Optical bus waveguide metallic hard mold fabrication with opposite 45º micro-mirrors

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ABSTRACT

In this paper, 3-to-3 metallic hard mold for optical bus waveguide with opposite 45º micro-mirrors was successfully fabricated using electroplating method. The optical bus waveguide pre-mold with 45º surfaces before electroplating was prepared using photopolymer SU-8 through tilted exposure process under de-ionized water. Metal nickel was electroplated into SU-8 defined bus waveguide trenches. The 45º slant angles can be well controlled through titled exposure, which have deviations of 0.15º and 0.27º for SU-8 pre-mold and Ni hard mold, respectively. This metallic hard mold provides a convenient way to fabricate the polymeric optical bus waveguide devices through imprint technique.

Key words: optical bus waveguide, tilted exposure, electroplating, metallic hard mold

1. INTRODUCTION

In the electrical interconnects, the point-to-point topology replaced the shared-bus topology because of its bandwidth. However, wiring congestion is the adverse consequence of this transition, because in order to route all memory modules to the central switch, the boards in a high performance computing system currently tend to use more than 50 wiring layers, and more than 700 signal pins are required for one board edge connector, which needs as large as 100 pounds insertion force to seat [1]. Optical bus architecture greatly mitigates the wiring congestions, while still allows multiple daughter boards to share a common data channel to transfer information at a high speed simultaneously [2-3]. There is no loading effect of optics analog to driving capacitance in electronic circuit, which means the signal propagation speed is a constant value of 0.6c of polymer waveguide regardless of the presence of the receiver boards. While for electrical bus, an unloaded PC board trace has a typical signal propagation speed of 0.6c to a fully loaded bus line of 0.2c. Higher speed as well as a much more stable signal round-trip time can be obtained by replacing the electrical bus with the proposed optical bus. Comparing with point to point interconnect, bus based interconnects represent the most complicated interconnect structure with full interconnectivity and broadcasting nature [4-5]. Fiber based optical interconnects, which is intrinsically for point-to-point interconnection, fails to provide the desired optical bus architecture. Here we designed the optical bus based interconnected system with 3-to-3, 4-to-4 or 8-to-8 nodes, which have the advantages of enhancing the bandwidth, increasing the reliability, providing package compatibility and reducing fabrication cost.

2. FABRICATION OF THE 3-TO-3 OPTICAL BUS PRE-MOLD

A plan view of the 3-to-3 optical bus architecture is shown in Figure 1. It consists of two parallel optical buses, with 50um width, which can transmit optical signals toward two opposite directions. Optical signals, either from laser diodes (LD) of the master unit or the slave units, will be transmitted bidiretionally through two connected unidirectional couplers. The detectors (D) of either the master unit or the slave units are capable of receiving optical signals from both directions also, benefited from the two unidirectional couplers connected to them. The two parallel optical buses in conjunction with unidirectional couplers ensure the completely non-blocking interconnection among any existing units, without any wiring congestions. The laser diodes and the photodetectors are located either on the associated cardboards or the backplane itself. The intra-plane interconnection, i.e., from the laser diodes and photodectors to the waveguides, are established through surface normal micro-mirrors. The optical waves can be either coupled into and out of the optical bus by two opposite-placed 45º micro-mirrors, or by one micro-mirror and equally split by a Y-branch coupler.

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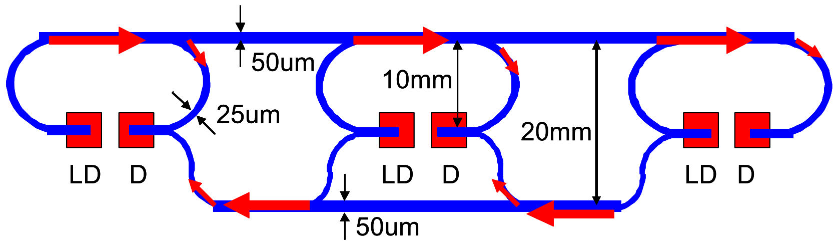

Fig.1 Schematic view of the 3-to-3 optical bus architecture

The fabrication process for the bidirectional bus structure is completely compatible with that for the parallel point-to-point optical interconnects [6]. First photopolymer SU-8 based bus pre-mold with 45º surfaces was achieved by tilted exposure under DI-water, then certain thickness metal Ni was electroplated into the SU-8 defined trenches. After that, SU-8 layer was removed and metal bus mold was achieved. Using the metal bus mold, polymeric optical bus device was formed by UV imprint method using UV curable polymer WIR-30 series.

