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High Performance Polarization Rotator-Splitter Based on Si_3N_4 Waveguide with Relaxed Fabrication Tolerance

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Abstract: *A novel polarization rotator-splitter is presented based on Si_3N_4 platform with relaxed fabrication-tolerance and high-performance. The proposed device is fabricated by standard-photolithography due to the introduced high-asymmetrical directional-coupler, and demonstrates a polarization extinction-ratio ~20dB with the fabrication-tolerance ~±150nm and polarization conversion-loss ~1.5dB across the C-band. ©2022 The Author(s)*

Introduction

Polarization handling devices play an important role in photonic integrated circuits (PICs) due to the birefringence of optical waveguides. The polarization mode dispersion deteriorates the signal transmission and it needs to be compensated. On the other hand, the employment of polarization-diversity can increase the data-carrying capacity. Therefore, it is desirable to realize the integrated polarization beam splitter (PBS) and polarization rotator-splitter (PRS) with high performance in PICs.

There have been many reports about PBS in different material platforms, including silicon-on-insulator (SOI), indium phosphide (InP), and silicon nitride [1-4]. However, it is not easy to realize PRS with common waveguide structures because the polarization rotating is dependent on the asymmetry and boundary perturbation of optical waveguides. Some fabricated PRSs have been reported based on SOI and InP platforms [5-6]. But the high-index contrast and ultra-high birefringence of SOI waveguides make PRS suffering tight fabrication tolerance and can't be produced with regular photolithography. Also, the SOI-based PIC faces the difficulty of the optical coupling with InP waveguides when hybrid integration with InP lasers chip. PRS realized on InP is very difficult to get strong mode hybridization due to the low-index contrast ($\Delta n \approx 0.15$).

In this paper, we present a novel polarization rotator-splitter based on Si_3N_4 platform with relaxed fabrication-tolerance and high-performance. By employing the high asymmetrical directional coupler (HADC) and the second mode conversion (2nd MC), the cross talk of the outputs has been dramatically depressed. The polarization distinction ratio (PER) is measured to be over 20 dB with polarization conversion loss (PCL) below 1.5dB across the C-band.

Design structure

The conventional PRS based on the mode conversion (MC), asymmetrical directional coupler (ADC), and multimode interference coupler (MMI), can work quite well to rotate TM0 to TE1 and divide them at the outputs, however, the PER is decreased because of the insufficient mode conversion and asymmetrical coupling. The design needs to be optimized to relax the fabrication tolerance and improve the performances of the device. Figure 1 shows the schematic of the proposed novel PRS. The high asymmetrical direction coupler (HADC) is employed to enhance the PER of the cross output. The second conversion (2nd MC) and MMI are used to rotate the remained TM0 mode and filter the TE1 mode. The 400 nm thickness Si3N4 waveguide is formed on SOI using low-pressure chemical vapor deposition (LPCVD). And the cladding is also the SiO2 deposited by plasma-enhanced chemical vapor deposition (PECVD). The ridge waveguide of the mode conversion is etched about 200 nm so that the mode field profile gets the maximum boundary perturbation.

A finite-difference method (FDE) mode solver (from Mode solution) is used to calculate the effective refractive index of TE0, TM0 and TE1 modes for the ridge waveguide and deep etched waveguide, respectively. The ridge waveguide of the mode conversion help strengthen the mode hybridization if the width is around 1.6μm

