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10 Gb/s Optical Interconnection on Flexible Optical Waveguide in Electronic Printed Circuit Board

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ABSTRACT

In this paper, we proposed 10 Gb/s transmission using 4-channel polymer waveguides on the optical electronic printed circuit board. It was simulated by the ray tracing method for tolerance study of optical interconnection and fabrication. In order for easy fabrication and high position accuracy, the polymer waveguides were forming silver coated 45° reflective mirrors by dicing method and e-beam deposition for 90° light beam turning. The coupling loss was demonstrated in different polishing grit sizes. The optical interconnection in board-embed 4-channel flexible waveguides was demonstrated with a low propagation loss of 0.1 dB/cm and a clear eye diagram at 2.5 Gb/s data rate per channel.

Keywords: Flexible Waveguide; Optical Electronic Printed Circuit Board

1. Introduction

The optical interconnection is a promising candidate to resolve the issues from the technical problems of electrical interconnections such as the upper limitation of transmission data speed, electric power consumption, crosstalk, and electromagnetic interference. [1,2]. The optical fibers have large advantage in long distance interconnection due to their low propagation loss, light weight, low cost, and immunity to electromagnetic interference. For in-device optical interconnection, the optical polymer waveguide transmission is better than fiber because of its easy fab- rication, productivity and enabling high density integra- tion in folded-type mobile device requirements. Some research combines flexible optical polymer waveguide and print circuit board (PCB) to realize flexible data transmission and optical electrical integration [3,4]. In order to realize the board-to-board or chip-to-chip inter- connection, the vertical coupling into optical waveguide had been studied, which included the 90º-bent fiber blocks [5], laser ablation processing [6], micro prisms [7], and dicing processing [3,4].

In this paper, we have fabricated a flexible optical waveguide (FOW) typed electronic printed circuit board (EPCB), which is containing flexible optical waveguide and electrical PCB. The waveguide terminal was made as 45º mirrors for vertical light beam coupling using dicing processing. The optical loss due to unexpected fabrication process and waveguide terminal roughness issue was also discussed.

2. Conceptual Structure

The optical interconnection conceptual structure for FOW typed EPCB is composed by the flexible polyimide substrate with optical waveguides, rigid PCB mounting vertical-cavity surface-emitting laser (VCSEL) and photodiode (PD) as shown in **Figure 1**.

The optical waveguide cross-section on the inputs is illustrated in **Figure 1(b)**. The refractive indices for the waveguide cladding and core layers were 1.551 and 1.585, respectively. The polyimide waveguide core size

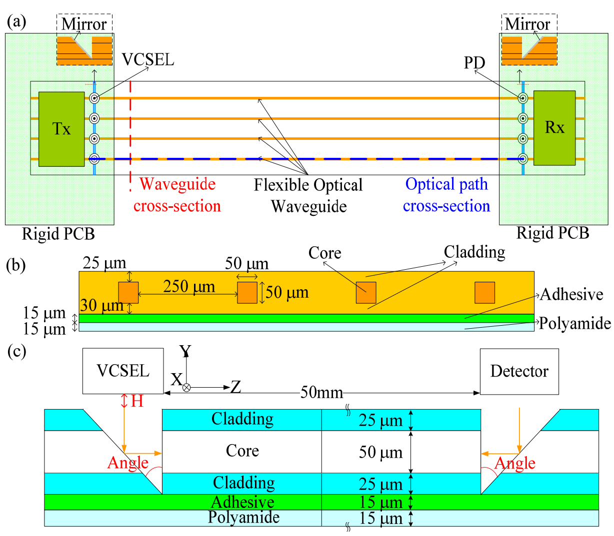

Figure 1. (a) FOW typed EPCB top view. (b) Waveguide cross-section on the inputs. (c) Optical path in cross-section.

is 50 μm × 50 μm, and the upper cladding thickness is 25 μm and lower one is 30 μm. The optical path in the FOW is illustrated in **Figure 1 (c)**. The VCSEL and PD area are 20 μm and 90 μm respectively. The light emitting from VCSEL to flexible polyimide waveguide was coupled by the silver coated 45° mirror. Then, the light is transmitted in the optical waveguide and vertically coupled to PD by the opposite silver mirror.