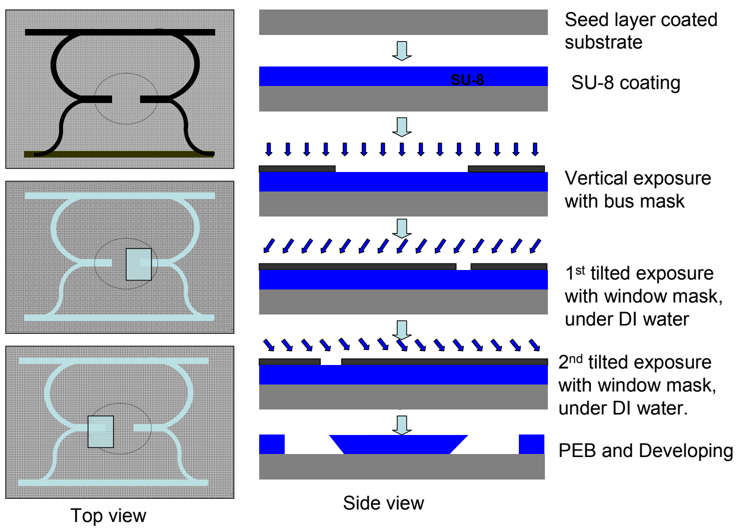

Fig.2 Schematic view of the optical bus pre-mold with 45º tilted surfaces preparation using SU-8 layer.

The schematic process to prepare the optical bus pre-mold is shown in Figure 2. A layer of 50um thick SU-8(from MicroChem) was first spin-coated onto a Ti/Au seed layer coated Si substrate. Three exposures were carried out in order to achieve the waveguide pattern and the opposite-placed 45º surfaces. The first exposure was carried out through vertical exposure to create the bus structure using the optical bus mask. The second and third exposures were carried out tiltedly under DI-Water to achieve 45º surfaces at the input and output node ends of the bus structure. The exposure setup under DI-water and the titled angle was calculated in else where [6]. After the three exposures, post-exposure bake and developing were carried out to achieve SU-8 based optical bus waveguide pre-mold.

The developed SU-8 based bus waveguide pre-mold was observed under scanning electron spectroscopy (SEM), shown in Figure 3. Fig.3a shows one of the input nodes with a Y-branch coupler. Fig.3b shows the branches connected with the bus. The actual slant angle of the 45º surface was measured, as shown in Fig.3c, which is 45.5º, with 0.5º deviation from the designed angle. We carried out a series of tilted exposure under DI-water and the slant angles for 10 samples were statistically measured (Fig.3d). The average angle is 45.3º with a standard deviation of 0.15º. This proves the slant angle can be controlled very well by tilted exposure under DI-water.