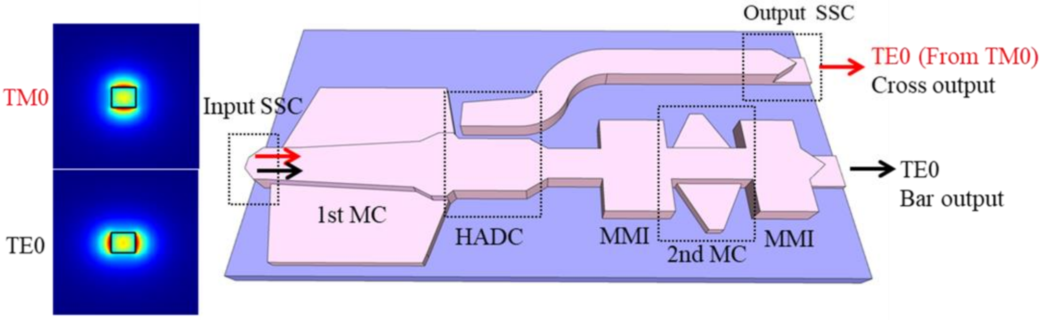
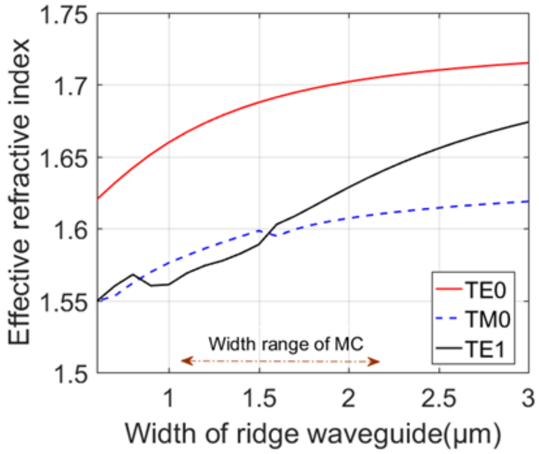
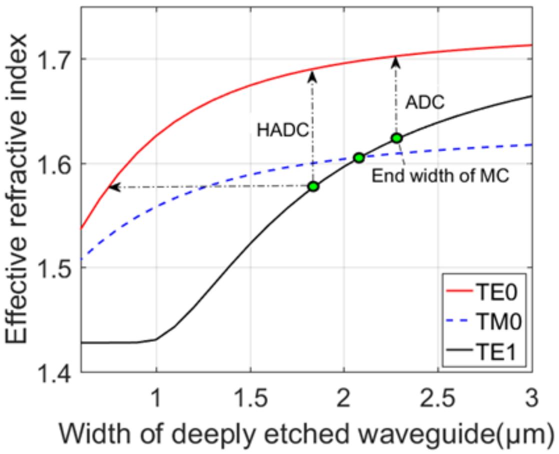


Fig. 1: Schematic image of the PRS consisting of two mode converters (1st MC and 2nd MC), high asymmetrical directional coupler (HADC), two multimode interference couplers (MMI) and spot-size converters (SSCs).

as shown in Fig. 2 (a). In this case, the TM0 and TE1 modes hybridize into super hybrid modes with the waveguide width range from 1.1µm to 2.1µm. The TM0 mode will be rotated into TE1 mode when propagating through the narrower tip to the wider tip of the mode conversion. After the TM0 converting into TE1 mode, the cascaded asymmetrical directional coupler (ADC) will split the TE1 and TE0 mode.



(a)



(b)

Fig. 2: The calculated effective indices for the eigen modes (TE0, TM0, TE1) of the ridge waveguide (a) and deep etched waveguide (b) as a function of width.

Theoretically, the TE1 mode in the wide waveguide will go into the narrow one as TE0 mode. And the TE0 mode in the wide one won't couple into the narrow one because the mismatch of the propagation constants. However, the TE0 mode still leaks to the narrow waveguide and the PER is dependent on the propagation difference of the TE0 mode for paired waveguides.

The deep etched waveguide exhibits larger propagation difference of the TE0 mode in paired waveguides than that of the ridged waveguide as Fig. 2 shows. Also, the width of ADC waveguide is usually beyond the range of mode conversion in Fig. 2(b). The asymmetry of the ADC should be enhanced to maximize the PER of the cross output. High asymmetrical directional coupler (HADC) can be employed with decreasing the width of ADC waveguides. In this case, it can improve the PER of the cross output due to the larger propagation difference of the TE0 mode. Also, the narrower waveguides of HADC lead to stronger coupling efficiency with the same gap and reduce the polarization conversion loss (PCL). Obviously, it pays the price that the width of HADC waveguide is below that of intersection point for TE1 and TM0 modes as Fig. 2(b) shows. Small part of the rotated TE1 mode will convert to the TM0 mode again in the transition deep etched waveguides between the MC and HADC. The remaining TM0 mode will go ahead to decrease the PER of the bar output. The second mode conversion (2nd MC) used here is to rotate the extra TM0 mode into TE1 mode and dissipate them in the multimode interference couplers (MMI).

Experiments

The performances of the proposed PRS will be improved benefiting from the HADC and 2nd MC. The input spot-size converter (SSC) is designed to be a square for the same coupling loss of TE0 and TM0 in the measurement. This will help characterize the PER of the fabricated PRS accurately. Both input and output SSCs are to decrease the coupling loss of the device with the lensed fibers.

The proposed PRS is fabricated using i-line stepper and exhibits good performance as shown in Fig. 3. The light is coupled in and out of the PRS chip through two lensed fibers. And the polarization can be adjusted to any position on the Poincare sphere using the HP 8169A polarization controller. The TE polarization outputs from the bar port and the TM polarization outputs from the cross port, respectively, as shown in Fig. 3 (a). The PER is over 20 dB across the C-band as seen from Fig. 3 (b).

