Design of a Low Loss and Large-Tolerance Optical Interface for Large-Area Optical Waveguides

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***Abstract* - An alternative interface structure design of a large-area optical waveguide for a large-area optical printed circuit board using a step-out fabrication technique is proposed. In this paper, we simulated and compared our proposed structure to a typical straight core structure in order to investigate the misalignment tolerances and coupling excess losses.**

I. Introduction

For backplane applications used in high-speed network equipment and supercomputers, optical printed circuit boards (PCBs) using polymeric optical waveguides have been studied as an alternative to high-speed electrical interconnections [1]-[4]. In these devices, large-area optical PCBs of approximately 50 cm x 50 cm in size are generally required. Therefore, the subsequent development of large-area optical waveguide technology is also needed in order to meet the manufacturing requirements of large-area optical PCBs.

Optical waveguides fabricated via conventional technologies such as photolithography and imprint lithography are usually produced using 4 inch masks of about 10 cm x 10 cm in size and generally have patterns with a fine resolution of 1 μm or less. However, for optical waveguides based on a sheet concept for large-area panels, it is not easy to maintain this level of pattern resolution, accuracy, and uniformity during the manufacturing process. Therefore, in previous attempts to overcome these problems, new fabrication methods for large-area optical waveguides have been developed, such as laser-beam writing techniques [1], photolithographic techniques [2], direct UV-laser writing techniques [3], and step-out projection photolithographic techniques [4].

The most notable technique in terms of scalability and fine patterning is usually the step-out technique, as shown in Fig. 1. This technique divides the large-area optical waveguide into segments and then combines the entire optical waveguide using the appropriate masks or masters for each segment. In this technique, however, a critical problem to consider is the misalignment of optical waveguides fabricated in each segment at each interface. In spite of the precision of the waveguide patterns, based on fine masters or marks, misalignment at the interface between the segments can still occur during the step-out process. Therefore, to minimize this misalignment problem this paper proposes an interface structure having a large alignment tolerance and low coupling loss.

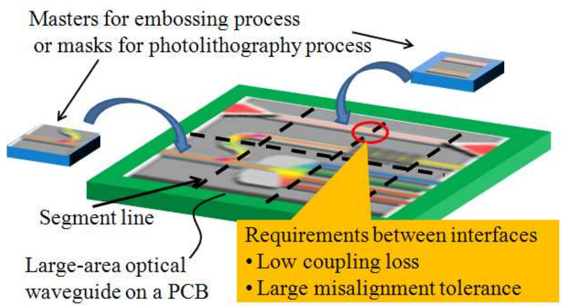


Fig. 1. Schematic configuration of a step-out technique and requirements between interfaces.

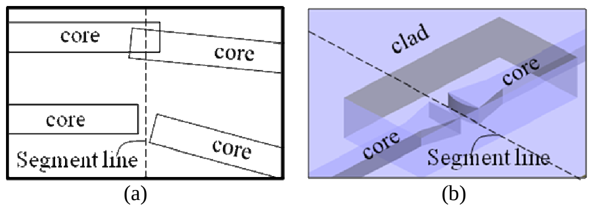


Fig. 2. Drawings of (a) a typical straight core interface and (b) the proposed interface structure.

II. Structure of Interface

During the step-out process, alignment errors up to a maximum of several tens of micrometers inevitably occur due to overlap or/and separation in the waveguide core pattern, in addition to lateral or/and angular misalignment, as shown in Fig. 2(a). Thus, we propose a new interface structure shown in Fig. 2(b) in order to achieve a larger alignment tolerance and lower coupling loss. In this proposed structure, the waveguide core has a tapered and lens-shaped structure and the waveguide clad is partially opened to strengthen the lens effect (hereinafter referred to as a “TLC-POC structure”).

Fig. 3 presents a detailed schematic of the proposed TLC-POC structure. In brief, the beam sequentially propagates through the core in segment-I passes along the straight zone, spreads in the taper zone, and is then laterally collimated in the lens zone. The beam is then coupled before it propagates through the lens, taper, and straight zone on the opposite side (segment-II). Here, the tapered structure serves to increase the lateral misalignment tolerance and the lens-shaped structure reduces the coupling loss and increases the longitudinal misalignment tolerance.

