Manufacturing of Board Level Waveguide Bus Using Hard Mold

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***Abstract*— Optical interconnects of straight waveguides and bi-directional bus architecture have been successfully fabricated on flexible substrate using nickel hard mold. Optical out-of-plane loss test and high speed data transmission at 10Gbps have been demonstrated.**

INTRODUCTION

The demand of high speed mass data transmission is pushing nowadays digital equipments to have the capability to meet such requirement. Traditional copper interconnect, however, is facing serious challenges when dealing with high frequency operation domain. Optical interconnects, as an alternative signal transmission method, are attracting more and more attention in different levels including chip-to-chip, board-to-board or even rack-to-rack interconnects. Chen et al investigated the differences of these two methods from many aspects including delay uncertainty, latency, power, and bandwidth density etc [1]. The main concern for the integrated optical interconnect is its cost and performance [2]. Many optical elements such as waveguides and gratings have been demonstrated by many research groups [3, 4]. In this work, we present a low cost molding method has been applied to fabricate optical waveguides. Furthermore, a novel bi-direction bus architecture is introduced and fabricated by this method. To evaluate the performance, an out-of-plan bending test is performed to the straight waveguides. High speed data transmission up to 10Gbps via straight waveguides and a bus structure is also demonstrated. Another highlight in this work is the 45^o embedded mirror which enables vertical coupling from VCSEL.

DESIGN AND FABRICATION

For optical interconnects, the main element is the waveguide. For parallel transmission, waveguide arrays can be used. Therefore, we design the array having 12 straight waveguides with 50μm ×50μm cross-section and 250μm in spacing. The waveguide materials are polymers that have low propagation loss in 850nm. The device is built on flexible substrate, which is flexible and can be bent to accommodate different application environments. For the bus structure, a 3-node bi-direction bus architecture is presented. The structure is shown in Fig. 1. It has 3 main elements: (1) nodes formed with a pair of laser diode (LD) and detector (D). Each node is able to send/receive signals to/from all other nodes at the same time, maximizing the efficiency of data transmission; (2) Embedded mirrors with 45^o slope. The mirrors enable light coupling into and out of the bus vertically using VCSELS; (3) variable ratio Y-splitter with engineered width ratio. By adjusting the width ratio of each branch, the light splitting ratio can be tuned.

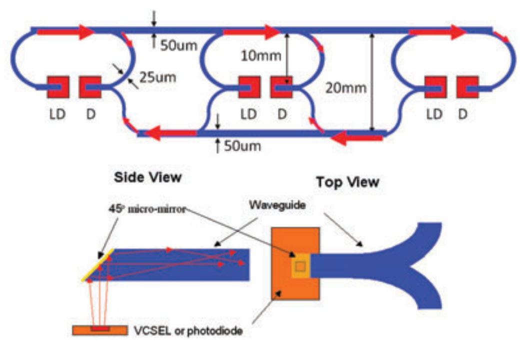

Fig. 1 board level, bi-direction optical bus architecture and vertical light coupling with embedded mirror

The molding method is applied to achieve both the waveguide array and bus architecture. The main steps together with SEM pictures after each step are shown in Fig. 2. It includes SU8 pre-mold fabrication, nickel metal mold by electroplating, molding process and final device fabrication. SU8 pre-mold fabrication is the key that ensures the quality of all the following processes. The 45^o degree slope is fabricated by tilted exposing the SU8 in DI water [5]. The hard nickel mold is prepared by electroplating desired thickness into the SU8 pattern, on pre-buried seed layer. The plating time, current density and stability during the plating should be carefully controlled to ensure good profile and smooth surfaces. After SU8 removal, the nickel mold is used to mold the bottom cladding polymer that is spin-coated on a flexible device substrate. After UV curing of the polymer, the mold is detached from the device substrate. Here, a thin layer of resist is pre-applied in between the mold and device, serving as release agent. Following that, gold is deposited on the 45^o slope to enhance the mirror reflectivity. The waveguide is finalized by coating the channels with core layer and top cladding layer, with proper UV curing.

