Ultra-compact Broadband Silicon Polarization Beam Splitter Based on a Bridged Bent Directional Coupler

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***Abstract*—An ultra-compact (coupling length ~ 6.28 μm) broadband polarization splitter is experimentally demonstrated based on a silicon bridged bent directional coupler. The polarization extinction ratios are > 15 dB and > 20 dB for the TE- and TM-polarized lights in the wavelength range of 90 nm, respectively.**

I. INTRODUCTION

Polarization handling devices, including polarization beam splitters (PBSs) and polarization rotators, are key devices in polarization diversity schemes to eliminate the polarization sensitivities [1]. Many schemes have been reported to realize the PBSs, including directional coupler [2, 3], multimode interference (MMI) [4], grating-assisted coupler [5], and so on. A PBS based on a bridged directional coupler was reported with polarization extinction ratios (PERs) of > 17 dB in the wavelength range of 100 nm. The coupling length is 7.5 μm [2]. An ultra-short PBS based on asymmetrical bent directional couplers was demonstrated with the PER of < 10 dB for TM polarization [3].

In this paper, we propose and experimentally demonstrate an ultra-compact broadband PBS based on a silicon bridged bent directional coupler. Bent and bridged waveguides are introduced to realize asymmetrical coupling and decrease the coupling length. The coupling length is 6.28 μm. The PERs of the fabricated PBS are higher than 15 dB and 20 dB for the TE- and TM-polarized lights in a broad wavelength range (> 90 nm), respectively. By placing a parallel bridged waveguide into the conventional bent directional coupler, higher PERs and broader operation bandwidths are obtained, comparing with the PBS based on conventional bent directional couplers [3].

II. DEVICE STRUCTURE AND OPERATION PRINCIPLE

Figures. 1(a) and (b) show the 3D view and top view of schematic configuration of the proposed PBS based on a bridged asymmetrical bent directional coupler, respectively. To realize a silicon PBS with high PER and broad operation bandwidth, a parallel bridged waveguide is placed in a conventional bent directional coupler. The three bent waveguides have different core widths of w_1, w_2 and w_3, respectively. The phase-matching condition is satisfied for the coupling of TM polarization between the three bent waveguides. The TM-polarized light is coupled to the Cross port. On the other hand, for the TE polarization, the phase-matching condition is not satisfied due to the birefringence of the waveguides. The TE-polarized light goes through the input waveguide without significant coupling and outputs at the Bar port.

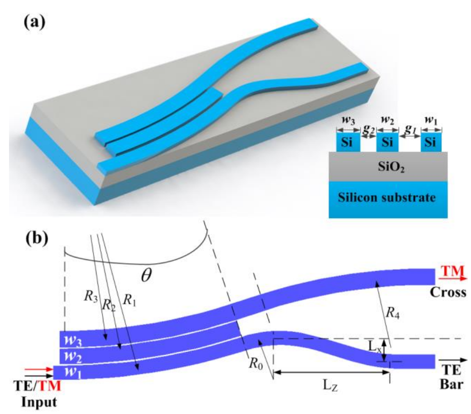

Fig. 1 Schematic configuration of the proposed silicon PBS.

The device is designed for the SOI wafer with a 220 nm-thick top silicon on a 3 μm-thick buried oxide (BOX). The bending radius of waveguide 1 (WG 1) is $R_1 = 20$ μm. This is chosen as a trade-off between low bending loss of the waveguide and large phase mismatch for the TE mode. The bending radius of waveguide 2 (WG 2) is $R_2 = R_1 - (w_1 + w_2) / 2 - g_1 = 19.415$ μm, and the bending radius of waveguide 3 (WG 3) is $R_3 = R_2 - (w_2 + w_3) / 2 - g_2 = 18.812$ μm. The arc-angle of the coupling region is 0.1π rad, and the corresponding coupling length is 6.28 μm. The S-bend at the Bar port is designed to separate the output waveguides. The bend at the Cross port has a radius of $R_4 = 18$ μm, which is large enough to give a low bending loss for the TM-polarized light.