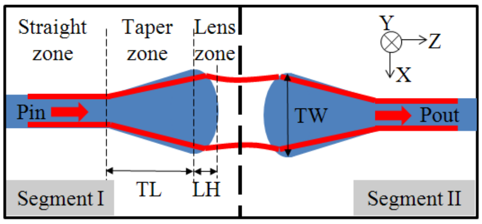


Fig. 3. Detailed schematic of our proposed TLC-POC interface structure.

TABLE I
DESIGN PARAMETERS FOR RAY-OPTIC SIMULATION

Parameters	Dimensions
Refractive index of core	1.54
Refractive index of clad	1.5
Core width and height	50 μm
Taper length (TL)	100 μm
Taper width (TW)	100 μm
Lens height (LH)	14 μm

III. MISALIGNMENT TOLERANCE SIMULATION OF TLC-POC

We conducted a 3D ray optic simulation using *LightTools* under the design parameters listed in Table I in order to verify the effectiveness of the TLC-POC structure. The design parameters were set by considering common specifications of optical waveguides for backplane applications.

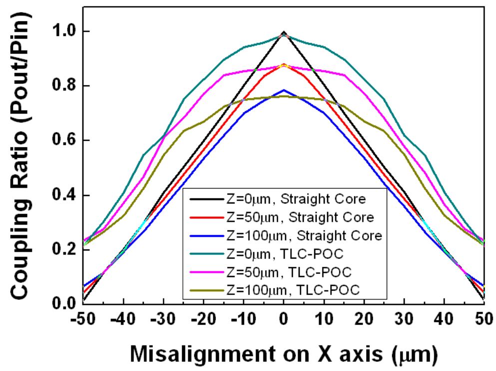
First, to determine the misalignment tolerance for the X-axis (lateral direction) and Z-axis (longitudinal direction), the coupling ratio was simulated. The coupling ratio defines the ratio of the output power (P_{out}) in segment-II and the input power (P_{in}) in segment-I. Fig. 4(a) shows the coupling ratio versus the misalignment on the X-axis. Here, for Z = 0 μm, Z = 50 μm, and Z = 100 μm the longitudinal separation distances from the segment line are 0 μm, ±25 μm, and ±50 μm, respectively. We can then obtain the comparative data of the 1-dB misalignment tolerance on the X-axis from the results of Fig. 4(a), as shown in Fig. 4(b). According to the results, the misalignment tolerance of the waveguide based on the TLC-POC structure was improved by at least 2 times, compared to that of the waveguide having a straight core.

Similarly, we analyzed the misalignment tolerance on the Y-axis and the tilt angle. To setup the simulation on the Y-axis, the height of the input core in segment-I was fixed at 50 μm and the output core height was varied from 40 μm to 60 μm. As a result, in the given range, the excess loss was calculated to be less than 1 dB. With a tilt angle change of ±10°, only a 0.3-dB excess loss was calculated.

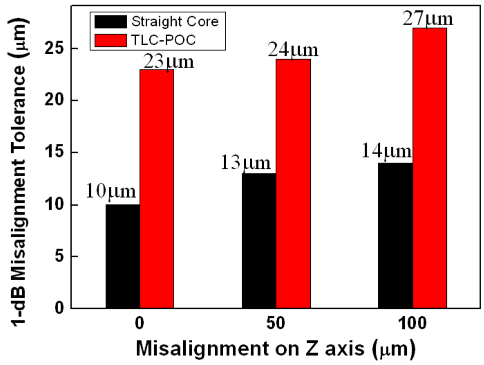
In summary, based on the results of simulations pertaining to deviations of the XYZ axes and tilt, the TLC-POC structure was confirmed to have a sufficiently large tolerance.

IV. CONCLUSION

In this paper, we proposed a TLC-POC interface structure having large misalignment tolerances in order to fabricate a large area optical waveguide using a step-out technique for backplane applications. We also analyzed the misalignment tolerances for all XYZ-axis deviations, including tilt angle, and verified the large tolerance. Therefore, we expect that the proposed structure will be more efficient in terms of scalability for a large-scale optical PCB.



(a)



(b)

Fig. 4. Simulated results of (a) coupling ratio versus misalignment on X-axis and (b) 1-dB lateral misalignment tolerance comparison.

ACKNOWLEDGMENT

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