Optoelectronic Printed Circuit Board Realised by Two Photon Absorption

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Abstract— The integration of optical interconnections onto PCBs (printed circuit boards) is an emerging field that arouses rapidly growing interest worldwide, due to a continuously increasing demand for high data rates, along with a progressive miniaturization of devices and components. For high-speed data transfer, materials and integration concepts are required for which enable high-speed short-range connections.

An innovative approach is presented which shows the fabrication of optical waveguides by TPA (two-photon absorption) processes. In contrast to one-photon absorption, which only allows a two-dimensional respectively lateral modification of a polymer, this technology allows a modification within the volume resulting in 3D-microstructures inside the polymer layer. Embedded opto-electronic components can easily be connected to corresponding waveguides and thereby bypassing expensive and time consuming active alignment processes. Recent experiments demonstrated 3-dimensional crossing waveguides transmitting data rates exceeding 6 Gbit/s.

Keywords: Optical waveguides; optical printed circuit board; two-photon absorption; integration

I. INTRODUCTION

Handheld devices like mobile phones, personal digital assistants, and mobile television sets are more and more equipped with features requiring high data rate wireless transmission in the high Mbit/s to low Gbit/s range. This includes still cameras, video cameras, mobile TV applications, multi-band transceivers, and others. Accommodating these features in the small volume dictated by the mobile phone drives the need for miniaturization and integration in all parts of the electrical design.

To accommodate the increasing data transfer, the number of flexible parallel copper lines for board-to-board connection is increasing. However, the mechanical design of equipment is constrained in case of a large number of parallel line paths. In order to relieve them, serialization of lines is inevitable. Some leading serialization interface standard committees like MDDI (Mobile Display Digital Interface) and MIPI (Mobile Industry Processor Interface) [1] are acting rigorously towards their own standard.

In clam-shell or slide-type mobile phone, one tries to merge several tens of parallel interface lines between main and user interface PCB (printed circuit board) into several serial interface lines in order to manage mechanical and signal line complexity problems. Therefore, the maximum data rate in one serial line can be as high as several Mbps today and might reach the Gbit/s range in the near future, depending on the quality and the pixel size of the display. However, electrical lines face EMI problems in connection with nearby antennas or ICs (Integrated Circuits). They may also suffer from a speed limit due to connector or line impedance mismatch on the flexible PCB (Printed Circuit Board). Today it is common sense, that optical interconnections can be considered a promising technology to solve all above mentioned problems.

II. EXPERIMENTAL

A. *TPA structuring of waveguides*

TPA (two-photon absorption) processing [2] was used for the fabrication of multimode waveguides [3] using an acrylate-modified inorganic-organic hybrid material [4] (modified ORMOCER®). A pulsed femtosecond laser is focused into the ORMOCER® layer previously applied to the PCB substrates. The material's absorption at the laser wavelength is low, thus enabling the fabrication of high precision structures deep below the layer's surfaces. The photon density within the focal volume is high enough to initiate an organic cross-linking of the acrylate groups. This results in solid structures embedded in the non-exposed material. The structures show a higher refractive index than the surrounding material and form the waveguide core. The waveguide formation process is subsequently completed by thermal treatment of the sample. Fig. 1 shows the circular cross-section of TPA-structured waveguides written into an ORMOCER® layer, as obtained by optical microscopy. The waveguides were written with different laser intensities, leading to different cross-section diameters.

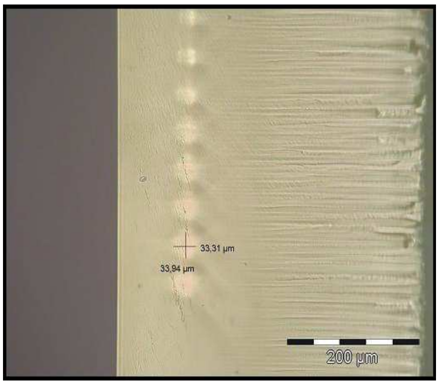

Figure 1. Cross-section of a number of waveguides written by TPA into an ORMOCER® layer

B. *Integration concept*

Fig. 2 shows an experimental PCB with integrated optical interconnections. VCSELs (vertical-cavity surface-emitting lasers) are mounted upright on the die edge facing to the right and emitting light at a wavelength of 850 nm parallel to the substrate surface. On the right hand side photodiodes are mounted upright on the die edge facing the VCSELs. Both components are embedded in a 300 µm thick ORMOCER® layer and are connected via a TPA written waveguide, which are directly connected by butt coupling to the optoelectronic components. There is a gap of about 50 µm between the waveguide and the optoelectronic components.