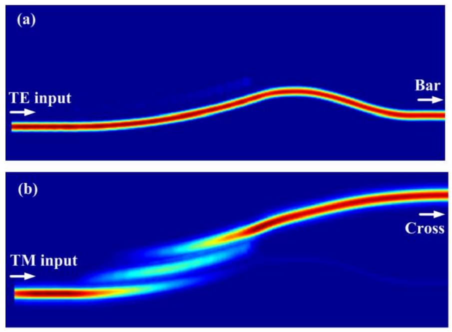

Fig. 2: (a)-(b) Simulated power distributions in the PBS for the TE- and TM-polarized inputs, respectively.

The effective indices and widths of three bent waveguides are optimized to realize equal optical path lengths and satisfy the phase-matching condition, which are calculated by finite-difference time-domain (FDTD) method. The widths of the three bent waveguides are 428, 482 and 524 nm, respectively. The 3D FDTD method is applied to simulate the PBS structure. The simulated power distributions for the TE- and TM- polarized light inputs are depicted in Figs. 2(a) and (b), respectively. The TM-polarized light is coupled and outputs from the Cross port, while the TE-polarized light goes through the waveguide and outputs from the Bar port.

III. Device Fabrication and Measured Results

In the experiment, the PBSs were fabricated on a SOI wafer by E-beam lithography (Vistec EBPG 5200) and inductively coupled plasma dry etching. Scanning electron microscope (SEM) photo of a fabricated PBS is shown in Fig. 3.

Two identical PBS devices were fabricated to measure the responses for the TE- and TM- polarized light inputs, respectively. The TE- and TM- polarized lights from a tunable continuous wave laser were coupled into/out of the chip by grating couplers, respectively. The output spectra were recorded by an optical power meter. Grating couplers exhibit high polarization dependences.

Figures 4(a) and (b) show the measured transmission responses at the Bar and Cross ports of the fabricated PBS when the TE- and TM- polarized lights are injected, respectively. For the TE-polarized light input, high-efficiency TE-polarized light output is obtained at the Bar port. The PER is higher than 15 dB in a broad wavelength range of 1507 nm ~ 1600 nm, and the insertion loss is < 1 dB. For the TM-polarized light input, the PER is higher than 20 dB in the wavelength range of 1507 nm ~ 1600 nm, and the corresponding insertion loss is < 1 dB in the broad wavelength range.

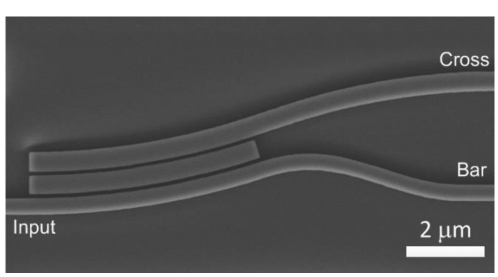

Fig. 3: Scanning electron microscope (SEM) photo of the fabricated PBS based on a bridged bent directional coupler.

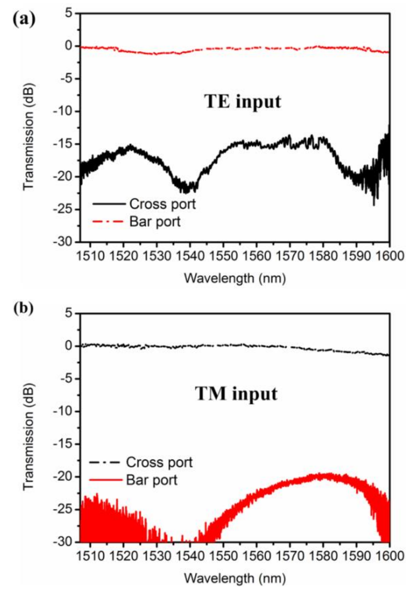

Fig. 4: Measured transmission responses at the Bar and Cross ports for (a) TE-polarized and (b) TM-polarized inputs.

IV. Conclusion

We have experimentally demonstrated an ultra-compact (coupling length ~ 6.28 μm) silicon polarization splitter based on a bridged bent directional coupler. The PBSs are fabricated by a single etch process. By placing a parallel bridged waveguide into the conventional bent directional coupler, higher PERs and broader operation bandwidths are obtained. The PERs are higher than 15 dB and 20 dB for the TE- and TM-polarized lights in a broad wavelength range (> 90 nm), respectively. The corresponding insertion losses are ~ 1 dB for both polarizations.

References

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