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Design of taper coupler for effective laser and single mode fiber coupling with large tolerance

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ABSTRACT

A new method of coupling the light from a laser diode to a Single Mode Fiber (SMF) with large alignment tolerances and without using coupling lenses is presented. A pseudo vertical tapered coupler is designed for light coupling between laser diode and single mode fiber. It has a large input aperture which is about 100 times the size of the laser waveguide cross-section. The tapered coupler provides single mode output and matches the mode size with the single mode fiber . The tapered coupler is fabricated on a silicon optical bench and is located between the laser and the fiber through the silicon micrfabrication process. The misalignment between the fiber and taper coupler can be very small since this is controlled by high precision silicon optical bench patterning processes. The coupler relaxes the laser diode placement accuracies and eliminates the need for a coupling lens. Design Studies showed that the tolerance between the laser diode and taper coupler can be more than +/-5µm misalignment at x-y, and +/-0.5degree tilting angle tolerance and the fabricated assembly results are encouraging with good placement tolerances and coupling efficiency. The laser to single mode fiber coupling tolerances is greatly improved and passive alignment for laser and single mode fiber is realized. The technology can be useful for multi channel optical assembly where significant device and process cost saving can be achieved and is suitable for functional integration for silicon photonics.

Keywords: Taper coupler, laser diode attachment, single mode fiber, coupling efficiency, tolerance

1. INTRODUCTION

A typical DFB laser diode has a small beam spot at the output with wide divergence angles of horizontal 20 degrees and vertical 40 degrees. Optical coupling between laser diode to single mode fiber or waveguide remains a major challenge in photonics packaging. The optical ICs are coupled to passive elements like fiber and waveguide using direct coupling (butt coupling), focusing lenses of different mechanisms and mode matching coupling structures. Butt coupling between laser and single mode fiber captures less than 10% of the laser power for an edge emitting laser. Besides, this approach is intolerant of small misalignment (1µm) between the laser and the fiber. To achieve better coupling efficiency, a lens can be used to convert the light source to a smaller angle distribution. Various lens were investigated for coupling application, including bi-focus lens [1], diffractive lens [2] and defocus lens. However, all these methods are sacrificing the coupling efficiency from less than 3dB coupling loss to more than 8dB coupling loss. The coupled power will drop dramatically even with a small misalignment of the lens. Therefore, the laser, lens and fiber placement accuracies are very severe and active alignment is necessary for the laser and fiber assembly. Tapererd coupler provides modes conversion through an adiabatic modal transformation thus resulting in small coupling loss [3] [4] [5]. However, to match with laser spot size and maintain single mode, the adiabatic modal converter has a small input region which results in small alignment tolerance between laser and taper structure. In this paper, we propose a taper coupler with larger tolerance (+/-5µm) with good coupling efficiency (≥-3dB to -6dB) for laser and single mode fiber coupling. The design is optimized and tolerance is studied.

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2. TAPER COUPLER DESIGN AND SIMULATION FOR LASER AND SINGLE MODE FIBER COUPLING

A taper coupler with mode size matching at both sides will convert the mode from laser diode to the single mode fiber or waveguide. But the mode size converter needs to be aligned with the laser diode precisely, as otherwise, most of the light from the laser diode will be lost. In order to achieve generous tolerance for passive alignment in low cost assembly, a taper coupler with relative large input opening is designed to couple the light from laser diode to single mode fiber. In order to make the fabrication simpler, the coupler is designed to have symmetric lateral taper and pseudo-vertical taper shape. The laser diode active waveguide faces the center of the entrance facet of taper coupler. Figure 1 and figure 2 show the top view and cross-sectional views of the designed tapered coupler structure.

The design of the coupler includes considerations of assembly and packaging. Considering the placement of laser diode will be at least several micrometers distance from the taper coupler, the laser beam will diverge to a beam spot of several micrometers diameter. Thus, we designed the opening at input side to be 20μm×20μm which is larger than the laser diode mode size. This helps in coupling the light into the coupler even if the laser diode has a few micrometers displacement. The designed taper waveguide has a core refractive index of 1.51 and clad refractive index of 1.46. This results in a multi modal tapered coupler. All the modes except the fundamental mode are suppressed during the propagation through the coupler by design optimization. The taper coupler has two layers to form the pseudo-vertical tapering structure as depicted in figure 2. Both the bottom layer and top layer are 10μm thick. The length of the bottom layer is optimized so that most of the light will be coupled into the top layer. The output end of the taper coupler has a core size whose fundamental mode matches with the mode in single mode fiber. The length of the top layer is optimized to achieve the best coupling between the taper coupler and the single mode fiber. Figure 3 shows the light propagation from laser diode to single mode fiber through taper coupler. By using such a taper coupler, a typical -3dB coupling efficiency is achieved.

