Integration of multimode waveguides and micromirror couplers in printed circuit boards using laser ablation

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Abstract

Integration of optical interconnections on a Printed Circuit Board (PCB) is very challenging, as it should remain compatible with existing PCB manufacturing technology. We will describe the use of laser ablation, already used in PCB manufacturing for microvia's, as a suitable technique for the fabrication of multimode waveguides and micromirrors to provide optical coupling. The focus is on ablation of waveguides using a frequency tripled Nd-YAG laser and on ablation of 45° facets using a KrF excimer laser. It is shown that these structures can be defined in one single processing step, resulting in a very accurate alignment.

Introduction

In present and future broadband networks, multi-gigabit transmission over longer distances is only feasible via optical interconnections that form the very heart of the network. Worldwide ongoing research aims at the extension of the optical interconnect to the board level and to the switching level. In spite of repeated predictions that the all optical interconnect is soon going to replace electrical interconnect on the board level, this turned out not to be yet the case. Integrating optical interconnections on a board level, covering distances from a few centimeters to a few meters is very challenging as the optical interconnection and mounting technology has to be integrated in existing PCB manufacturing technology.

Fiber based interconnections are already available [1]-[2]-[3], but new solutions for integrating a guided wave based optical interconnection layer in a standard FR4-based electrical PCB are emerging [4]. These technologies are based on either organic materials or glass sheets integrated in the FR4-stack. Within the range of materials that can be used for the optical layer, we have chosen for the use of ORMOCER®-materials (inorganic-organic copolymer) in view of their temperature stability, optical & planarisation properties, manufacturability,… The ORMOCER®-material is a registered trademark of the Fraunhofer-Gesellschaft, Germany and is commercially available [5]-[6]. Typical losses for waveguides fabricated in these materials are 0.06 dB/cm at 633 nm, 0.20dB/cm at 1320 nm and 0.50 dB/cm at 1550 nm.

The technique we propose here for the fabrication of the optical interconnects is the use of laser ablation [7], all ready being used in PCB manufacturing for the drilling of microvia's. This means that the optical interconnection technology is fully compatible with standard electrical PCB manufacturing which is an important advantage comparing to other technologies. The technique is already well known since many years. Early experiments indicated an excellent control over the ablation depth by varying the number of laser light pulses. Despite the wide range of applications, to our knowledge, this technique has not been proved so far for patterning optical layers to form optical waveguiding structures.

Experiments

Laser ablation is a very flexible technology that is particularly well suited for structuring of polymers because of their excellent UV-absorption properties and highly non-thermal ablation behavior. The entire optical interconnection can be fabricated using one technology. A frequency tripled Nd-YAG laser working at 355 nm is used for the definition of the waveguides, a KrF excimer laser working at 248 nm for the fabrication of the 45° micromirrors to provide surface normal coupling.

Fig. 1 shows a cross sectional view of a PCB containing an optical waveguide layer. Waveguides are formed using photolithography and have a square shape of 20 μm x 20 μm arranged at 250 μm pitch. What we intend to do, is to replace the UV-defined waveguides by laser-ablated waveguides. Laser ablation allows adapting the pattern as a function of distortion and shifts in the pattern. Such distortion is frequently encountered when defining patterns on FR4-susbtrates as these materials tend to show torsion and deformation during lamination of the stack.

SEM (scanning electron microscope) was used for visual inspection of both the waveguides and the micromirrors. Surface roughness measurements or optical loss measurements are subject for future work.