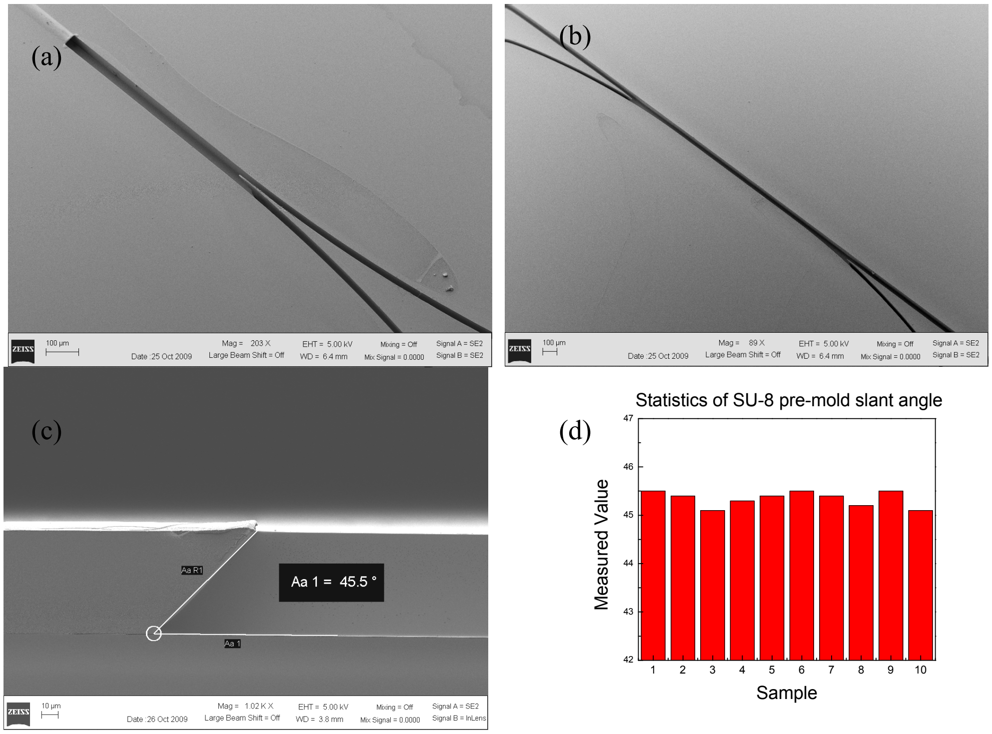

Fig.3 (a) Top view SEM image of SU-8 pre-mold input node with Y-branch coupler. (b) SEM of waveguide bus and branches. (c) Slant angle measurement of the 45º surface (d) Statistics of SU-8 pre-mold slant angle.

3. ELECTROPLATING FABRICATION OF Ni METALLIC HARD MOLD

After successfully achieving the SU-8 based optical bus pre-mold, Ni metal was electroplated into the SU-8 defined bus structure trenches. Figure 4 shows the whole electroplating process. Ni metal was grown on the seed layer where SU-8 was not covered. The detailed plating parameters were described else where [6]. Normal plating current density is around 10mA/cm^2. To obtain a 50um thickness of plated metal, total plating time is around 6-7hours. Small current density (<2mA/cm^2) was used at the beginning and the end of electroplating to achieve stronger adhesion and better polished finish surface. After successfully plating Ni metal, SU-8 pre-mold layer was removed by remover PG. SU-8 residues were removed using O_2 plasma.

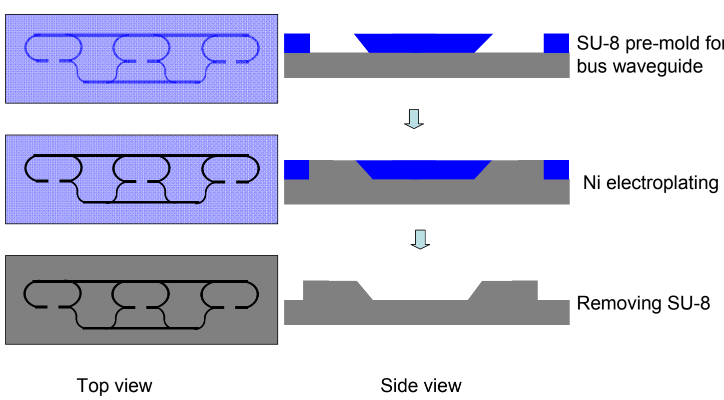

Fig.4 Schematic process of Ni hard mold electroplating. Top view and side view are shown on left hand side and right hand side, respectively.

The fabricated Ni hard mold was studied under SEM, shown in Figure 5. Fig.5a shows the input and output node with two opposite 45 surfaces on the ends. Y-branch couplers are also shown. Fig.5b and 5c show a larger magnification of the 45º surface and Y-branch coupler, respectively. Almost all SU-8 residues inside the Y-branch coupler slot were removed. The 45º surface actual slant angle was measured to be 45.2º under SEM, in Fig.5d. The height of the metal mold was scanned by a contact profilometer Dektak150, in Fig.5e. The height is around 50um, which is consistent with the SEM measurement in Fig.5d. By doing a series of electroplating process, 45º surface slant angles of 10 samples are measured, as listed in Fig.5f. The average angle is 44.8º with a standard deviation of 0.27º. This is consistent very well with the SU-8 pre-mold slant angle measurement results.

