A novel polished conical silicon-cored-fiber based edge coupler for silicon photonics

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***Abstract*—A silicon-cored-fiber (SCF) is proposed for coplanar light coupling from an incoming fiber to a silicon waveguide. The simulation results show that an optimized polished conical SCF coupler can have high coupling efficiencies in both TE and TM modes and with low polarization penalty.**

Keywords—Fiber-to-chip coupling, Edge coupling, Silicon-cored-fiber.

I. Introduction

In silicon photonics, fiber-to-chip coupling from a light source to a silicon-on-insulator platform is a crucial topic. While having good misalignment tolerances, the commonly used vertical coupling supported by a grating coupler is usually bulky as a result of its non-coplanar architecture with a silicon chip [1]. On the other hand, edge couplers are anticipated to have better packing density and integrate more seamlessly with silicon chips. However, it is well known that a commercial single mode fiber (SMF) is not suitable for direct edge coupling because of significant refractive index difference and mode size mismatch between a silicon chip and an SMF.

To solve these problems, we propose a novel SCF-based edge coupler. First of all, SCFs can be spliced with SMFs at one end and edge-coupled to silicon waveguides at the other end with low splicing loss [2]. Secondly, since both silicon waveguides on silicon chips and SCFs are made from silicon, the inherent Fresnel reflection loss between them would be eliminated. Furthermore, based on our preliminary experimental results, which indicate the feasibility of fabrication, a polished conical SCF coupler combining fiber tapering and side polishing is analyzed.

II. Coupler Design and Analysis

It has been reported that a tapered SCF with a sub-micrometer tip could be fabricated by sleeving the SCF into a hollow core fiber before tapering process [3]. Moreover, based on the modified side polishing techniques [4], a polished SCF with a D-shaped region could be fabricated under careful control. Therefore, by combining two methods for shaping SCF geometry, a novel polished conical SCF coupler is proposed. Fig. 1(a) shows the schematic of a polished conical SCF coupler coupling to a silicon single mode strip waveguide (Si SMWG). Fig. 1(b) shows the definitions for segmented areas of our polished conical SCF coupler, including an input region, a tapered region that reduces the diameter of the SCF, a polished region where the materials are partially removed by a circular polishing wheel, and the Si SMWG to be coupled.

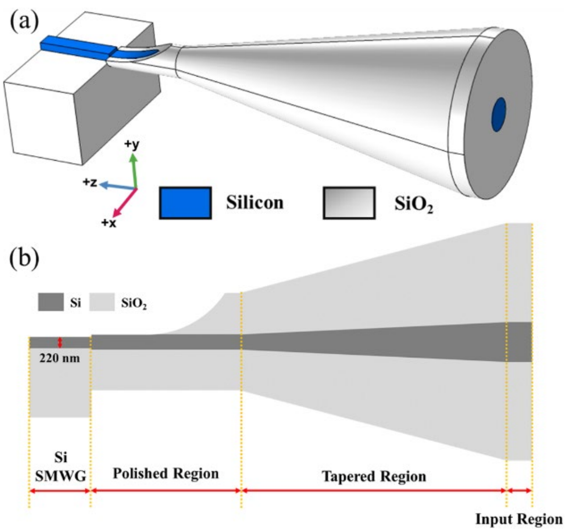

Fig. 1 (a) Schematic of the polished conical SCF coupler coupling to a Si SMWG. (b) The defined terms of the overall coupling scheme.

Firstly, the mode match between the polished conical SCF coupler and the Si SMWG is quantified. The modal overlap integral η is investigated and can be expressed as:

$$\eta = \frac{\left|\int_A E_1^* E_2 dA\right|^2}{\int_A |E_1|^2 dA \cdot \int_A |E_2|^2 dA} \qquad (1)$$

where A is the area of integration and E_1, E_2 are the electric fields of the output mode of the polished conical SCF and the mode of Si SMWG, respectively. To find the maximal coupling efficiency, we calculate the two-dimensional (2D) electric field intensity distributions at 1550 nm wavelength based on the finite element method in Rsoft, without considering the effect of diameter variation on the light propagation in the coupler. Fig. 2(a) shows the effective mode indices of a half-polished conical SCF. The intersection of the effective mode index between the polished conical SCF and the Si SMWG proves the inherent advantage of SCF eliminating the Fresnel loss caused by refractive index mismatch. Fig. 2(b) shows the variations of the modal overlap integral when the polished position changes. According to Fig. 2(b), when the polished position has not yet reached the boundary of the core, the polishing process won't have a significant impact on the modal overlap integral. When the polished position has just reached the boundary of the core and further goes down for a short range, the modal overlap integral will rise slightly. However, when the polished position continues to go downward, the modal overlap integral will drop rapidly and significantly.