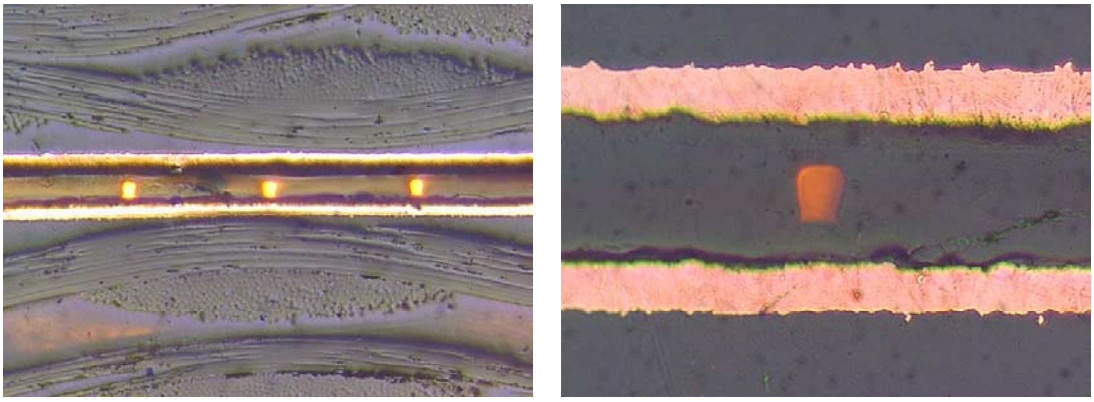
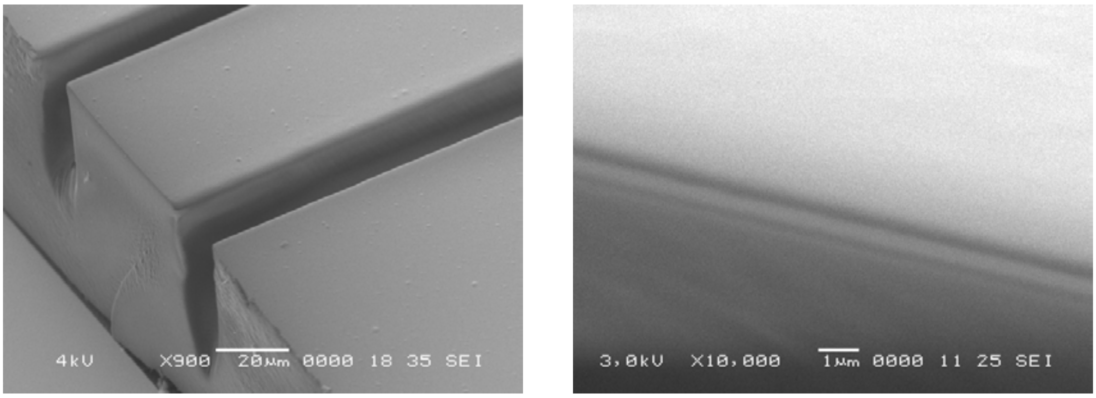


Fig.1. Cross sectional view of a PCB containing an optical waveguide layer.

Results

Optical waveguides

Fig.2a shows a SEM picture of a laser-ablated waveguide (50 μm x 50 μm), using a frequency tripled Nd-YAG laser working at a wavelength of 355 nm. The laser beam is focussed on the sample and moved over the surface. The beam is pulsed and of high energy and the impact ablates material from the substrate. The material is removed by photo-dissociation on both sides of the resulting waveguide. After ablation of the waveguide, the upper-cladding layer can be deposited. The ablation speed is in the range of 1 mm per second, acceptable for the fabrication of large boards. Clean surfaces were obtained after optimizing ablation parameters; energy and frequency of the pulsed laser beam have a critical impact on the smoothness of the waveguide sidewall (Fig. 2b). Because of the higher wavelength of the laser (Nd-YAG at 355 nm compared to KrF excimer laser at 248 nm) additional thermal effects seem to be important in order to get a smooth surface.



(a) (b)

Fig.2. (a) Laser-ablated waveguide using a frequency tripled Nd-YAG laser, terminated by cleaving the GaAs substrate. (b) Sidewall roughness.

Excimer laser ablation seems to be less suited for the definition of the waveguides because of the lower ablation speed, the trapezoidal shape of the waveguide (Fig. 3), and the higher surface roughness.

Deflecting optics

One of the most critical problems on the integration of optical interconnections in PCB's is coupling the light in and out of the optical plane. Because in our set-up the excimer laser beam can be tilted, the 45° micromirrors can be easily fabricated using laser ablation. Each facet is fabricated by sending the laser beam through a rectangular aperture that is projected on the sample. The facets are based on total internal reflection at the interface between the ORMOCER®-material and the air gap. Fig.4 shows a SEM picture of a facet fabricated on a GaAs substrate (ease of cleaving for inspection under SEM). It can be seen that using the excimer laser, there is always a certain tapering of the edges, depending on the ablation settings and on the material being ablated. However, the tapering can be measured and there can be compensated for this effect. Fig. 5 shows that the angle of 45° can be achieved accurately.