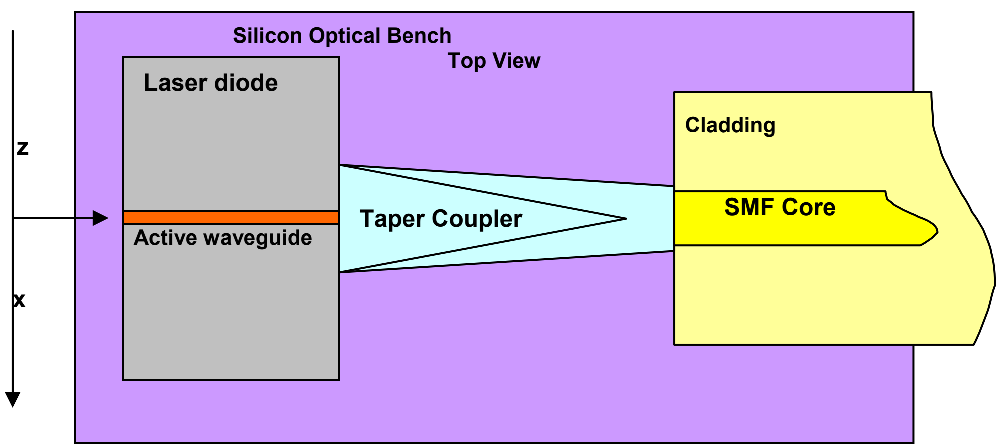

Fig. 1 Top view of a taper coupler between laser diode and single mode fiber.

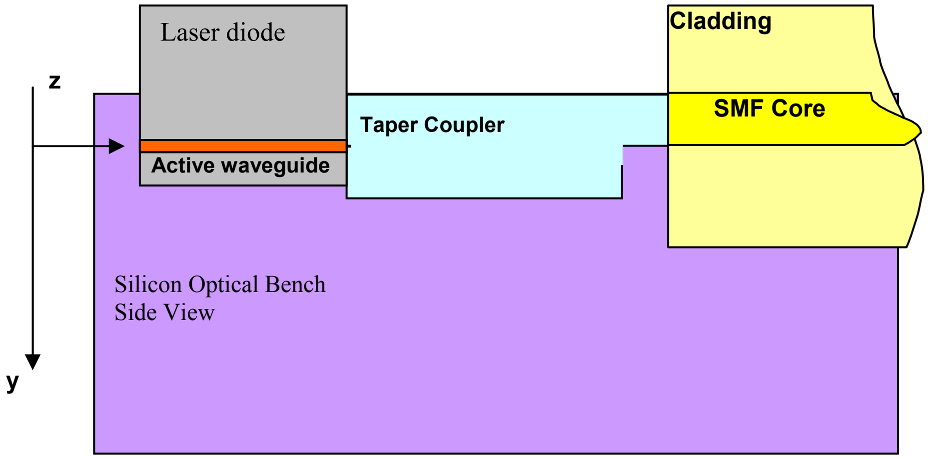

Fig. 2 Side view of a taper coupler between laser diode and single mode fiber.

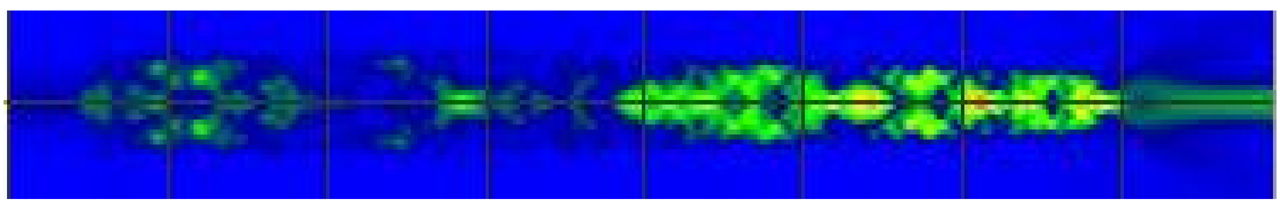

Fig. 3 Light propagation from laser diode to single mode fiber through taper coupler

3. LASER DIODE TOLERANCE STUDY DURING DESIGN

To study the possible tolerance values of laser diode placement, simulation studies were carried out by shifting the input mode to the tapered coupler in both horizontal and vertical positions. The placement tolerances were studied from -5µm to +5µm offset both laterally and vertically. Figure 4 shows that the coupling variation is less than 2dB when the lateral offset of laser placement ranges from -5µm to +5µm for an ideal vertical location. Figure 5 shows that the coupling variation is less than 3dB when the vertical tolerance ranges from –3µm to +6µm for an ideal horizontal location. In these two sets of simulations, we assume there is not tilting at the active waveguide of laser diode relative to the optical axis of taper coupler and fiber.

