Dual-polarization Ultra-wideband Nanophotonic Beam Splitter

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ABSTRACT

High-performance optical beam splitters are of fundamental importance for the development of advanced silicon photonics integrated circuits. However, the performance of state-of-the-art silicon nanophotonic splitters is limited in terms of bandwidth and polarization dependence. Here, we present a new beam splitter approach that exploits modal engineering in slotted waveguides to overcome these limitations, enabling ultra-broadband polarization-insensitive optical power splitting. The proposed splitter relies on a single-mode slot waveguide that is gradually transformed into two strip waveguides by a symmetric taper, yielding equal power splitting. Based on this concept, we experimentally demonstrate insertion loss and power imbalance lower than 1 dB for both, transverse-electric (TE) and transverse-magnetic (TM) polarizations in an unprecedented bandwidth of 390 nm (1260 - 1650 nm).

Keywords: beam splitter, silicon-on-insulator, ultra-wideband, dual-polarization.

1. INTRODUCTION

The high index contrast in Si wire waveguides enables the implementation of ultra-compact photonic circuits. However, this tight modal confinement also poses important challenges for the realization of polarization-independent circuits with a large bandwidth. Hence, silicon-on-insulator (SOI) circuits typically operate in a single polarization state, within a limited wavelength range. More specifically, the performance of conventional silicon beam splitters is particularly limited by the strong wavelength and polarization sensitivity of the SOI platform.

Several beam splitters with different advantages and limitations have been proposed over the past few years. Directional couplers (DCs) are typically narrowband and exhibit a strong polarization dependence [1],[2]. Silicon-bent [3] and subwavelength-grating-assisted DCs [4] have recently been demonstrated to exhibit polarization-independent or ultra-broadband behaviour separately. Y-junctions suffer from strong insertion loss due to the abrupt discontinuity at the branch intersection. Different Y-branch variations have been recently reported, alleviating this limitation with relatively broad bandwidths [5],[6]. Multimode interference couplers (MMIs) achieve low losses but provide only limited bandwidth- and polarization-dependent behaviour. Sub-wavelength engineering has been applied to increase the operational bandwidths of MMIs [7], but only in single-polarization operation.

In this work, we present a novel beam splitter concept harnessing modal engineering in slotted waveguides to provide ultra-broadband and polarization-independent operation. We experimentally show insertion loss and power imbalance below 1 dB in an unprecedented bandwidth of 390 nm for both the transverse-electric (TE) and transverse-magnetic (TM) polarizations.

2. DESIGN

The proposed beam splitter is schematically shown in Fig. 1. A single-mode slot waveguide is used to equally split the injected power into two output strip waveguides in a wavelength- and polarization-agnostic fashion. The proposed device comprises three sections: a strip-to-slot mode converter, a slot waveguide and a slot-to-strip splitting transition. The single-mode operation of the slot waveguide is of fundamental importance to our device as it precludes any wavelength-dependent mode beating, which is the main bandwidth limitation in DCs and MMIs. The adiabatic strip-to-slot mode converter circumvents any abrupt index discontinuity, which is the major source of loss in conventional Y-junctions. In addition, the symmetric slot-to-strip transition yields equal power splitting between the two output waveguides, independent of the polarization and wavelength.

For the design of the splitter, we considered 220-nm-thick Si with a buried silicon dioxide layer (BOX) and polymethyl methacrylate (PMMA) upper cladding. Input and output waveguides have a width of and W_I = 450 nm. In the optimized splitter, the central slot waveguide has a rail width of W_R = 150 nm and a slot width of G_S = 100 nm, that ensure single-mode behaviour in the wavelength range between 1200 nm and 1700 nm. The lengths of the different sections of the coupler are optimized to minimize insertion loss by 3D EME simulations [8].

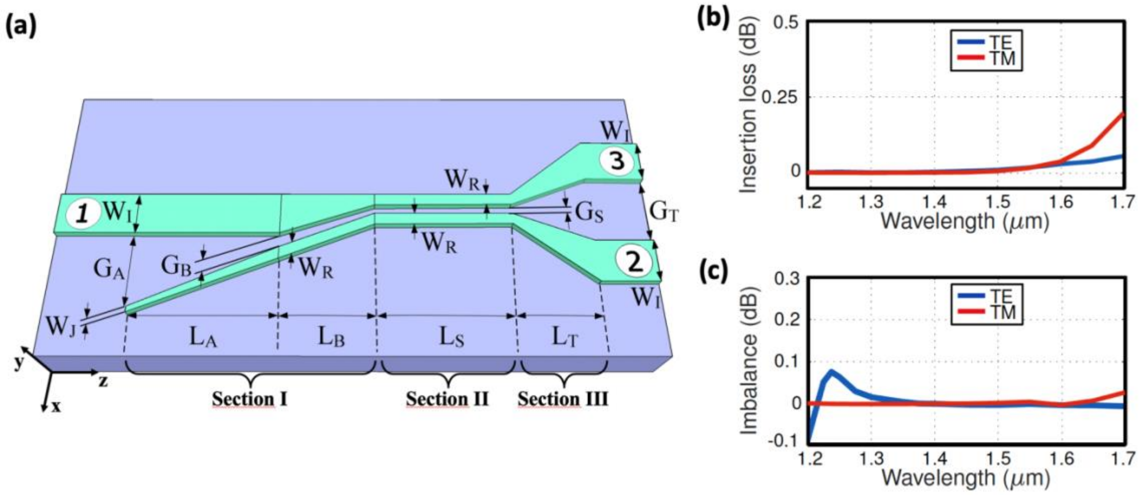

Figure 1. (a) Schematic of the proposed nanophotonic beam splitter based on single-mode slot waveguide. Calculated insertion loss (b) and power imbalance (c) for the optimized splitter considering both, TE and TM polarizations.