Fig. 6 and Fig. 7 show pictures of light spots radiated from out-of-plane branching mirrors. Red light (630 nm) was used for demonstration purposes only.

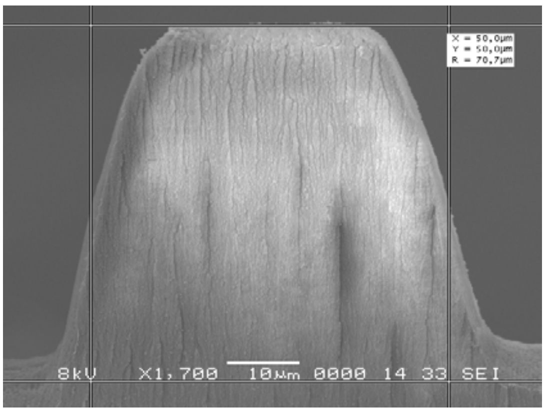


Fig.3. Trapezoidal shape of a laser-ablated waveguide using a KrF Excimer laser.

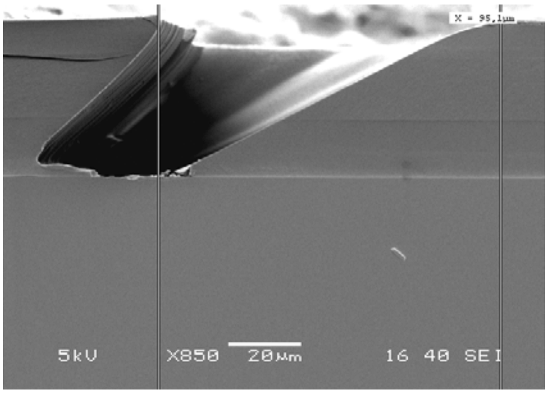


Fig.4. Cross section of TIR micromirror.

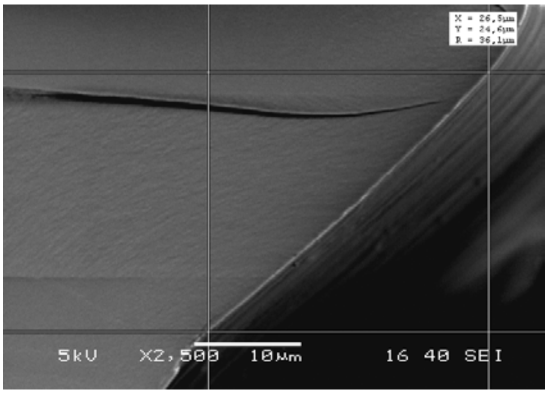


Fig.5. Closer view on the angle of 45°.

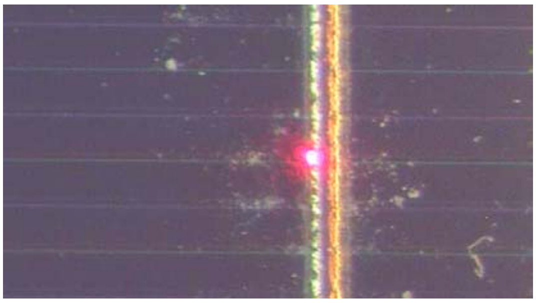


Fig.6. Light spot deflecting at out-of-plane branching mirror on GaAs substrate

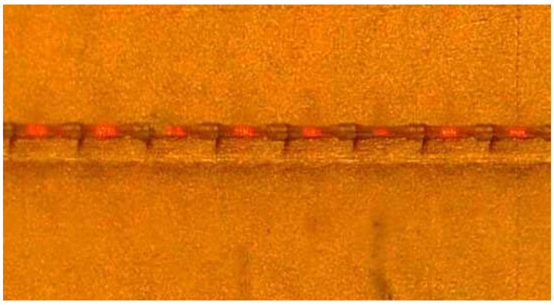


Fig.7. Light spots deflecting at an array of out-of-plane branching mirrors on FR4 substrate

Conclusion

We have fabricated laser-ablated optical interconnections integrated on a standard PCB. Both the waveguides and the micromirrors can be defined using laser ablation; SEM pictures show very smooth surfaces. Future work includes both measurements of the surface roughness and loss measurements at 850 µm.

References

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