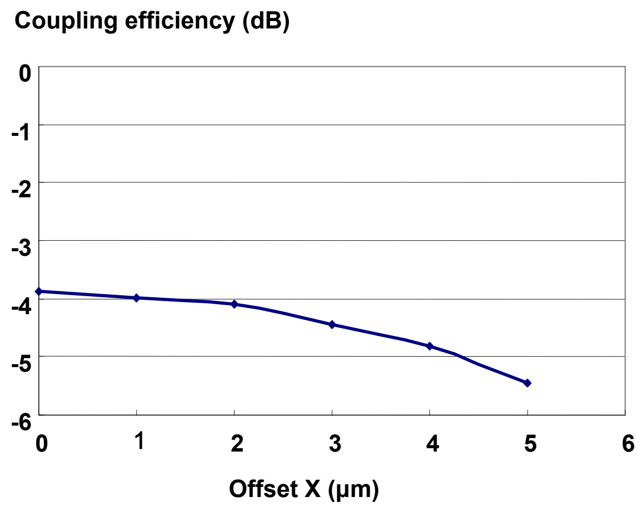

Fig. 4 Coupling efficiency vs. lateral offset

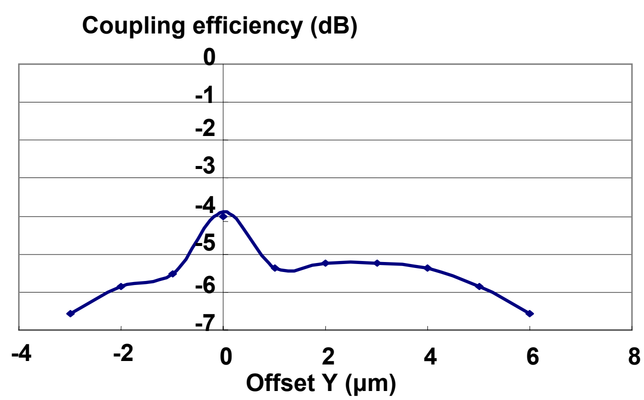

Fig. 5 Coupling efficiency vs. vertical offset

It is also observed that when there is a slight angle between the laser diode axis and the taper coupler axis, the coupling between laser diode to coupler and fiber is better due to the suppression of some of the input modes. The schematic configuration of tilting between laser diode and coupler is shown in Fig. 6. The coupling efficiency results over a range of tilting angle are presented in fig. 7. When there is a deliberate tilt of 0.2 degrees, the coupling efficiency improves from -3.5dB to -2.5dB. Figure 8 shows the light propagation from laser to taper coupler then to the fiber when laser diode is tilted at 0.2 degree. It can be seen that the modes are launched asymmetrically in taper coupled so that some modes are suppressed and more energy is coupled into the single mode fiber.

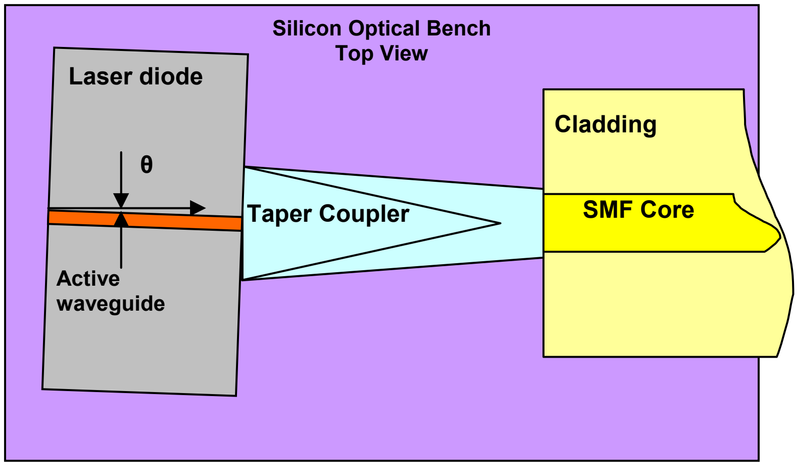

Fig. 6 Top view of a taper coupler between a lateral tilting laser diode and single mode fiber.