To assess the performance of the splitter, we considered the insertion loss (IL), defined as the amount of power relative to the input power that is not transferred to any output, and the imbalance (IB), defined as the power difference between the two output ports. As shown in Figs. 1(b) and (c), the proposed splitter yields calculated IL lower than 0.5 dB and imbalance better than 0.3 dB for both, TE and TM polarizations in the wavelength range between 1200 nm and 1700 nm.

3. EXPERIMENTAL RESULTS

The silicon beam splitter was fabricated using electron beam lithography (Nanobeam NB-4 system, 80 kV) and dry etch process. Then, the circuits were covered with a 1-µm-thick PMMA layer. Figure 2 shows the scanning electron microscope (SEM) images of the fabricated device.

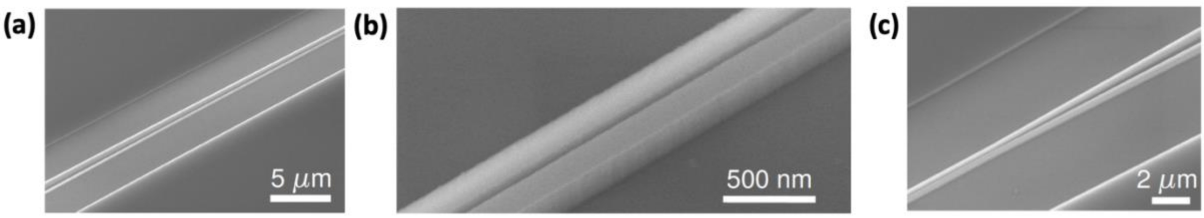

Figure 2. Scanning electron microscope (SEM) images of the fabricated device, showing (a) strip-to-slot transition at the input of the splitter, (b) central slot region, and (c) slot-to-strip transition at the output of the splitter.

To experimentally characterize the splitter, we used two configurations: a Mach-Zehnder interferometer (MZI) and cascaded splitters. The MZI configuration allows precise estimation of the imbalance, while the configuration comprising cascaded splitters allows accurate characterization of the insertion loss.

In the MZI configuration, two identical splitters are connected in a back-to-back configuration with an arm length difference of 40 μm. We estimated the power imbalance from the measured extinction ratio. As shown in Fig. 3(a), our splitter ensures an imbalance below 1 dB in the full wavelength range for both polarizations.

To characterize insertion loss, we cascaded five beam splitter stages. Insertion loss is extracted from the linear regression fitting of the transmission in the five splitters. Figure 3(b) shows that the proposed splitter provides insertion loss lower than 1 dB in a 390 nm bandwidth, between 1260 nm and 1650 nm wavelength, for both TE and TM polarizations.

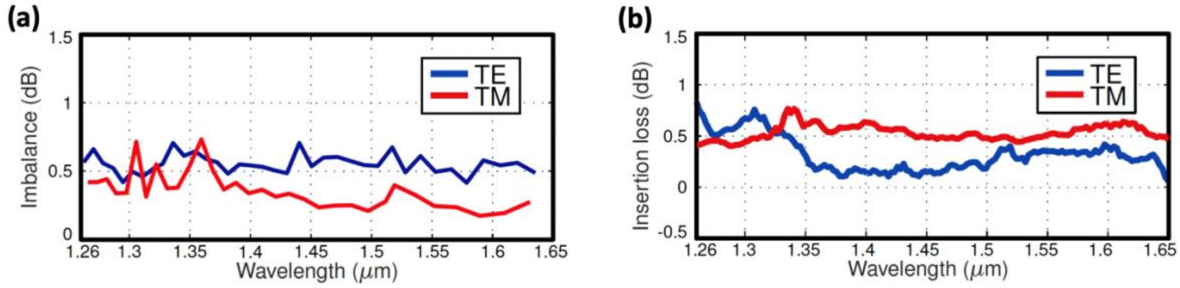

Figure 3. (a) Experimental power imbalance extracted from the measured extinction ratio in a MZI comprising two identical slot-based power splitters. (b) Measured insertion loss of a single splitter extracted from measurement of 5 cascaded splitters.

4. CONCLUSIONS

In conclusion, we report the experimental demonstration of an ultra-broadband and polarization-independent optical beam splitter. The proposed device relies on a single-mode slot waveguide with a symmetric slot-to-strip transition. The single-mode operation of the slotted section prevents wavelength-dependent mode beating, which is the major bandwidth limitation in conventional DCs and MMIs. On the other hand, the symmetric geometry ensures equal power splitting for both the TE and TM, independent of the wavelength. Based on this concept, we experimentally show near-ideal power splitting with insertion loss and power imbalance below 1 dB for both TE and TM polarizations, covering the O, E, S, C and L telecommunication bands. The proposed optical beam splitter opens new venues for the implementation of dual-polarization and ultra-broadband silicon photonics circuits.

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