3. Optical Interconnection Loss for FOW

The ray trace simulation demonstrated that the optical interconnection loss from VECEL to PD was less than 0.1 dB. The investigation for the process tolerance and multilayer structure misalignment is crucial in FOW typed EPCB. In **Figure 2**, the optical loss in different mirror angles and VCSEL/PD height away from the waveguide surface (H) are considered. The simulation results were showing that the VCSEL/PD height could achieve lower optical loss and there was no obvious loss difference, less than 0.5 dB, between the mirror angles from 44º to 46º. The optical loss was less than 1 dB while the VCSEL and PD were mounted at 75 μm away from the waveguide surface. Besides, the lower H owns the higher alignment tolerance for the mirror. Hence, the angle and height precisely control during process are important.

To simulate another optical alignment tolerance between mirror and VSCEL/PD, the horizontal directional shift (X-axis and Z-axis) was considered as shown in **Figure 3**. The loss due to 20 μm misalignment was about 2 - 3dB.

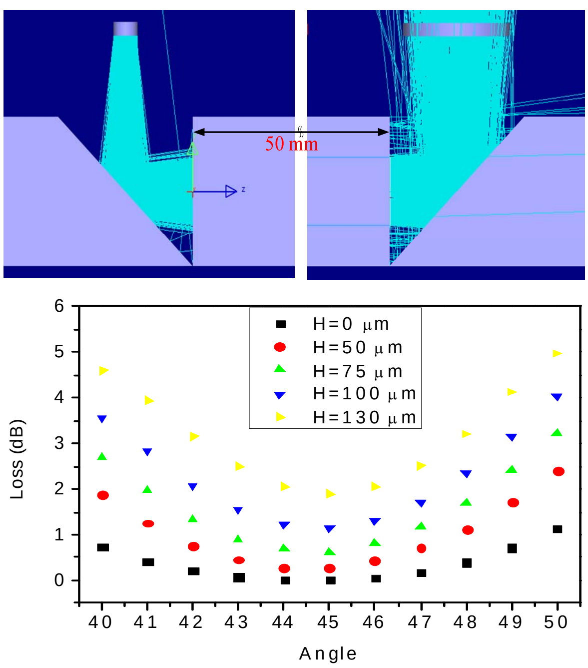

Figure 2. Mirror angle tolerance calculation.

4. Fabrication and Measurement of FOW Typed EPCB

We fabricated a flexible multimode waveguide by using the film shaped optical waveguide materials, enabling easier film thickness control and handling. To make the channel optical waveguide, the core layer was laminated by a roll-to-roll method and the pattern was defined by UV exposure through a photo mask and followed by the development. After the thermal curing, an over-clad sheet was covered, being thermally compressed with the same condition with the under-clad lamination process, as shown in **Figure 4**.

The fabricated flexible waveguide reliability was evaluated as follows. A high-temperature/humidity test at 85 ºC /85%RH for 1000h were carried out. There was no detectable peeling-off or separation occurred among any layers. It indicates that the developed materials and fabricated waveguide are demonstrating the high reliability. Moreover, the bending measurements for optical loss and

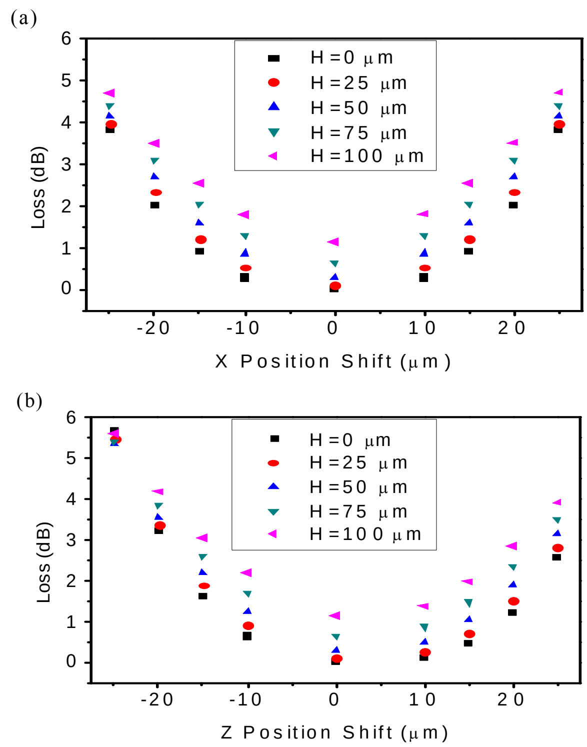

Figure 3. (a) X position and (b) Z position shift tolerance calculation.