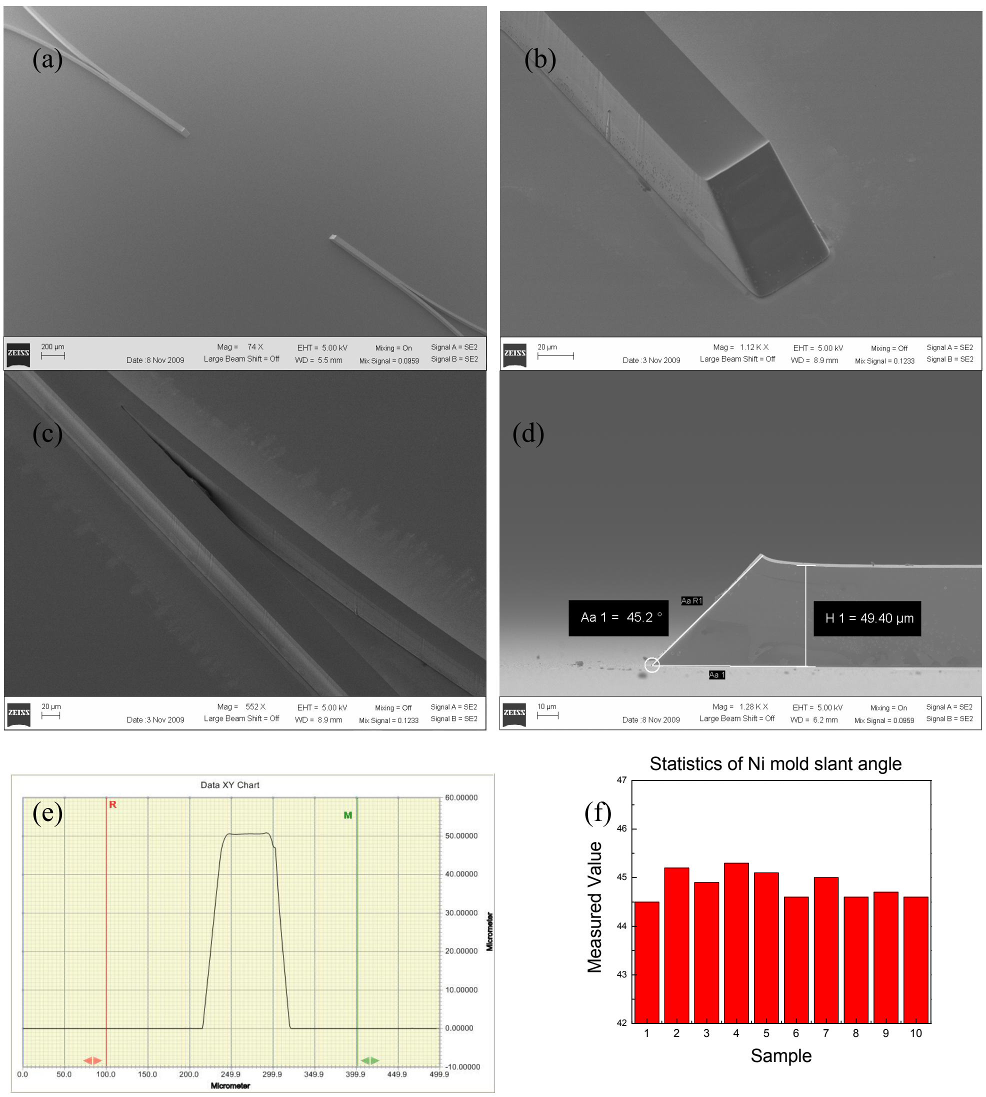

Fig.5 (a) SEM images of the input and output nodes of the Ni metal bus mold. Lager views of (b) the 45º surface and (c) the Y-branch coupler. (d) Actual slant angle measurement. (e) Height measurement using a surface contact profilometer Dektak150. (f) Statistics measurement of 10 Ni mold slant angles.

