Broadband mode-evolution-based four-port polarizing beam splitter

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Abstract: The first demonstration of a four-port integrated polarizing beam splitter is reported. The device was fabricated on a silicon-on-insulator platform and exhibits crosstalk level < -10dB over a 150nm bandwidth.

OCIS codes: (130.3120) Integrated optics devices; (130.2790) Guided waves; (230.5440) Polarization-selective devices.

1. Introduction

Integrated silicon photonics [1], which offers single-mode operation, unprecedented bandwidth density, and compactness, is growing rapidly with the exponential increasing demand for bandwidth with the Internet and within the data centers. While communications are the main driving force for silicon photonics, the resulting silicon photonics platforms can be applied to numerous problems, ranging from sensing, microwave photonics and quantum optics, offering degrees of performance unachievable with their free-space counterparts [2,3]. The general applicability of the platform is determined by how extensive the component libraries are and how easily free-space optical systems can be implemented. However, among the components demonstrated previously, an exact correspondence to a free-space polarizing beam splitter (PBS) [shown in Fig. 1(a)], which has four ports (2-input 2-output), is still missing. All "so-called" polarizing beam splitters demonstrated so far, with 10dB extinction bandwidth of 50, 60, 70, and 100nm [4-7], are in themselves polarization splitters, with only one input and two outputs and not true four-port polarizing beam splitters.

In this paper, we propose and demonstrate the first four-port integrated polarizing beam splitter. The structure was implemented on a 300mm silicon-on-insulator (SOI) wafer with a 220nm device layer, showing less than -10dB crosstalk over a broad 150nm bandwidth. Importantly, this device provides a substantial addition to the component library with immediate application to compact on-chip interferometers and quantum information processing.

2. Design and Fabrication

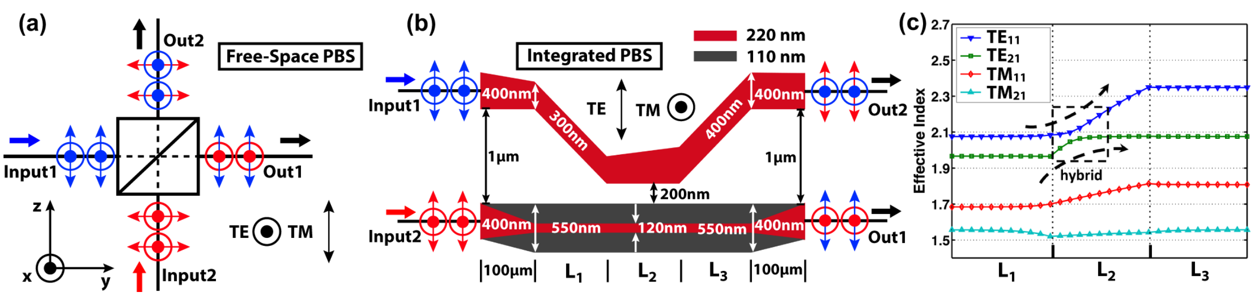

Fig. 1. (a) The operation of a traditional free-space PBS cube. (b) Proposed integrated PBS. L_1=L_3=500µm. L_2=200µm. Note: the TE/TM polarization convention is inverted on-chip compared to the free-space case. (c) Eigenmode effective indices evolutions from the beginning of the L_1 part to the end of L_3 part in (b) for wavelength of 1440nm.

The proposed structure is depicted in Fig. 1(b). Two well-separated 400nm width full-thickness input waveguides are first converted to a narrow full-thickness waveguide and a wide half-thickness waveguide with a narrow ridge. The large separation ensures a smooth transition of individual modes of the waveguides without mutual coupling, which would otherwise reduce the operating bandwidth. This sets the initial condition for the effective indices to $\bar{n}_{TE_{11}} > \bar{n}_{TE_{21}} > \bar{n}_{TM_{11}} > \bar{n}_{TM_{21}}$, with the fundamental TE mode propagating in the lower waveguide and fundamental TM mode propagating in the upper waveguide [shown in the start of Fig. 1(c)]. The two waveguides are then brought close to each other, and the modes of the individual waveguides become super-modes of the two-waveguide system. Under the adiabatic limit, the modes will evolve following the effective index curve [shown in Fig. 1(c)] and stay in the eigenmodes along the propagation [8]. Thus, through tapering the full-thickness waveguide from 300nm to 400nm, the fundamental mode TE_{11} gradually evolves to the upper waveguide and the TE_{21} mode is transferred to the lower waveguide while the TM modes remain in their respective waveguides. The two waveguides are then separated adiabatically and converted to traditional 400nm width full-thickness waveguides to connect to other on-chip devices. Though adiabatic devices are generally larger in footprint than nonadiabatic ones, the larger bandwidths and fabrication tolerances make them more suitable candidates for wafer-scale production.

