European Conference on Optical Communication (ECOC) 2022 © Optica Publishing Group 2022

Compact and High-Performance Mode Evolution based Polarization Splitter-Rotator in Standard Active Silicon Platform

Zakriya Mohammed [(1)], Reza Safian [(2)], Bruna Paredes [(3)], Leimeng Zhuang [(2)] and Mahmoud Rasras [(3)]

[(1)] ECE Department, New York University-Tandon School of Engineering, Brooklyn, NY 11201 USA, zm775@nyu.edu
[(2)] imec USA, 194 NeoCity Way, Kissimmee, FL 34744, USA
[(3)] ECE Department, New York University Abu Dhabi, Abu Dhabi, UAE

Abstract *An entirely-mode-evolution-based polarization splitter-rotator assisted by a tapered TE-pass polarizer on a compact footprint of 185 μm is demonstrated. The measurement results show an insertion loss < 1.2 dB and extinction ratio > 25 dB over the complete C+L wavelength band. ©2022 The Author(s)*

Introduction

Silicon (Si) on insulator (SOI) is an excellent platform for fabricating photonic integrated circuits (PICs) that can be used to develop coherent transceivers with compact footprint and low cost. The polarization splitter-rotator (PSR) is one of the integral devices in the PIC that allows the coherent optical transceiver to transmit signals in different polarizations. The PSR's function is to rotate the transverse-magnetic (TM) portion of the input light to transverse-electric (TE) and split this converted portion as well as the TE portion of the input into two output ports. For coherent transmitters, the PSR functions as a polarization rotator and combiner (PRS), changing and combining both polarizations [1].

Many PSR devices recently proposed on the SOI platform can be classified into three types: mode-coupling-based [2], entirely mode-evolution-based [3–4], and a hybrid (combination of mode coupling and mode evolution). The hybrid PSR type employs mode evolution for the rotation function and mode coupling for the splitting function [5]. When compared to the entirely mode-evolution-based devices, all devices that use mode coupling (either completely or in hybrid form) have lower tolerances to fabrication variations and are narrow band. However, PSRs based on entirely on mode evolution, though they have higher tolerances to fabrication variations and wider bandwidths, they have a large footprint and extinction ratios of less than 15 dB.

This paper proposes a compact entirely-mode-evolution-based PSR based on partial etch ridge waveguides. Previously, only the mode converter section of the PSR was designed with a ridge waveguide that transitioned to a fully etched adiabatic section [3]. This transition increases loss, decreasing the extinction ratio and increasing the overall footprint. Ridge waveguides, on the other hand, can help to reduce the adiabatic device length due to the increased coupling strength between the waveguides. Larger transverse mode field diameters result in a stronger coupling, and thus larger mode overlaps [6]. A fabrication-insensitive tapered TE-pass polarizer is also added to further improve the extinction ratio.

Design Methodology

The proposed PSR is built on a 220 nm SOI platform with 2 μm cladding and buried oxide. Figure 1 depicts the proposed PSR design schematic. The PSR is divided into three sections (Region I, Region II, and Region III). Region I is the device's polarization rotation section, which is built with a bi-level taper. In the bi-level taper, the Si ridge and partially etched slab are continuously widened.

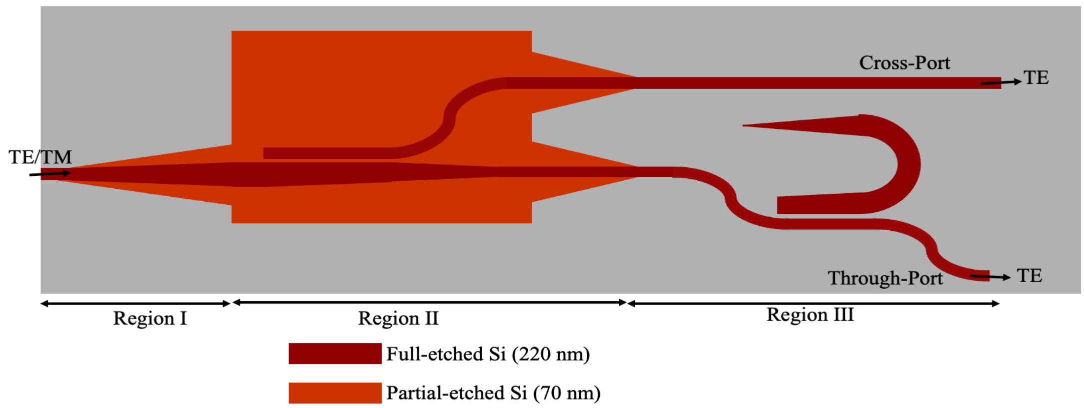

Fig.1 Schematic of the proposed PSR.