Figure 4. CCD image of waveguide cross-section.

fatigue were carried out to evaluate the bending properties of flexible waveguides. The results of bending fatigue test with conditions of bending angle from 0 to 180 degrees and 2-mm bending radius were showing the loss was increased lower than 0.2 dB after ten thousand repetitions.

In order to evaluate the total loss of the FOW typed EPCB, we analyzed the waveguide propagation loss, reflective mirror loss and coupling loss from the mirror to waveguide.

The propagation loss and coupling loss of the flexible waveguide were analyzed by a cutback method. The propagation loss was about 0.1 dB/cm measured with a VCSEL light source at wavelength of 850 nm. The waveguide coupling loss in different waveguide terminal surface was shown in **Figure 5**. In this structure, two kinds of waveguide terminal surfaces, 45° surface for 90° beam turning and vertical surface for light into/out of the waveguide were demonstrated. The samples were polished with different polishing films which had the grit sizes of 0.1-μm, 1-μm, 3-μm, and 9-μm. The diamond-blade method was utilizing the grit size of 1 - 2 μm and the 45° and 90° surfaces with spindle speed 24000 rpm were fabricated and cut speed 0.5 mm/s, as shown in **Figure 6**. The 45° surface angle error was within 45 ± 1°. The waveguide end surface image and coupling loss were also shown in **Figures 7** and **8**, respectively.

Figure 5. Photo image for FOW typed EPCB.

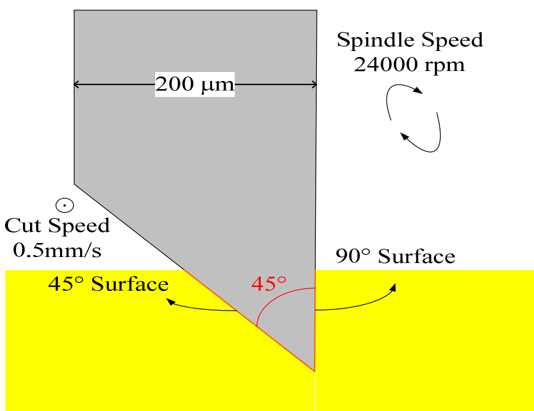

Figure 6. Diamond-blade method.

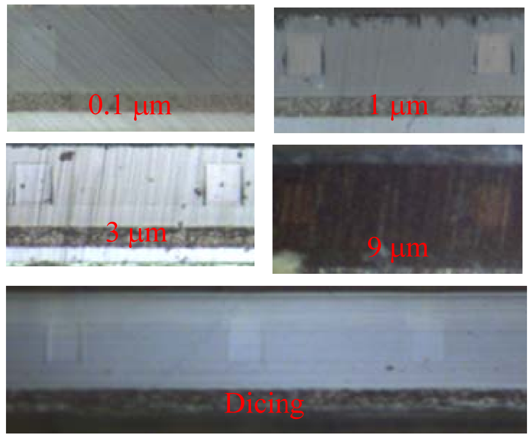

Figure 7. Waveguide terminal surface image.

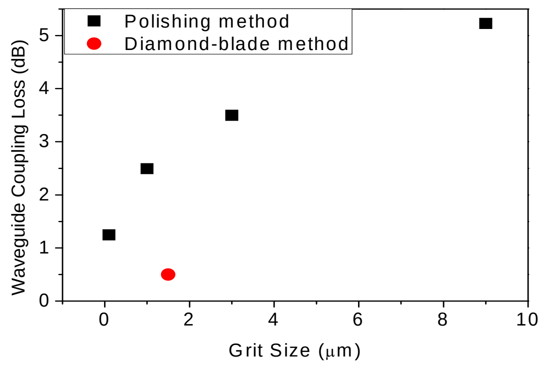

Figure 8. Waveguide coupling loss between different waveguide terminal surfaces.

The Ag reflection from 45° mirrors was deposited by the e-beam evaporation process and the thickness was about 400 nm on the waveguide terminal 45°-ended. The vertical incident light source into the 45°-mirror causes the optical loss less than 0.8 dB from 90° turning points.

