Low-loss and broadband adiabatic polarization splitter rotator on a CMOS-integrated silicon photonics platform

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Abstract: We experimentally demonstrate an adiabatic polarization-splitter-rotator on a monolithic SiPh platform. Our measurements indicate an insertion-loss of ~-0.42dB for TM input and polarization-dependent-loss of <0.1dB across the O-band, accompanied by a polarization extinction exceeding 45dB. © 2024

1. Introduction

Polarization control in integrated photonics plays a crucial role in ensuring the high-speed, error-free operation of transceiver circuits leveraging silicon photonics (SiPh) platform [1]. Due to the relatively lower aspect ratio (height < width) of most photonic waveguides, SiPh circuits are typically optimized for a single polarization state (e.g. transverse electric (TE) polarization). However, other polarization components can be inadvertently excited within the photonic circuits due to possible fabrication imperfections. Similarly, when interfacing with single-mode fiber, receiver circuits may potentially suffer from mixed polarization signal [2]. Since Si waveguides (WGs) typically exhibit birefringence, this can significantly impact the bandwidth of the optical receiver.

To address this issue, polarization splitter rotators (PSRs) are employed for on-chip polarization control [3-4]. Various approaches have been explored in the SiPh platform to achieve polarization splitting and/or rotation. Among the existing solutions including compact designs, PSR based on adiabatic transitions are preferred, as they ensure broadband operation (e.g. wavelength range > 100 nm) with minimal polarization-dependent loss (PDL) and crosstalk [5]. In this paper, we report an adiabatic PSR implemented on a monolithic SiPh platform that leverages both Si and SiN layers to achieve efficient polarization manipulation [6, 7]. The PSR operates efficiently across the entire O-band and is seamlessly integrated with other photonic and CMOS components on the same silicon-on-insulator (SOI) wafer [8].

2. Monolithically integrated adiabatic PSR

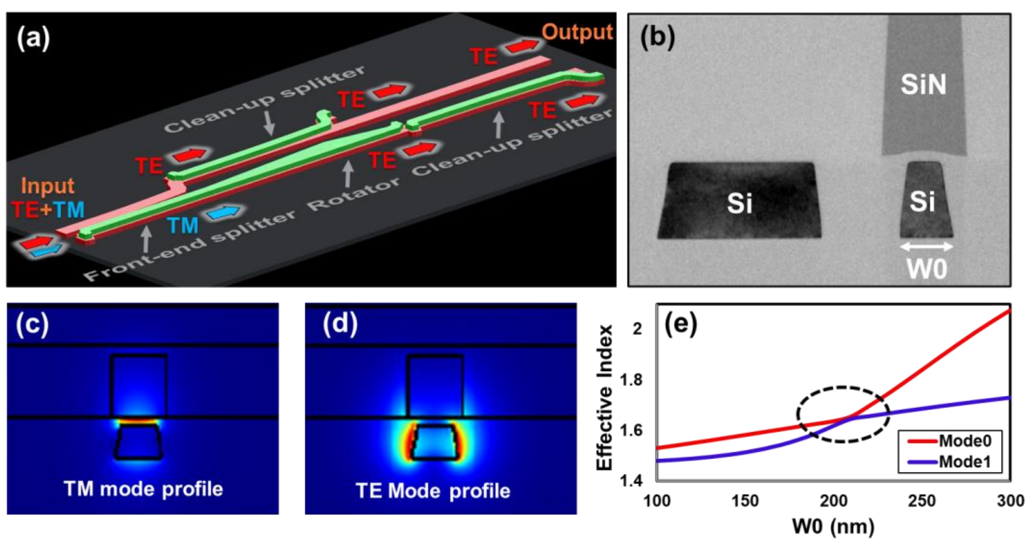

Fig. 1 (a) Schematic view of the PSR structure with separated polarization splitter, rotator, and cleanup filters. (b) Cross-section SEM image of the splitter section with minimum feature for Si. Simulated mode profiles for TM (c) and TE (d) of the hybrid structure with stacked silicon (Si) and silicon nitride (SiN). (e) Simulated effective indices of the fundamental and first order modes for the hybrid structure; highlight region shows the cross over point for the TE and TM modes.