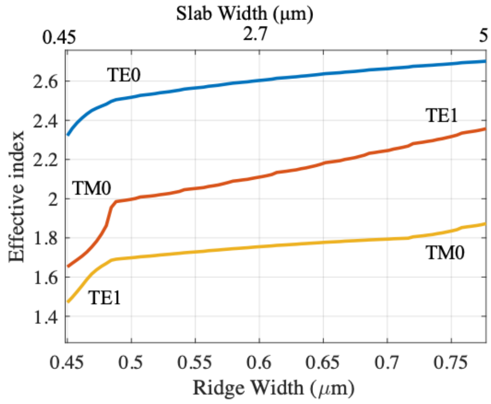

Fig.2 Calculated effective indices of the first three modes along the bi-level taper.

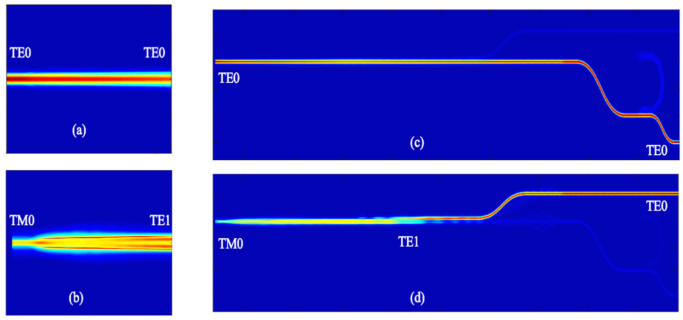

Fig.3 Simulated electric field distribution at 1550 nm for the bi-level taper when launching (a) TE0 mode. (b) TM0 mode. Field propagation through entire PSR at 1550 nm when launching (a) TE0 mode. (b) TM0 mode.

The partially etched slab breaks the waveguide's vertical symmetry, allowing mode hybridization to realize a TM0 to TE1 mode converter. The mode hybridization region, as shown in figure 2, has a width (ridge) of 490 nm. As a result, in the bi-level taper, the ridge and slab waveguides widen from 0.45 μm to 0.8 μm and 5 μm, respectively, to facilitate mode conversion from TM0 to TE1. A TE0 input, on the other hand, remains in TE0 mode throughout the taper, with no mode hybridization. Figures 3 (a) and 3 (b) show the mode evolution of the bi-level taper for TE0 and TM0 inputs, respectively. The TE0 and TE1 modes are present in the wide waveguide after the bi-level taper. Then region II is added, which is an adiabatic coupler that couples TE1 to the cross-port while leaving the TE0 mode unaffected. The bi-level taper is used here to connect directly to the ridge waveguide-based adiabatic coupler, which is a key difference from previous PSR designs. The footprint of an adiabatic coupler on a ridge waveguide is significantly reduced. The TE1 mode couples adiabatically to the upper waveguide and evolves into the TE0 mode at the cross-port. A tapered directional coupler-based TE-pass polarizer is added in region III to remove any residual TM0 mode and increase the port's extinction ratio (ER). A tapered directional coupler-based design can help overcome the fabrication and bandwidth limitations of a conventional directional coupler (DC) [9]. To reduce crosstalk and improve the extinction ratio, a unique combination of 180-degree bend and S-bend is used. Figure 3 depicts the field propagation of the entire PSR (c-d).

Fabrication and Experimental Results

The designed PSR is fabricated using Applied Nanotools Inc.'s NanoSOI process, which is based on direct-write 100 keV electron beam lithography technology. Figure 4 shows electron microscope (SEM) micrographs of the fabricated device. As a source, a Keysight 81600B tunable laser was used, and an external polarization controller was used to switch between TE0 and TM0 modes. An inverse taper-based spot size converter edge coupled light from a lensed fiber into the silicon chip.

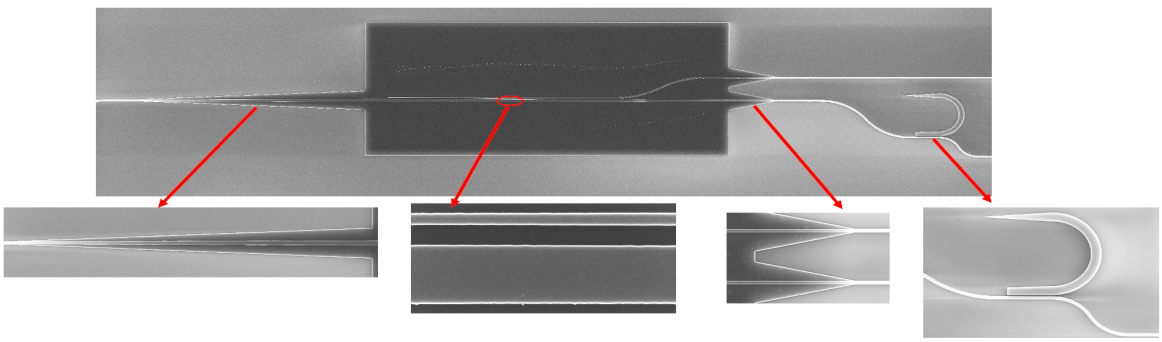

Fig.4 SEM images of the fabricated PSR.

