Intra- and Inter- Board Optical Interconnects by Polymeric Waveguides and Mirror Coupler with Inkjet-printed Micro-lenses

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***Abstract*— We experimentally demonstrate intra- and inter- board optical interconnects utilizing molded waveguides and mirror couplers with inkjet-printed micro-lenses. 10 Gbps Data transmission reveals inter-board interconnects with BER 1.1×10^{-10} and 6.2×10^{-13} without and with micro-lenses, respectively.**

Parallel data transmission through optical means between boards has been demonstrated with complex packaging involving discrete micro and macro lenses and stage-alignment tools [1, 2]. Free-space optical interconnects between VCSELs and PDs placed on separate boards have been demonstrated in which fixed integrated micro-lens arrays [3] or MEMS controlled lens arrays were used to lower optical loss by reducing the beam divergence [4, 5]. In this paper, intra-board and inter-board optical interconnects are demonstrated. Intra-board interconnects are realized using 50 µm×50 µm polymer waveguides. Inter-board coupling scheme is realized by 45 degree mirrors and integrated inkjet-printed micro-lenses. It provides free-space optical interconnects between waveguides located on different boards. The 45 degree mirrors, which are fabricated through molding technique, enable vertical coupling of guided-wave with high efficiency. Inkjet-printed micro-lenses are able to decrease the divergence and increase the quality of the vertical beam collimation.

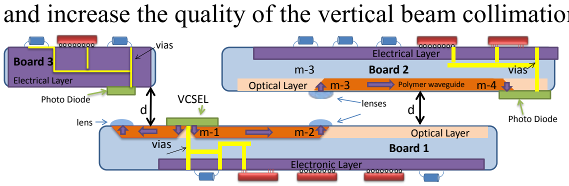

Fig. 1 Inter- and intra-board optical interconnects with polymer waveguides and 45° couplers with ink-jet printed micro-lenses.

A schematic of the presented board-to-board optical communication scheme is shown in Fig. 1. The VCSEL and PD can be controlled by signals transmitted through vias from the electric layer onto the other side of the board. The boards are positioned back-to-back to enable the data transfer via the optical couplers. This technique can be used to couple light between waveguides, i.e., light from a VCSEL into an input waveguide, or light from an output waveguide into a PD. We investigate the optical transmission quality in setups using two mirrors and four mirrors in the optical path. The total loss as a function of different board-to-board separations is also measured. In order to investigate the effects of inkjet-printed micro-lens, insertion loss values with and without the micro-lenses are compared.

45 degree mirror couplers were previously used for integrating VCSELs and PDs in one of PCB board layers by Choi [6] and Wang [7] etc. In this work, we fabricate embedded total internal reflection (TIR) mirrors in a single-step molding process using nickel mold. The fabrication is composed of four main steps: (a) 50µm thick SU8 pre-mold with 45 degree slope shape is fabricated on silicon substrate. Tilted exposure is used as described in [8]. (b) Nickel is electroplated on the SU8 template. Compared to the evaporation/lift-off methods, electroplating is featured by its high deposition rate. A gold seed layer is pre-buried underneath SU8 to enable electroplating process. (c) Molding process: The bottom cladding material WIR30-450 (n=1.45@850 nm) is spin-coated on the substrate precoated with an adhesion promoter. Nickel mold is brought into contact with the bottom cladding followed by Ultraviolet (UV) curing. (d) Waveguide fabrication. After demolding, the molded bottom cladding layer is mounted on the evaporation chamber and 200 nm of gold is coated onto the slope region using a shadow mask to form the reflective mirror. Then, the imprinted trenches are filled with core material WIR30-470 (n=1.47@850 nm) and UV cured for 12 mins followed by coating of the top cladding polymer WIR30-450.

In the present experiment, the optical signal receiving area is about the same size as the output end. Therefore, the light collected is very limited due to divergence and separation between two boards. Inserting a micro-lens in the optical path helps in reducing the divergence angle of output light from the 45 degree mirrors so that more signal can be collected. The micro-lenses have been fabricated based on photoresist melt-and-reflow technique [9]. In this work, the micro-lenses are directly ink-jet printed over the 45 degree mirrors. In our experiment, we use diluted glycerol (glycerol:BPS=3:7 by volume) to form the micro-lens with index of

This work was supported in part by the National Science Foundation. The fabrication and testing facilities at the University of Texas at Austin are supported through NNIN program.