Moreover, the bending loss and bending fatigue were carried to evaluate the flexible waveguide reliability. The bending fatigue characterization was showing that the excess loss was lower than 0.2 dB after one hundred thousand of 0° - 180° bends with 2-mm bending radius.

To measure the transmission quality from VCSEL to PD of the interconnection module, a DC voltage of 3.3 V was supplied into the transmitter and the current generated in receiver was characterized. In **Figure 9**, it shows that the implementation and integration were implemented for the proposed active electro-optical bus module. A 1×4 VCSEL array and a 1×4 PD array both with 2.5 Gbps/channel are directly die-bonded on the transmission and the receiving boards, working with 2.5 Gbps driver chips, amplifiers, and other active/passive devices. An electric signal of clear 2.5 Gb/s generated by a pulse pattern generator was supplied to the transmitter module through the SMA connector and the signals transmitted to the receiver module through the waveguide with SONET OC-48 eye mask as shown in **Figure 10**. As a result, the eye diagram of the electrical output signal from the receiver on flexible opto-electrical interconnect module was tested with network analyzer and shown in **Figure 11**.

5. Conclusions

In this paper, the optical interconnection loss in FOW typed EPCB was discussed for fabrication tolerance study. The optical loss variation due to mirror angles

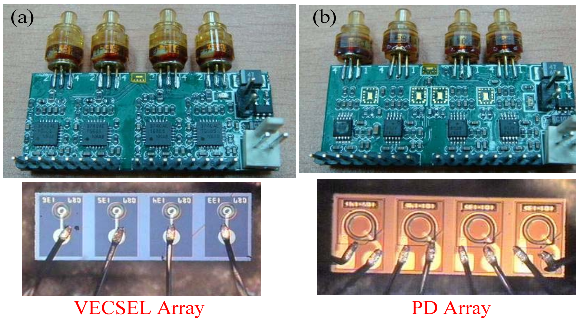

Figure 9. (a) Transmitter and (b) receiver active electro-optical module with 4-channel VECSEL array and PD array respectively.

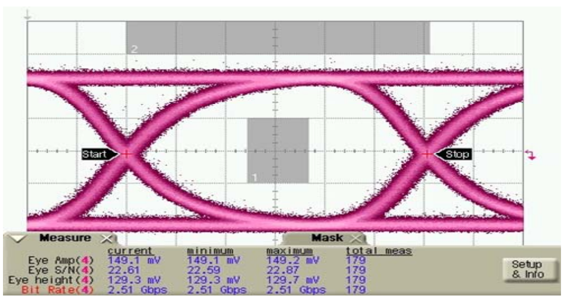

Figure 10. 2.5 Gb/s Eye diagram for one channel polymer waveguide.

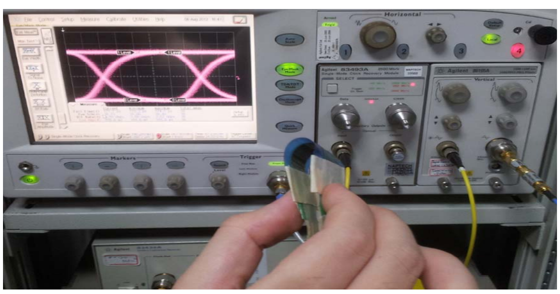

Figure 11. 2.5 Gb/s eye-diagram per channel for the FOW typed EPCB at 180° bend.

from 44° to 46° was less than 0.5 dB. The diamond-blade method was applied and implemented on the 45±1° mirror. The waveguide coupling loss was discussed by different waveguide terminal surfaces. The diamond-blade method could provide smooth surface and low coupling loss. A prototyped FOW combined with EPCB was fabricated and demonstrating the propagation loss and mirror coupling loss as 0.1 dB/cm and 0.8 dB, respectively. After one hundred thousand of 0° - 180° bending fatigue tests, the propagation loss was increased lower than 0.2 dB. An EPCB typed the optical flexible waveguide and electrical rigid PCB was verified and its performance achieved practical applications for the optical interconnection. We also confirmed that a 4-ch VCSEL array and a 4-ch PD array could successfully transmit light signals at a speed of 2.5 Gb/s per channel.

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