Fig. 1(a) shows the schematic view of the PSR which includes polarization splitter, rotator and clean-up filter sections. At the input, incoming signal is coupled to a standard single-mode Si WG. The splitter section is formed by evanescently coupling a hybrid WG (with Si and SiN) to the single-mode WG. Here the hybrid structure effectively forms a vertical WG with higher effective index for the transverse magnetic (TM) mode. As a result, TM mode is coupled to the hybrid WG while the fundamental TE mode remains in the Si WG forming the polarization splitter. TE path of the splitter is then attached to a clean-up section to filter out any undesired TM fraction coupled to this path. In contrast, the TM path is cascaded with a polarization rotator section to convert the TM signal into TE. In the rotator section, WG symmetry is carefully broken by modifying the WG geometry of the hybrid WG adiabatically along the propagation direction to effectively rotate the orientation of the propagating signal. Adiabatic transition ensures minimal loss and high extinction ratio. After the rotator section, TM path is attached to a clean-up section to filter out undesired TM component in the TM path. Fig. 1 (b) shows the SEM image of the critical region (minimum Si width) of the splitter cross-section. It is worth mentioning here that a slight variation in the WG geometry can significantly impact the performance of the polarization filter, especially due to the fact that TE and TM modes can potentially hybridized at this section. Fig. 1 (c) and (d) show the simulated TE and TM mode profiles of the hybrid structure at the splitter section with minimum Si width. Fig. 1 (e) shows the effective indices of the fundamental (mode0) and first order (mode1) modes of the hybrid structure as a function of the critical dimension of Si. It is evident from the plot that the effective indices of TE and TM modes are nearly equal at specific Si WG widths. This implies that the TE and TM modes in the hybrid WG section travel at same phase velocity. In the tapered hybrid WG within the splitter section, there is a possibility of breaking mode orthogonality, resulting in mode overlap. This, combined with matched effective indices, can lead to significant polarization rotation and crosstalk. Therefore, it is crucial to carefully design the splitter section to avoid this critical hybrid WG geometry and minimize polarization rotation at the splitter.

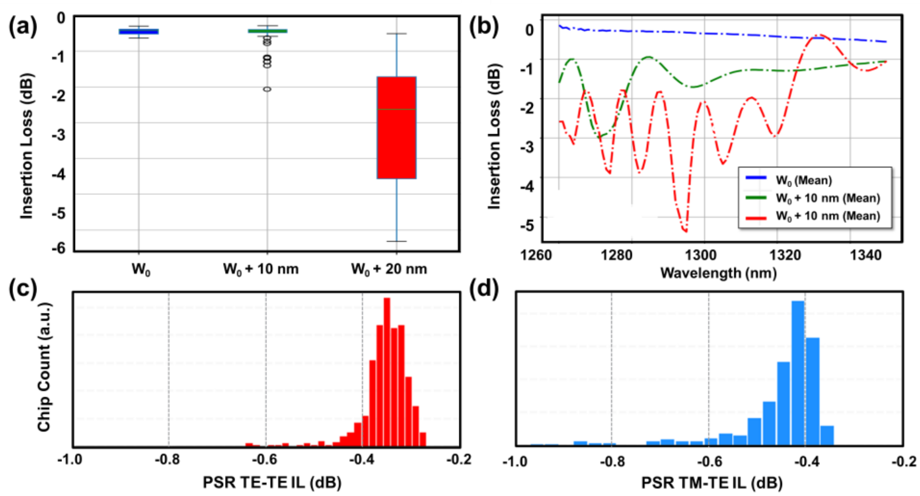

Fig. 2 Measured TM-TE IL of the PSR for different Si WG widths (a) Statistical distribution at 1310 nm. (b) Through-band performance. (c)-(d) Histograms for TE-TE and TM-TE ILs at 1310 nm.

PSR device structure was optimized (by satisfying design rules of GlobalFoundries Fotonix™ technology) to obtain low polarization dependent insertion loss and high extinction ratio. The footprint of the PSR design is ~ 1.34 mm × 0.039 mm. To estimate the insertion loss of the device, we have adopted a cut-back approach by connecting multiple PSRs in a cascading arrangement. Grating couplers were used to interface singlemode fibers at the input and output. Polarization rotators were used at the input and output regions of the PSR to characterize TM-TE path as the grating couplers were optimized for TE polarization only. Fig. 2 (a) illustrates the measured insertion loss (IL) at 1310 nm wavelength for TM-TE path of the PSR for various critical width of Si in the hybrid WG structure. As discussed above, it's noted that the IL increases as the critical width of Si in the hybrid WG structure is scaled up. An interesting observation is the substantial variation in IL for W0+20 nm, hinting that the potential occurrence of polarization rotation at the splitter section. In contrast, the measured IL for the optimized structure (W0) remains consistently stable. The wavelength sweep data, as shown in Fig. 2 (b), further supports these findings. In the case of the optimized structure (W0), the wavelength response remains stable and flat across the entire O-band. However, for PSRs with Si critical widths of W0+10nm and W0+20nm, ripples are evident towards the lower wavelength regime for the former, and across the entire wavelength spectrum for the latter. This behavior suggests that polarization rotation, primarily occurring at the splitter section, has a significant impact on the PSR performance, and this is substantiated by 3D FDTD simulation results. Fig 2(c) and (d) show measured IL distribution for the TE-TE and TM-TE paths in the optimal PSR, respectively. Average insertion loss for the TE and TM input signals were measured to be -0.35 dB and -0.42 dB, resulting in an ultra-low polarization dependent loss of < 0.1 dB at a wavelength of 1310 nm.