978-1-4673-5063-1/13/$31.00 ©2013 IEEE

1.46556 at 850 nm wavelength. The ink-jet printer used in this work is a Fujifilm Dimatix Materials Printer (DMP-2800). It utilizes a piezoelectric printing cartridge (DMC-11610), which dispenses a nominal volume of 10pL per cycle per nozzle. By specifying the desired printing position, the micro-lens can be placed above the targeted 45 mirror coupler with good accuracy. Fig. 2(a) and Fig. 2(b) show the top view of the mirror before and after inkjet-printing the micro-lens. A contact angle goniometer is used to capture the profile of the droplet, as shown in Fig. 2(c).

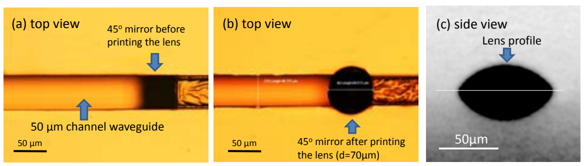

Fig. 2 (a) top view of embedded mirror before printing micro-lens (b) top view of embedded mirror after printing micro-lens with d=70µm. (c) the lens profile taken by contact angle goniometer.

The optical loss is measured and it is found that each 45 mirror coupler contributes 1.888 dB loss to the total loss of the optical path and corresponds to 64.86% coupling efficiency. As shown in Fig. 3(a), when the separation between the two boards increases, the total insertion loss increases. However, each inkjet-printed lens can help reduce the loss by 1.5 dB at shorter separation (1-2 mm) and by 3.7 dB at longer separation (4 mm). Besides, the free space coupling loss due to the beam divergence can also be extracted from the total insertion loss, as shown in Fig. 3(b). For comparison, the loss versus distance result from a previous report that utilized relatively larger lenses (240 µm in diameter) mounted on both the output and input ends [10] is also plotted. The minimum loss presented in [10] occurred at a free space propagation distance corresponding to the confocal length of the two lens system.

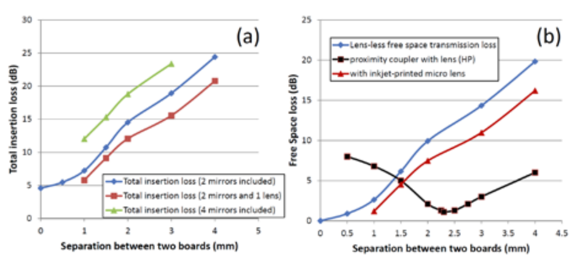

Fig. 3 (a) Total insertion loss with the separation between two boards, when 2 mirrors, 2 mirrors w/lens and 4 mirrors are included. (b) Transmission loss in free space when using 45 degree coupler with/without lens and proximity coupler with lens from [10]

Furthermore, we conduct high speed tests using the samples showing the increase of signal quality with the inkjet-printed microlenses. Light from VCSEL is directly modulated at RF frequencies ranging from 1GHz to 10GHz with random signal level of ±0.3V using Agilent ParBERT 81250 system. The separation between the input and the output boards is varied as before. The Q factors are measured at *d*=0, *d*=1 mm and *d*=2 mm, with and without the inkjet-printed micro-lens, as shown in Fig. 4(a). The corresponding Bit Error Rate (BER) data is shown in Fig. 4(b). The Q factor decreases quickly for *d*=2 mm, indicating a high loss and large divergence of the beam in free space. In modern optical networks, data communication with a BER<10^{-9} is considered “error-free”. Without a micro-lens, at *d*=2 mm separation case, only data rate below 3 Gbps can be transmitted error-free. On the other hand, the micro-lenses increase the error-free data transmission to 7 Gbps.

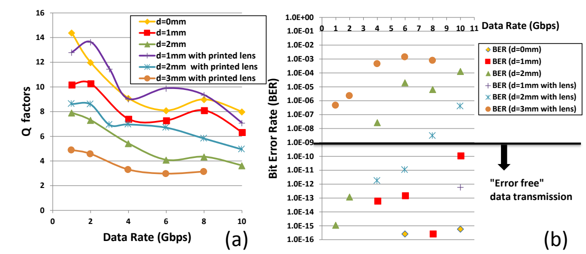

Fig. 4 (a) Q factors with different data rate, at different separations. Two mirror couplers are included (b) Bit Error Rate distribution (BER) with data rate at different separations with/without inkjet-printed lens.

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