45° micromirrors. There are various techniques to fabricate these micromirrors. Micro machining techniques using a 90° V-shaped diamond blade [2] can provide an excellent cut surface, but due to the physical size of the machining tool, it is difficult to cut individual waveguides on the same substrate. Reactive ion etching RIE [3] where the slope of the mirror is formed by 45° oblique etching is limited by directional freedom. Temperature controlled RIE [4] is not limited by directional freedom but this method has the disadvantage of being material dependent. In this paper we present laser ablation as a versatile technology for the fabrication of the micromirrors. We use a KrF Excimer laser or a CO_2 laser depending on the material, i.e. whether the waveguides are defined in polymer layers or in glass sheets.

Board level optical interconnects

A cross section of the board level optical interconnection is schematically shown in Fig.1. The optical layers are placed on top of the board, but can also be laminated in the board. The total internal reflection (TIR) mirrors are formed at both end facets of the 50 x 50 μm^2 square waveguides to deflect the beams vertically towards the MT-based connector. Microlenses, defined in a 250 µm thick polycarbonate (PC) plate, are fabricated to focus the optical beams and consequently minimize coupling losses towards the fiber ribbon. In this paper, we focus on the fabrication of the micromirrors. Although, the entire optical interconnection can be fabricated using laser ablation [1].

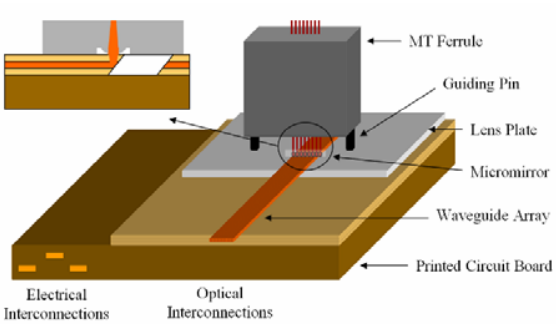

Fig.1. Cross-sectional schematic diagram of the optical interconnection

Laser Ablation

The PCB containing the optical layers is positioned on a high accuracy x-y translation stage (1 µm motion resolution). Sample motion and laser beam handling is fully computer controlled. The pulsed laser beam is focused on the sample, and the impact of the high-energy beam ablates material from the substrate. The material is removed by photo-dissociation or by photo-thermal ablation.

Attenuation	0.06 dB/cm at 633 nm
	0.20 dB/cm at 1320 nm
	0.50 dB/cm at 1550 nm
Decomposition temperature	270 °C
Index tuning range	1.5306 to 1.5475 at 830 nm
Good adhesion to	FR4
(crosshatch ASTM D 3359, tape test)	most oxidized surfaces
Water absorption	< 0.5 %
CTE (20 - 100 °C)	100 - 130 ppm/K
Shrinkage during curing	2 - 8 Vol.%

TABLE I
SELECTED PROPERTIES OF ORMOCER®-MATERIALS FOR OPTICAL APPLICATIONS

Polymer layers

Within the range of polymers that can be used for the optical layer, we have chosen the use of silicate-based inorganic-organic hybrid polymers (ORMOCER®s) [5]. The ORMOCER®-material is a registered trademark of the Fraunhofer-Gesellschaft, Germany and is commercially available. The most important properties of the ORMOCER®-materials to be used for board-level optical interconnects are listed in TABLE I.

KrF excimer laser ablation (wavelength 248 nm) is particularly well suited for structuring of polymers because of their excellent UV-absorption properties and highly non-thermal ablation behavior. In our setup, the excimer laser beam can be tilted by simply changing the angle of a turning mirror. Each facet is fabricated by sending the laser beam through a rectangular aperture that is projected on the sample. The micromirrors are based on TIR at the interface between the ORMOCER®-material and the air gap (left part of Fig. 2, negative facet). It can be seen that using the excimer laser, there is always a certain tapering of the edges, depending on the ablation settings. However, this tapering can be measured and as it is highly reproducible, this effect can be compensated for in order to realize an angle of 45° at the negative facet. Table II gives an overview of the ablation parameters. The light beam reflected at the out of plane turning mirror is given in Fig. 3.

The right part of Fig. 2 shows a WYKO plot (non-contact optical profiler, available in the Department of Applied Physics and Photonics, Vrije Universiteit Brussel) of such a laser ablated micromirror. The Ra roughness of the mirror is 80 nm and the RMS roughness 110 nm, with good reproducibility.

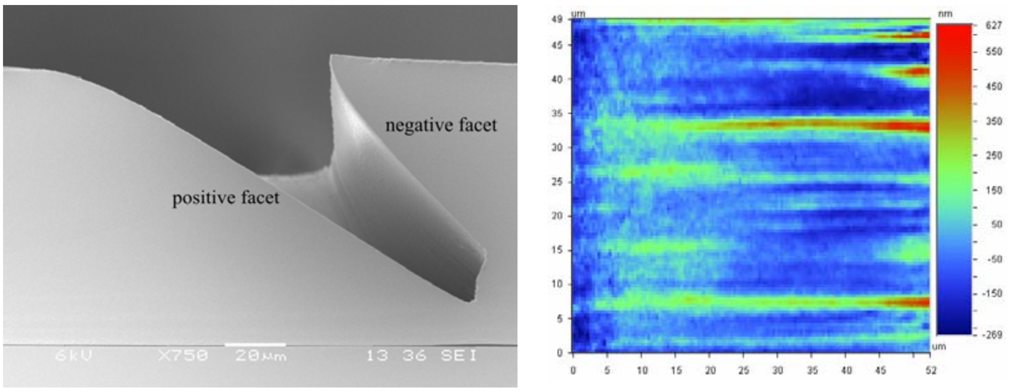

Fig.2. Micromirror fabricated in ORMOCER® using excimer laser ablation. Left: SEM picture of cross section. Right: WYKO plot to analyze surface roughness

Fluence	5 ± 0.5 J/cm^2
Repetition Rate	200 Hz
Number of pulses	200
Fabrication time	1 sec
Tapering	9°

TABLE II
PARAMETERS FOR EXCIMER LASER ABLATION OF A 45° MICROMIRROR IN ORMOCER®

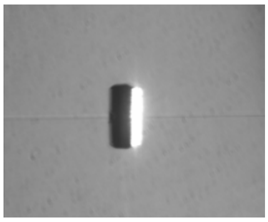

Fig.3. Light reflected at out of plane turning mirror

Glass sheets

In the glass-layer-concept the polymer optical layer is replaced by a glass made one. The thin glass sheet (D 263 T, supplied by Schott) can be used as an optical layer with multimode waveguide structures [6-7]. The advantage is that the waveguides are of high thermal reliability and low loss.
The CO_2 laser light (wavelength 9.6 µm) is strongly absorbed in glasses, allowing photo-thermal ablation. In Fig. 4 a SEM picture of such a laser ablated micromirror is shown. The surface roughness is not yet measured, but as can be seen, the surface of the mirror is very smooth.

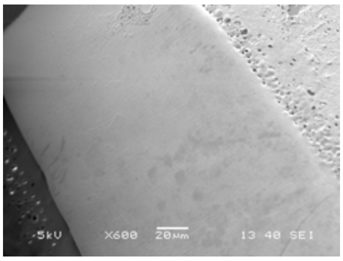

Fig.4. SEM picture of a micromirror fabricated in a 100 µm thick glass sheet using CO_2 laser ablation

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