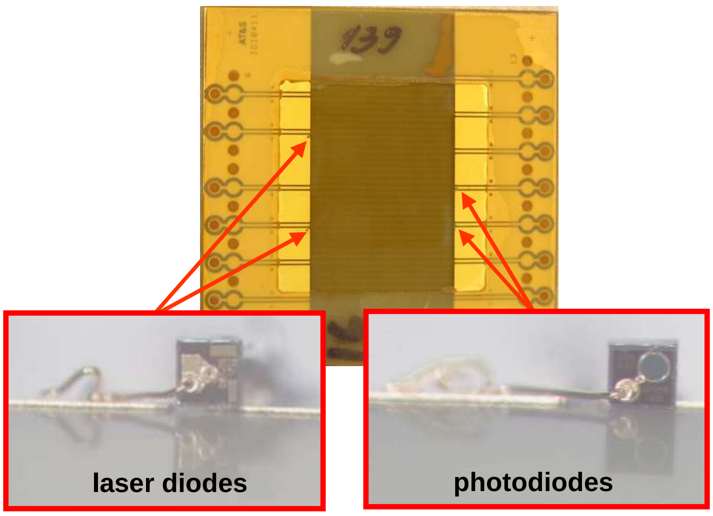

Figure 2. Printed circuit board with integrated optical interconnections. On the left hand side the laser diode and on the right hand side the photodiode chips are mounted. The components are connected by TPA written waveguides

C. *Connection of components*

Before starting the actual waveguide patterning process, a precise 3D registration of the sample is required in order to align the waveguide relative to the active facets of the optoelectronic components [5]. The lateral gauging of the chips, i.e. their x-y position is determined with a CCD camera. Thus, the positions of the laser and the photodiode are registered, the waveguide design is defined, and the ORMOCER® surface along the waveguide path is mapped by monitoring the intensity of the back-reflected light of a He-Ne laser with a photodiode in a confocal setup. The latter method is also used to determine the z-position of each optoelectronic component attached to the PCB substrate (see Fig. 3). With this information available, the starting point, the end point, and the path of the waveguide within the ORMOCER® layer can be defined. The precise 3D registration of the sample is important since otherwise a misalignment of the waveguide and the optoelectronic components would occur, resulting in an inefficient of the light into and out of the waveguides. This would increase the optical losses and thus lead to either a larger number of bit errors or a reduction of the maximum data rate.

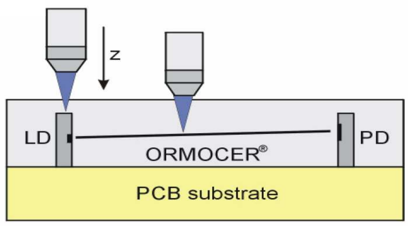

Figure 3. Fabrication principle of an embedded waveguide, written by TPA and connecting a laser diode and a photodiode

III. RESULTS AND DISCUSSION

One major advantage of the TPA process is the ability to write structures in three dimensions into an optical material. Therefore it is also possible to realise waveguides in different depths of the optical layer.

In the specific PCB described here two crossing optical interconnections was realised. One waveguide connects laser diode LD1 and photodiode PD2 while the other connects laser diode LD2 and photodiode PD1, as sketched in Fig. 4. Half way along the board Fig. 4 shows a cross-over. However, the two waveguides do not touch each other, as they are structured at different depths with a distance in z-direction, i.e. in depth, of about 50 µm. Such a design strongly decreases or even avoids any crosstalk between the waveguides.