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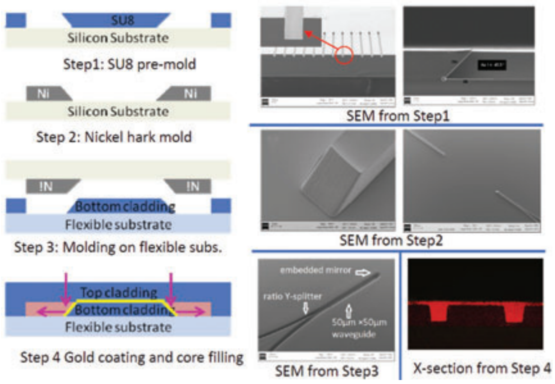

Fig. 2 main fabrication processes with SEM pictures of each step. Nickel is deposited using electroplating method in step 2.

DEVICE EVALUATION

The devices are evaluated using VCSELs emitting 850nm laser. For straight waveguides, out-of-plane bending insertion loss test structure and test results are shown in Fig. 3. Devices are tested under flat condition and 9 different bending radii. It is shown that when the bending radius gets smaller than 9mm, the measured loss increased rapidly which indicates the loss due to sharp bending is dominating compared to the existing propagation loss. Another evidence of this is that the loss difference between measurements using single mode fiber (SMF) and multi mode fiber (MMF) is getting smaller with reducing bending radii. Further reducing the bending radius may cause irreversible plastic deformation of the waveguide materials and fail the device.

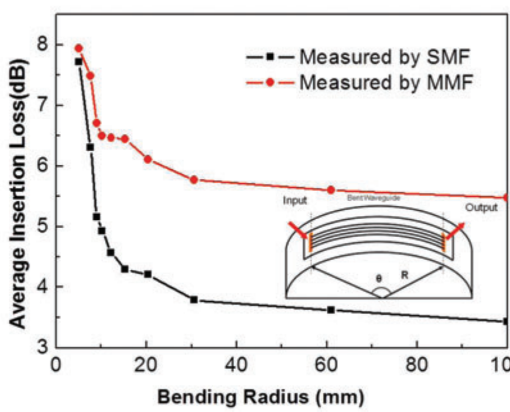

Fig. 3 Loss test of straight waveguide with different bending radii.

High speed data transmission tests are performed to both the straight waveguide device and the optical bus architecture. The test structure is shown in Fig. 4. The Q factor and Bit Error Rate (BER) of one typical straight waveguide at 10Gbps are shown in Fig. 5. The BER was calculated by assuming the presence of Gaussian distributed noises at each frequency. For most of the radii, the waveguide has good performance with BERs<10^{-12}. However, the BER for 5mm radius bending at 10Gbps is larger than 10^{-10} (Q=6.1) which indicates the challenge of data transmission with small bending radius. For the bus architecture, the loss is mainly contributed by to the curved waveguide and Y-splitter. Therefore, the achieved BERs are 2.3×10^{-10} (Q=6.23) at 1Gbps and 1.5×10^{-10} (Q=4.67) at 10Gbps. Future work includes lowering the BERs during high speed transmission, so that it can better fit various application environments.

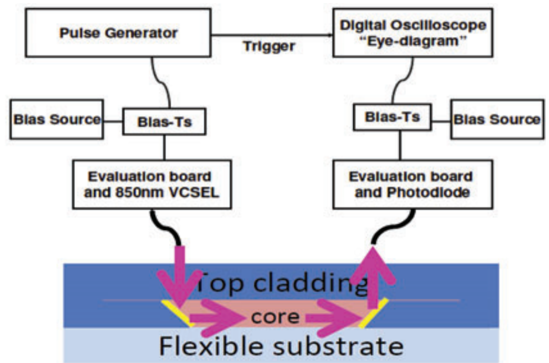

Fig. 4 high speed data transmission test setup

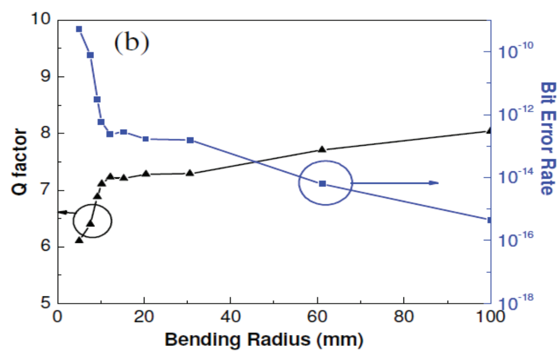

Fig. 5 Q factors and BERs of 10Gbps transmission test when straight waveguides are tested with different bending radii.

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