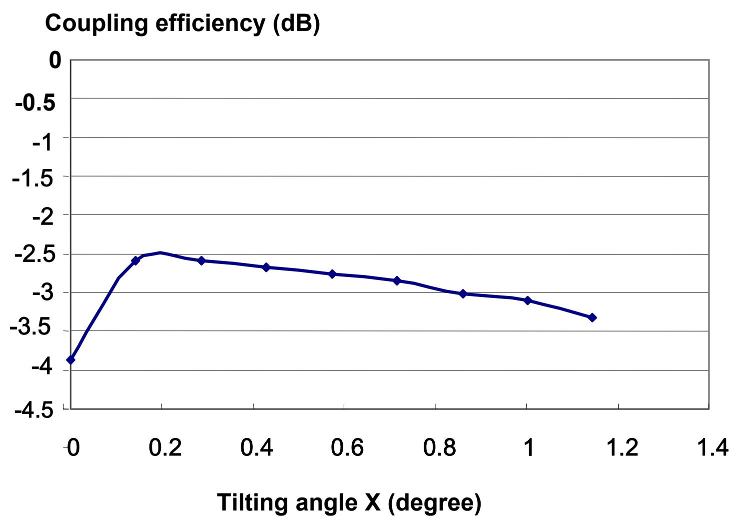

Fig. 7 Coupling efficiency vs. lateral tilting angle

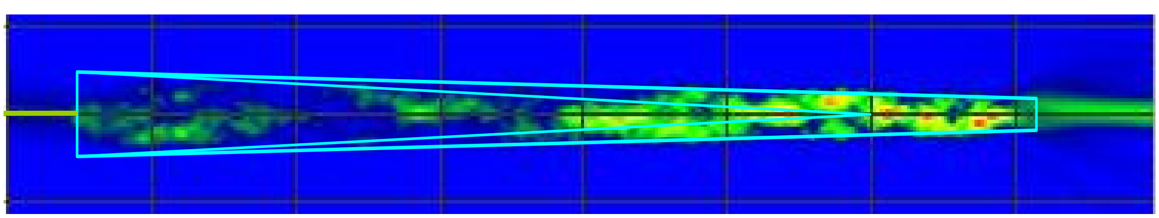

Fig. 8 Light propagation from Laser to fiber through taper coupler with tilting angle

4. FABRICATION AND EXPERIMENTAL RESULTS

The test structure is fabricated on silicon optical bench. The length of the taper coupler is 1.7mm. The width of the fabricated taper coupler at the input side is 23µm and the depth is 19µm. The size at the output side of taper coupler is 8µm by 9µm. The output of the taper coupler is attached to a single mode fiber. Figure 9 shows the experimental configuration of the silicon optical bench. Figure 10 shows the cross-section of the taper coupler fabricated in silicon.

To study the tolerance of the taper coupler, we use a lensed single mode fiber as the input. The lensed fiber has about 2µm beam size and relative large divergence angle, which is similar to laser diode output. We aligned the lensed fiber with the taper coupler to achieve the best coupling from the lensed fiber through taper coupler to output single mode fiber. Then we shift the lensed fiber laterally and vertically. Figure 11 shows the lateral tolerance study. With lateral offset from -5µm to +5µm, the coupling efficiency variation is 6dB. Figure 12 shows the vertical tolerance study. With vertical offset from -6µm to +3µm, the coupling efficiency variation is 6dB. The coupling variation is 3dB more than the simulation result for the same tolerance range, which may due to the non-perfect input facet of the taper coupler which is not flat and smooth in this experiment.