4. IMPRINT OF POLYMERIC OPTICAL BUS WAVEGUIDE

Polymeric optical bus waveguide was successfully fabricated using the electroplated Ni metal bus waveguide mold through UV emboss method. UV curable polymers WIR30 series (from ChemOptics), WIR30-450 (n=1.45@850nm), WIR30-470 (n=1.47@850nm) were used for the waveguide cladding and core, respectively [7]. 200um thick TEONEX thin film (from Dupont Teijin Films Inc.) was used as the TOPAS substrate. The imprint process is shown in Figure 6. Firstly, a thin bottom cladding layer of WIR-30-450 was coated on the TOPAS film followed by UV cure. A 1.0um of AZ photoresist was coated on the Ni bus hard mold as the release layer. Then, put the Ni bus hard mold onto the TOPAS film with WIR-30-450 in between, UV cure for 12min to solidify the polymer. Release the hard mold in acetone. After detached from the Ni mold, 200nm of Au mirrors were fabricated. Core material and top cladding were filled and coated followed by UV cure.

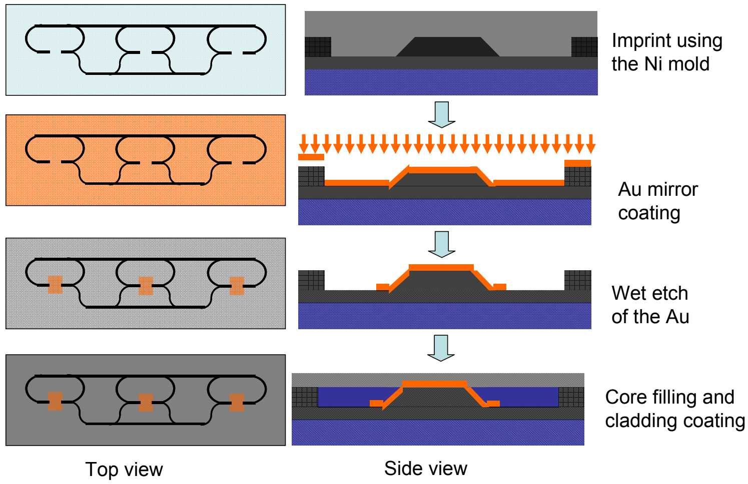

Fig.6 UV imprint process to fabricate polymeric optical bus waveguide devices using Ni bus hard mold

Before core filling, SEM images of the imprinted optical bus waveguide were taken, as shown in Figure 7. Fig.7a shows the input node, Y-branch coupler, with 45º micro-mirror part. Fig.7b is the larger view of the 45º micro-mirror part, where the waveguide width is measured to be 50um. Fig.7c and 7d are the coupling in and out junctions SEM of branches with the bus waveguide.

