Compact CMOS-compatible Polarization Splitter and Rotator Based on 90° Bends

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ABSTRACT

We propose and experimentally demonstrate a compact highly-efficient CMOS-compatible polarization splitter and rotator (PSR) with a wide bandwidth covering the whole O-band. It benefits from the different confinement capability of TE and TM modes in bend structure. The fabricated PSR achieves a high TM-TE conversion efficiency of -0.4 dB and high TE-TE conversion efficiency of -0.2 dB at 1310 nm, while the extinction ratio is better than 18 dB.

I. INTRODUCTION

As essential building blocks, polarization beam splitter and rotator (PSR) plays a significant role in most photonic integrated circuits where polarization handling is needed, including telecom, datacom, quantum circuits, etc [1]. Compact and highly efficient PSR is desired for manipulating polarization-entangled photons as well as coherent transceivers in large-scale high-density photonic integrated chips. Different types of PSRs have been reported with various structures, such as Mach-Zehnder interferometer, asymmetric Y-junction, directional coupler [2, 3], slot waveguides, and photonic crystals.

Those structures commonly use straight waveguides for achieving PSRs as their design rules are relatively easy [2, 3]. Liu Liu and Yunhong Ding et al have demonstrated an efficient PSR by using two parallel straight strip waveguides with air top cladding [2]. Although this PSR is compact with a length of ~30μm at 1550nm, it uses 100-nm gap for efficient coupling, which is not applicable for current standard foundry service [4]. The lack of solid upper cladding breaks the vertical symmetry of strip waveguide, making polarization rotation achieved more easily. However, that also induces incompatibility and greatly complicates its integration with other building blocks based on most metal back-end-of-line processes. PSRs using SiO_2 layer as cladding have recently been reported based on an SOI platform [3]. However, these designs are relatively long with a device length of several tens or hundreds of microns.

In this work we exploit two 90° bends with a radius of 10 μm to build an O-band compact PSR, since photonic integrated devices operating at O-band have recently attracted more and more attention, especially in the areas of datacom, and quantum communication. As known, the bend structure creates different confinement capability for TE and TM modes, which is undesirable in most devices reported previously. However, here we take advantage of it to help shorten the PSR and maintain high efficiency, realizing the bending, polarization splitting, rotating of input light beam at the same time. The fabricated PSR achieves a high TM-TE conversion efficiency of -0.4 dB and high TE-TE conversion efficiency of -0.2 dB at 1310 nm, while the extinction ratio is better than 18 dB. Moreover, the 3-dB bandwidth of fabricated PSR covers all the O-band range. Furthermore, this design uses SiO_2 as top-cladding, making it compatible with current multi-layer CMOS foundry services [4].

II. PRINCIPLES AND SIMULATION

As shown in Fig. 1, the inner bend of proposed PSR is set as the through waveguide so that this design is able to exploit the different confinement of TE and TM in bend structure, i.e., the TE is naturally better confined in the inner bend while TM is relatively easier leaking into the outer bend.

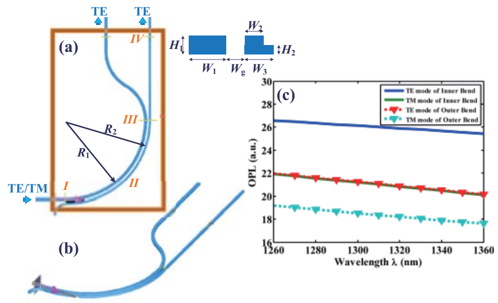

Fig. 1. (a) Top view and (b) three-dimensional view of the PSR based on the 90° bends. For clarity, the SiO_2 cladding is not shown. (c) OPLs of the TE and TM mode supported by the inner and outer bend.

Here we design a sample operating at O-band based on SOI platform with top silicon thickness H=220nm. In order to take advantage of the better confinement for TE mode than TM mode in bend structure, the width and radius of inner bend are chosen as 400 nm and 10 μm respectively, which keeps low loss for fundamental modes in the bend structure. Although smaller gap can increase the coupling efficiency and thus shorten the device length, the gap between two parallel waveguides cannot be too small as it would make the fabrication difficult. Since the 248-nm optical lithography technology typically uses 200-nm gap, here the gap W_g is 0.2 μm [4]. In order to have a complete coupling of TM mode supported by the inner bend and TE mode supported by the outer bend, theoretically these two bends need proper cross sections for satisfying the phase-matching conditions, i.e. their optical path lengths (OPLs) should be the same [5]. Here the height of etched slab H_2 is 110nm. We choose the width of the fully-etched layer W_2 to be 0.21 μm and the width of partial-etched layer W_3 to be 0.29 μm, which makes the OPLs in these two bends match with each other. In order to convert the partial etched outer bend into a stripe waveguide, a taper is exploited at the end of the outer bend with a length of 5 μm.