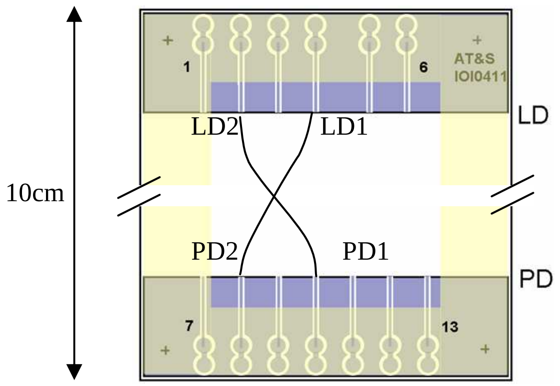

Figure 4. Layout of an PCP with crossing waveguides which are written in different depths and do not touch each other

Bit error ratio (BER) measurements were performed, not only to find the highest possible data rate for the transmission channels of the boards, but also to investigate a possibly detrimental crosstalk caused by the other channel. The bit error ratio was measured with simultaneous data transmission on both channels, in particular when testing the connection LD2-PD1. The data signal to be transmitted was generated by a bit error ratio tester (BERT) and applied to one of the transmission channels. The second laser diode was simultaneously driven by a pattern generator, and the signal received by the second photodiode was fed into a matched termination. The pattern generator was set to the same data rate as the BERT as this should cause the worst-case cross talk. The VCSELs LD1 and LD2 were biased at a current of 6 mA and 5.3 mA, respectively. This yielded DC-photodiode currents of 220 µA and 40 µA at photodiodes PD2 and PD1, respectively. Data modulation was achieved in binary on-off format with a peak-to-peak modulation voltage of 340 mV. The test words used on both channels were uncorrelated pseudo random bit sequences of length 2^{23-1}.

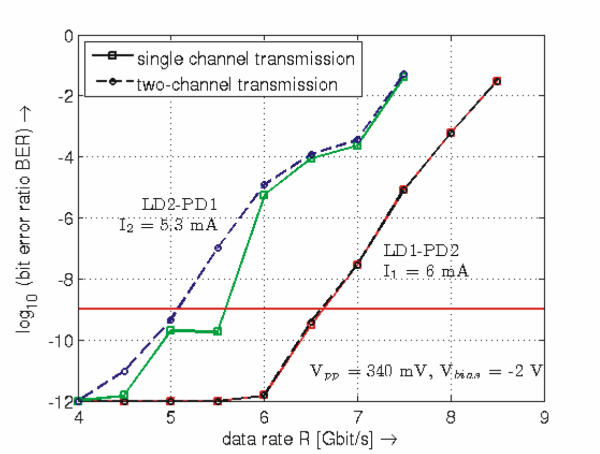

Figure 5. BER vs. data rate for both channels of the PCB with crossed waveguides with and without simultaneous transmission via the second channel

Fig. 5 shows the measurement results for both channels, without and with simultaneous data transmission on the second channel. The impact of data transmission on the second channel is remarkably low. Just at one data rate, namely at 5.5 Gbit/s, the BER of connection LD2-PD1 deteriorated noticeably, however only resulting in a reduction of the maximum data rate from 5.5 Gbit/s to 5 Gbit/s. For the connection LD1-PD2, we found no influence of cross talk. With this connection we could transmit signals with data rates up to 6.5 Gbit/s.

IV. CONCLUSION

The electronic industry is strongly driven by four global electronic trends: (1) Miniaturization, (2) flexibility, (3) reliability and (4) cost reduction. From a PCB manufacture's point of view, the prime and most delicate aspect is the rapidly continuing miniaturization of electronic systems that targets at the reduction of system size and/or the increase in density with respect to functionality. To satisfy this trend we are working on a project dealing with the development of integrated optical interconnections on PCBs.

In this paper an innovative concept for the integration of an optical interconnection system in PCBs is presented. This revolutionary concept is well suited to support the worldwide trend towards miniaturization of not only electronic but also optoelectronic systems in PCBs. The biggest problem that has to be solved for realizing integrated optical interconnections in PCBs, namely the alignment of the optoelectronic components to the waveguides [6], is solved by using a particular waveguide structuring method, two-photon absorption. It is shown that the TPA technique enables structuring waveguides in ORMOCER® in such a way that 3D optical circuits can be integrated into PCBs. We demonstrated data transmission of up to 6.5 Gbit/s at a bit error rate of 10^{-9} at an optical interconnection crossed by a second one with negligible cross talk.

ACKNOWLEDGMENT

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