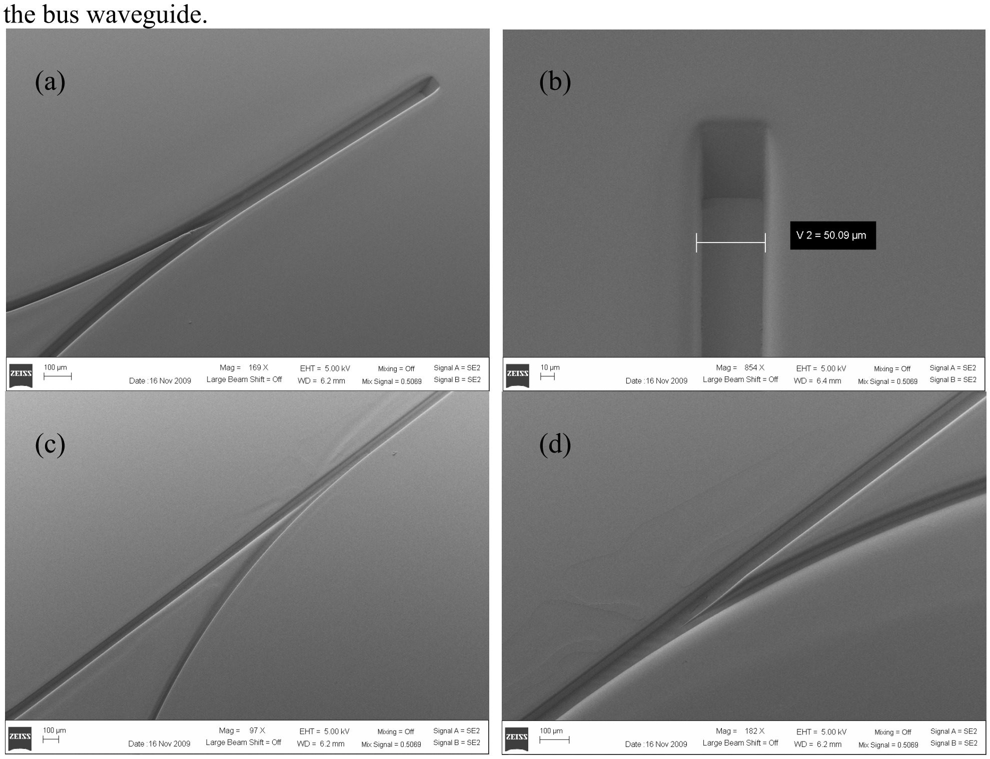

Fig.7 SEM images of the optical bus waveguide after UV imprint. (a) Input node, Y splitter and 45º micro-mirror (b) larger view of the 45º micro-mirror. (c) and (d) Junctions of the branches with the bus.

A 635nm laser source was used to observe the output of the optical bus waveguide (Fig.8a). A single mode fiber was fixed above 45º micro-mirror region of the input node. Fig. 8b shows the optical test image with 1 input and 2 outputs.

The third output is not shown clearly in Fig.8b because it is very near to the input node. Optical test based on the 850nm wavelength laser source was also carried out using an 850nm laser diode with a 9/125um SMF pigtail, which was surface normally coupled into the waveguide through the 45º micro-mirror. The output light intensity was measured by an 850nm photodetector which was fixed at the output end of the waveguide array. The experimental data will be reported in the near future.

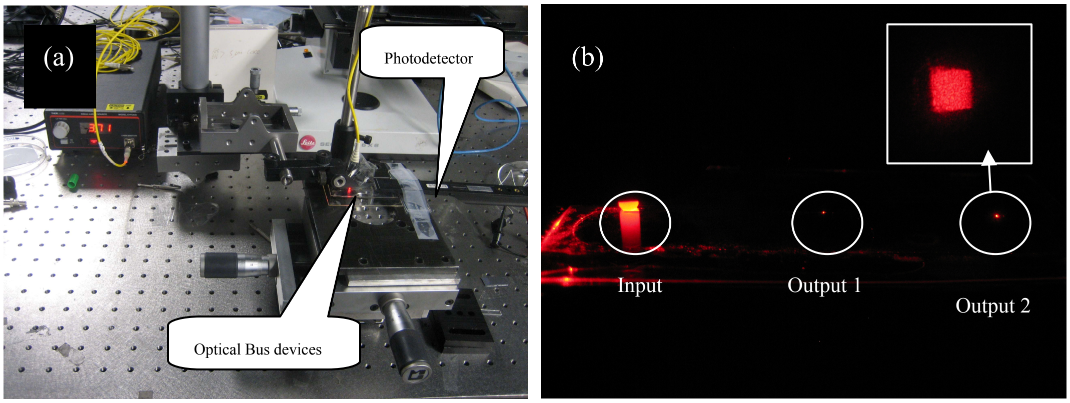

Fig. 8 Optical test setup on the bus waveguide. Inset shows the pattern through microscope.

In summary, we have successfully fabricated polymeric optical bus waveguide with 3 input and 3 output nodes embedded with two-opposite 45º micro-mirrors using Ni metal bus waveguide mold by UV imprint technique. The Ni metal bus waveguide mold was prepared through electroplating metal Ni into SU-8 defined bus pre-mold which formed opposite 45º surfaces at the input and output node ends by tilted exposure under DI-Water. This work is supported by the National Science Foundation. Helpful discussion on Ni electroplating with Dr. Domesh is acknowledged.

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