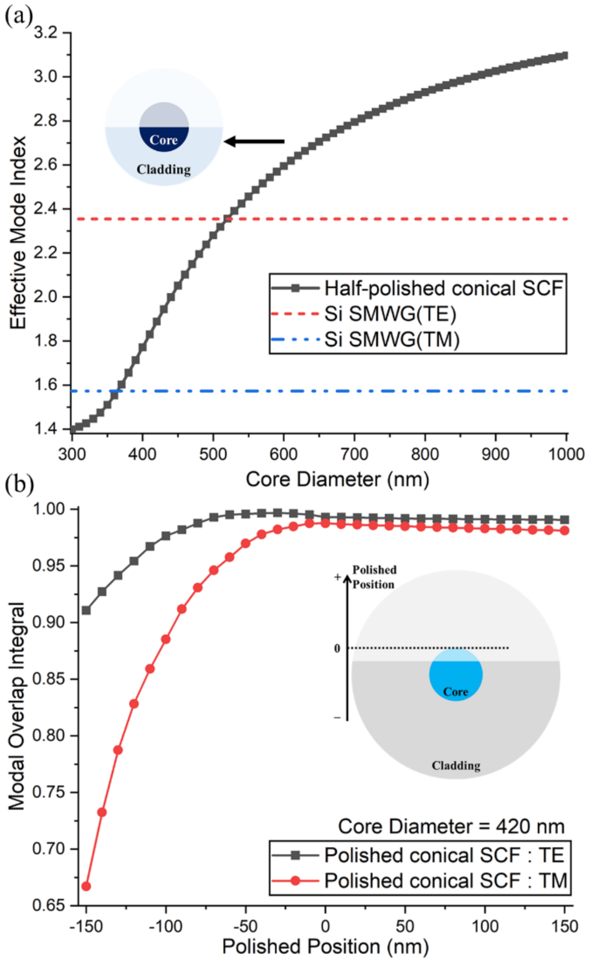

Fig. 2. (a) The calculated effective mode index of the eigenmodes in the Si SMWG and the polished conical SCF,where the polished conical SCF is half -polished. It shows the inherent advantage of SCF eliminating refractive index mismatch. (b) The variations of the modal overlap integral when the polished position changes while the core diameter is fixed at 420 nm.

Based on the results of 2D modal overlap integral, the parameters for further optimization are set as follows: the input core diameter is 2 μm, the core diameter after the tapered region is 420 nm, and the polished position is zero. The length of polished region is as short as possible without affecting other structures. Although the modal overlap integral hasn't reached its peak at this polished position, the polarization penalty is relatively smaller. Next, the three-dimensional beam propagation method simulation is applied to calculate the coupling efficiency and explore the difference between TE and TM. Fig. 3 shows the beam propagation along the coupler, and the coupling efficiency regarding of TE mode and TM mode is marked out in the figure. A promising high coupling efficiency of 99.0% in TE mode is derived from the pathway monitors. Moreover, the TM mode polarization penalty is only -0.037 dB, implying a low polarization dependence.

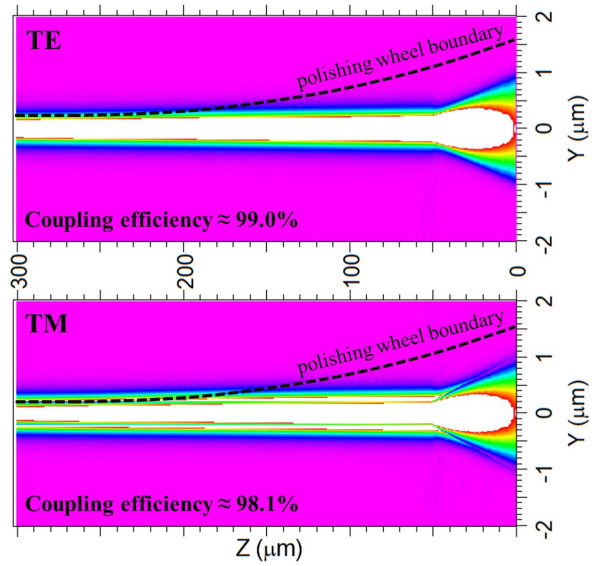

Fig. 3. The beam propagation along the polished conical SCF coupler and the coupling efficiency regarding of TE mode and TM mode.

III. Conclusion

A novel SCF-based coupler with polished conical shape for fiber-to-chip coplanar edge coupling is proposed and optimized at 1550 nm wavelength. The simulated results show that a high coupling efficiency of 99.0% and 98.1% can be obtained in TE and TM modes, respectively, with a polarization penalty of only -0.037dB. Such a polished conical SCF coupler may provide an alternative light coupling commonly required between an incoming optical fiber and a silicon waveguide in silicon photonics.

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