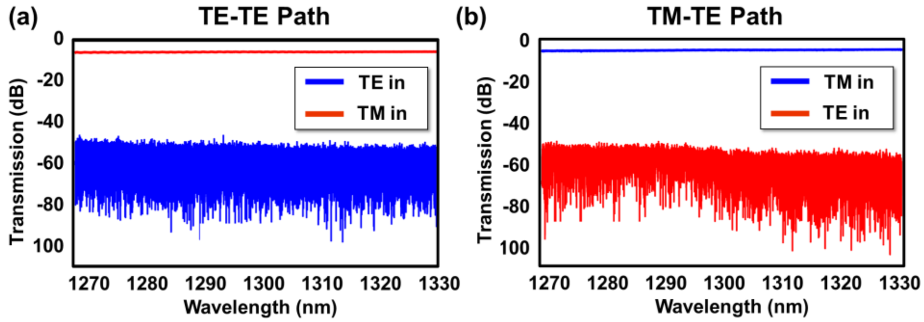

Fig. 3 PSR IL and crosstalk measurements for (a) the TE-TE path output, and (b) the TM-TE path output. The contrast between the red and blue traces in both figures represents the polarization extinction. Si edge couplers and routing waveguide losses were included in the measurement data.

To measure the crosstalk of the PSR, we have designed the layout with edge couplers at the input and output to couple light from standard singlemode fiber. The adiabatic PSR was characterized using an optical vector analyzer (OVA). The OVA accurately adjusted the input polarization to the chip, and the power at the TE-TE and TM-TE outputs was subsequently measured. Fig. 3 (a) and (b) show the insertion loss and crosstalk measurement for the TE-TE and TM-TE paths, respectively. TE-TE path insertion loss and crosstalk are measured by coupling TE and TM signals, respectively. Similarly, insertion loss and crosstalk at the TM-TE path is measured by launching TM and TE light at the input, respectively. Insertion loss is measured to be slightly more than the values estimated from the cut-back method due to the added loss from edge couplers. Crosstalk for both the TE-TE and TM-TE paths were measured well below -45 dB. It's important to note that the OVA characterization lacks the capability to decompose the output signal into its polarization components. This introduces an additional challenge in the effort to separate the TE and TM fractions for the measured crosstalk value. We plan to overcome this limitation in the future using alternative measurement techniques. Performance comparison of this work with reported devices (see Table 1) clearly show a significant benefit in terms of loss and extinction.

Design Approach	Loss [dB]	Extinction [dB]	Length [μm]	Reference
Adiabatic	< 1	> 27	401	W. D. Sacher et al. [5]
Adiabatic	< 0.9	NA	420	K. Giewont et. al [8]
Subwavelength grating	< 1.3	> 15	185	M. Ma et al. [10]
Mode Converter	< 1.5	> 22	475	W. D. Sacher et al. [4]
Adiabatic	< 0.42	> 45	1340	This work

Table 1. Performance comparison of this work with the PSRs reported in the literature.

3. Conclusion

In summary, we have demonstrated a broadband adiabatic polarization splitter/rotator implemented on a monolithic SiPh platform. As part of our design optimization, we carefully examined the critical geometrical aspects of the PSR, aiming to reduce crosstalk while minimizing IL. In addition, we have meticulously engineered the splitter section to eliminate unwanted polarization components. By incorporating adiabatic transitions in both the splitter and rotator sections, we were able to achieve low IL (-0.35 dB for TE input and –0.42 dB for TM input), minimal PDL (<0.1 dB), and successfully suppressed crosstalk to levels below -45 dB. Our monolithic PSR holds promise for a diverse array of applications, including polarization diversity schemes for optical receivers and various integrated photonic platforms.

4. References

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