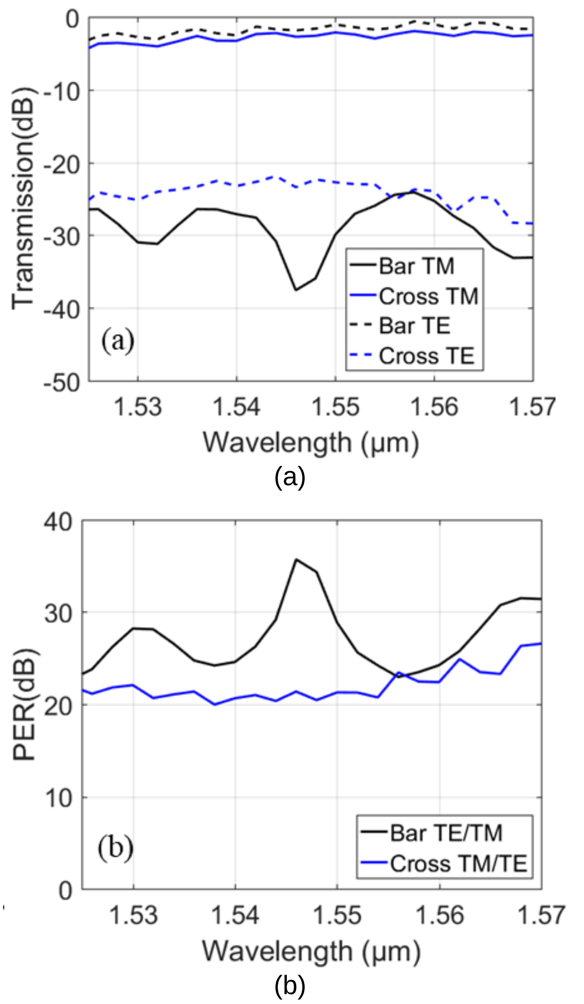


Fig. 3: Measured transmission (a) and polarization extinction ratio (PER) (b) as a function of wavelength

The transmission excludes the coupling loss of around 4 dB per facet and the on-chip loss is 3 dB resulting from the imperfect etching process. The transmission power of the cross output for the TM0 mode is below that of TE0 mode from the bar output. And the PCL of the PRS is around 1.5 dB. The PER is still over 16 dB over the whole C band when the width of the device suffers a deviation of +100nm and -200nm as shown in Fig. 4.

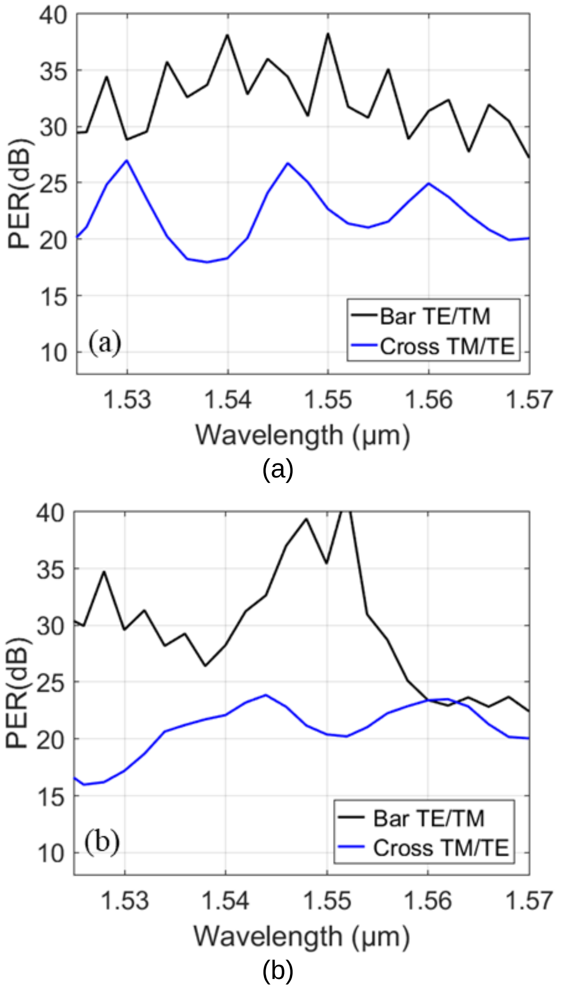


Fig. 4: Measured polarization extinction ratio (PER) for the device width being (a) +100 nm and (b) -200nm as a function of wavelength

Conclusion

In summary, we propose a novel PRS based on Si_3N_4 waveguide that has good performance and fabrication tolerance. The measured results indicate the PER over 20 dB and the PCL below 1.5 dB across the C-band. It still maintains good performances allowing the waveguide width deviation of around ±150 nm. The results around the wavelength of L-band were not characterized due to the limitation of the tunable laser but the numerical simulation shows this design covering C+L band. We believe the proposed PRS could be in application for the future PICs.

Acknowledgements

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