Figure 1 (c) shows the numerically calculated OPL for TE and TM mode as the wavelength varies from 1.26 μm to 1.36 μm. The OPL of TE mode in the inner bend is much larger than that of the modes in the outer bend, which prevents any mode coupling when TE mode is injected into the inner bend. At the same time, the OPL of TM mode supported by inner bend is almost the same as that of TE mode supported by outer bend within 100-nm wavelength range, which makes possible a high efficient coupling from TM mode of inner bend to TE mode of outer bend within a broad bandwidth.

By exploiting three-dimensional finite-difference-time-domain method, the simulation result of light propagation is depicted in Fig. 2 (a) and (b), when TE and TM modes at 1310-nm wavelength are stimulated in the inner bend. As predicted in the design principles, when the TE mode is injected into the inner bend, the light beam is well confined and maintains its propagation in the inner bend. When TM mode is stimulated in the inner bend, light is efficiently coupled to TE mode in the outer bend and then exits from the cross output port. The TM mode splitting and rotating process is further demonstrated in Fig. 2 (c)-(f).

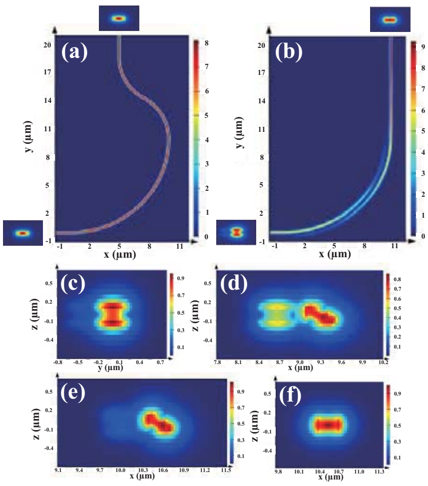

Fig. 2. The light propagation when (a) TE mode and (b) TM mode is stimulated in the inner bend. (c) The TM mode at the input port of inner bend. (d) The hybrid mode at the middle of the bend, where the energy carried by TM mode is converting into TE-like mode in the outer bend. (e) Most energy is coupled into TE-like mode in the outer bend. (f) Converted TE mode at the cross output of the outer bend. The light wavelength is 1310 nm.

III. EXPERIMENTAL RESULTS

Figure 3 shows the experimental testing results for the fabricated device. The 3-dB bandwidth of fabricated PSR covers the whole O-band. The conversion efficiency (CE) of TM-TE and TE-TE mode conversion at 1310 nm are -0.4 dB and -0.2 dB respectively, while the extinction ratio (ER) is better than 18 dB.

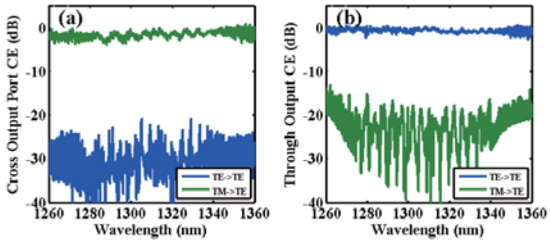

Fig. 3. The mode conversion efficiency as a function of the wavelength in the cross output port (a) and through output port (b).

IV. CONCLUSIONS

In summary, we have proposed an O-band compact PSR by exploiting 90˚ bends. We take advantage of bend structure with a radius of only 10 μm to help shorten the PSR and maintain high efficiency, achieving the bending, polarization splitting, rotating of input light beam at the same time. Smaller radius might be possible to be used for even shorter PSR design. The fabricated PSR has a high TM-TE polarization CE of -0.4 dB and high TE-TE CE of -0.2 dB at 1310nm, while the ER is better than 18 dB. Due to its general principle, similar design with different parameters can be specifically designed for operating in other different wavelength ranges, including C-band, L-band, and mid-IR. This design provides a potential solution as a building block for polarization handing in future large-scale high-density photonic integrated chips.

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