The proposed structure was fabricated on a 300mm SOI wafer with 220nm device layer and 2μm thick buried oxide (BOX) layer using 193nm optical immersion lithography. The device was then covered with a 3.3μm thick top oxide layer. The cross-section SEM image of the fabricated device within the L_1 region of Fig. 1(b) is shown in Fig. 2(a). The ridge waveguide has a 110nm ridge thickness, a 120nm width on top and a 550nm width at the bottom.

2. Experimental Results

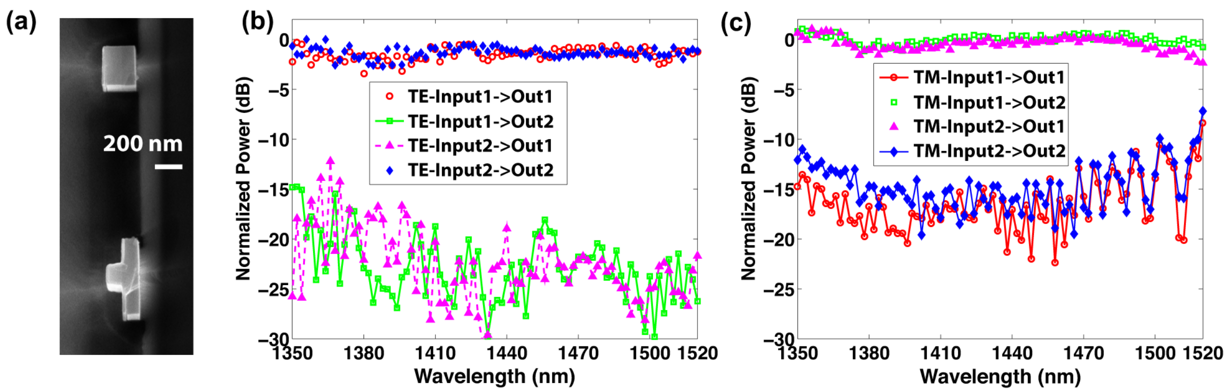

Fig. 2. (a) Cross-section scanning electron microscope (SEM) image of the fabricated device in L_1 region of Fig. 1(b). (b) Transmission spectra of the fabricated device for TE-input polarization. (c) Transmission spectra of the fabricated device for TM-input polarization.

The cross- and through-transmission spectra of the fabricated device were measured though identical lensed single mode fibers. At both ends of the chip, identical inverse tapered waveguide couplers were used to match the waveguide mode to the fiber mode, maximizing the coupling between the fiber and chip. An external polarization controller was used to adjust the input polarization to be transverse electric (TE) or transverse magnetic (TM) polarized with respect to on-chip polarization references. The power for each polarization was normalized to a nearby straight waveguide with identical inversely tapered waveguide couplers. The TE modes from both inputs ports were excited separately, and both output ports were measured to identify crosstalk level. The transmission spectra from λ=1350 to λ=1520nm are depicted in Fig. 2(b). The TE modes, excited from either input, achieve over 170nm bandwidth with less than -10dB crosstalk level. Similarly, the TM mode transmission spectra are shown in Fig. 2(c), indicating over 150 nm bandwidth from λ=1350 to λ=1500nm with less than -10dB crosstalk level. The bandwidth for the TE modes is likely limited by high-order-mode interaction and insufficient transition length for wavelength shorter than 1350nm, while the TM modes are limited by the substrate leakage for wavelength of longer than 1500nm. Thus, by improving the TM modes confinement while preserving the same mode evolutions scheme along propagation, the bandwidth of the device can be further extended to C and L bands.

3. Conclusions

A four-port (two input and two output ports) integrated polarizing beam splitter (PBS) is demonstrated for the first time and with a massive bandwidth of over 150nm while maintaining less than -10dB crosstalk for TE and TM modes on a 300mm CMOS-compatible SOI platform. The device provides a substantial addition to the silicon photonics component library with immediate application to compact on-chip interferometers and quantum information processing.

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4. References

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