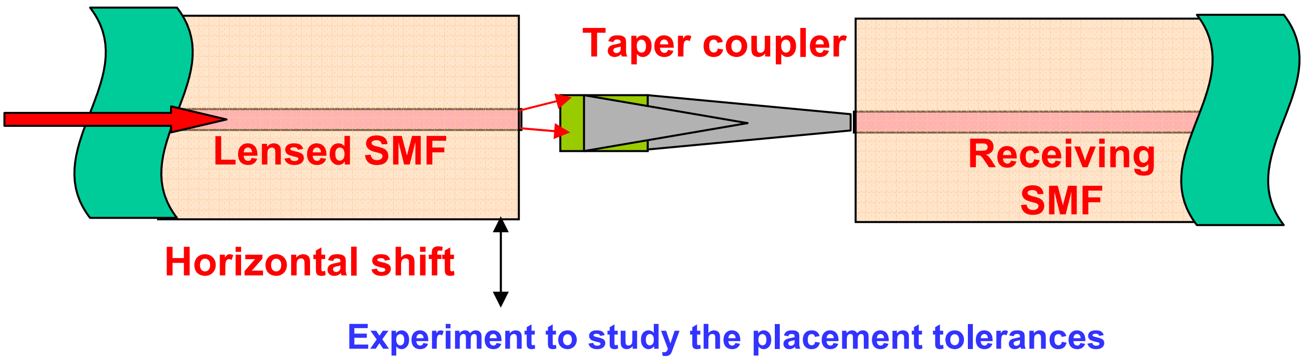

Fig. 9 Silicon optical bench for taper coupler.

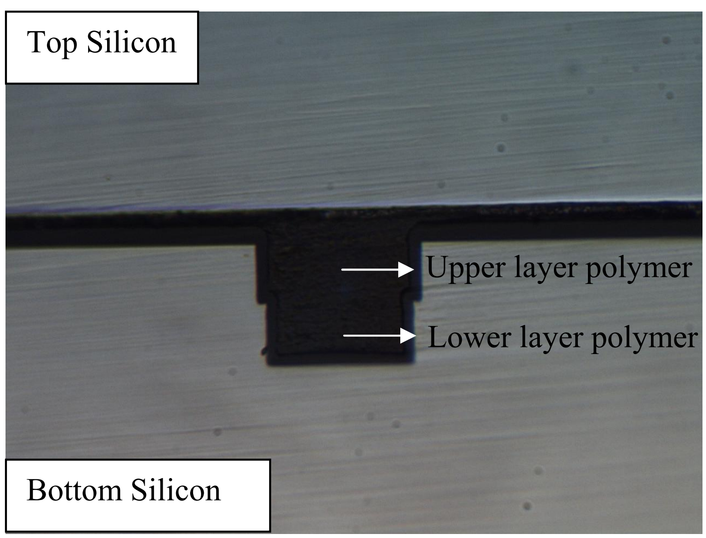

Fig. 10 Cross-section of taper coupler waveguide.

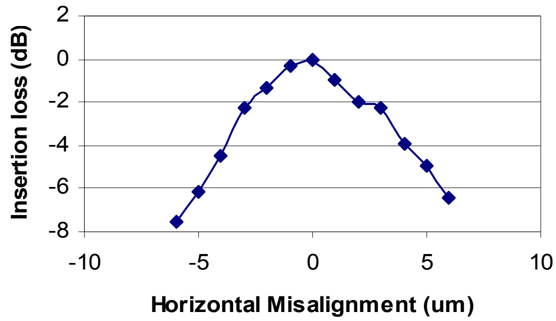

Fig. 11 Insertion loss variation over lateral tolerance

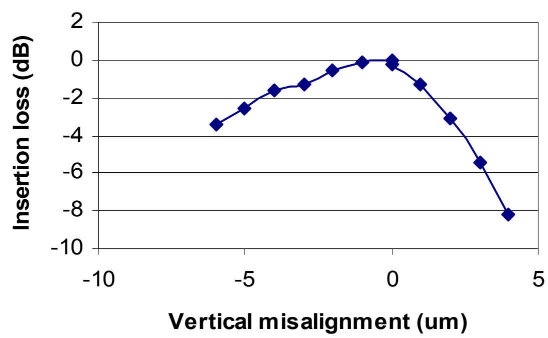

Fig. 12 Insertion loss variation over vertical tolerance

5. CONCLUSIONS

In this paper a taper coupler with multimode input and single mode output is presented for coupling between edge emitting laser diode and single mode fiber. A prototype is fabricated and tolerance for laser diode placement is studied. A coupling efficiency of -6dB is achieved from laser diode to single mode fiber. A tolerance of +/-5µm is achieved both laterally and vertically. The tolerance is large compared with other methods. The coupling efficiency can be further improved by assembling the laser diode closer to the taper coupler structure. The new design can be applied to photonics packaging because it will make passive assembly easier by having larger tolerance for packaging compared with the conventional method with lens. Important results are summarized as followings:

1) A taper coupler is designed for larger tolerance laser diode and single mode fiber light coupling;

2) With +/-5µm laser diode offset, the coupling efficiency varies only 3dB;

3) Slight tilting at the laser diode will improve the coupling efficiency;

4) The lateral tilting angle tolerance at the laser diode is more than 1 degree.

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