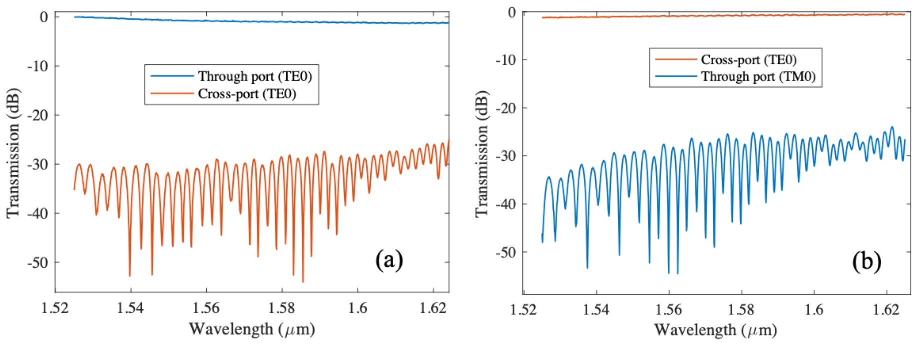

Fig.5 Measured transmission spectra of the fabricated PSRs, with (a) TE0 mode and (b) TM0 mode inputs.

The device wavelength response was measured using a Keysight N7744A optical detector sensor. The calibrated measured transmission spectra for TE0 and TM0 inputs are shown in Figure 5. Over a wavelength range of 1525-1625 nm, the insertion loss (IL) was less than 1.2 dB. It is possible to achieve more than 25 dB ER over 100 nm bandwidth for both inputs.

Table 1 shows a performance comparison of the proposed PSR. When compared to other published results, the PSR under consideration has a larger bandwidth, lower insertion loss, and a higher extinction ratio. Furthermore, in the class of entirely mode evolution based PSRs, the device is relatively small with an overall footprint of only 185 µm.

Table.1 Summary of demonstrated Polarization Splitters rotators

Ref	Exp/Sim	Length (µm)	IL (dB)	ER (dB)	BW (nm)
[3]	Experiment	475	1	13	50
[4]	Experiment	~370	1.5	19	80
[7]	Simulation	70	0.25	10	70
[8]	Simulation	~203	0.5	17	35
This work	Experiment	185	<1.2	>25	100

Conclusions

We demonstrate an entirely mode evolution based PSR on a partial etch ridge waveguide. The device achieves a compact footprint (185 µm) and excellent crosstalk performance (ER > 25 dB). Finally, the design is robust, amenable to foundry fabrication, and active photonic integration (oxide cladding).

References

[1] C. Doerr *et al.*, “Single-Chip Silicon Photonics 100-Gb/s Coherent Transceiver”, in Proc. Optical Fiber Communication Conference (OFC 2014), San Francisco, USA, Mar. 2014, pp. 1-3.

[2] Y. Wang *et al.*,” Ultra-compact sub-wavelength grating polarization splitter-rotator for silicon-on-insulator platform,” IEEE Photonics J., vol. 8, pp.1-9, 2016.

[3] W.D. Sacher et al., “Polarization rotator-splitter in standard active silicon photonics platforms,” Opt. Express, vol. 22, pp. 3777-3786, 2014.

[4] W.D. Sacher et al., “Polarization rotator-splitter and controllers in a Si4N4-on-SOI integrated photonics platform”, Opt. Express, vol. 22, pp. 11167-11174, 2014.

[5] D. Dai *et al.*,” Realization of a compact polarization splitter-rotator on silicon,” Opt. Lett., vol. 41, pp. 2346-2349, 2016.

[6] Z. Mohammed *et al.*,” Effect of Process Parameters on Mode Conversion in Submicron Tapered Silicon Ridge Waveguides,” Appl. Sci., vol. 11, pp. 2366, 2021.

[7] D. Dai and J. E. Bowers, “Novel concept for ultracompact polarization splitter-rotator based on silicon nanowires,” Opt. Express, vol. 19, pp. 10940-10949, 2011.

[8] J. Wang et al., “Proposal for fabrication-tolerant SOI polarization splitter-rotator based on cascaded MMI couplers and an assisted bi-level taper,” Opt. Express, vol. 22, pp. 27869-27879, 2014.

[9] B. Paredes *et al.*, “ An Ultra-Broadband Two-Mode Transverse-Electric Multiplexer in SOI platfrom”, in Proc. Optical Fiber Communication Conference (OFC 2021), San Francisco, USA, 2021, pp. 1-3.