Ultra-Compact Polarization Mode Converter Implemented in a Dual-Trench Silicon-On-Insulator Waveguide

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Abstract: We demonstrate an ultracompact polarization mode converter based on a silicon-on-insulator waveguide with two longitudinal subwavelength trenches. An extinction ratio of 16 dB at 1.5 µm is achieved for a device length of 10 µm.

OCIS codes: (130.3120) Integrated optic devices, (130.5440) Polarization-selective devices.

1. Introduction

The high index contrast of the silicon-on-insulator (SOI) platform, while advantageous for device footprint reduction and high-density integration, implies polarization dependent mode properties such as birefringence and polarization dependent loss. Therefore, polarization handling systems are usually required for SOI waveguides. Various waveguide geometries have been proposed to perform polarization mode conversion [1,2], but complex fabrication processes with multiple etching steps are required. Recently, polarization converters with a single etch depth have been reported [3,4], demonstrating conversion lengths down to 44 µm. Furthermore, polarization rotating properties of asymmetric GaAs waveguides with longitudinal trenches have been demonstrated [5,6].

In this work, we present the design, fabrication and experimental characterization of a polarization mode converter based on a dual-trenched SOI waveguide, which only requires a single patterning and etching step.

2. Design and fabrication

The cross-section of the polarization-rotating waveguide is shown in Fig. 1a, comprising a rectangular section with two adjacent subwavelength trenches with varying widths (W1, W2) and depths (D1, D2). With a judicious design of the trench parameters, the resulting refractive index asymmetry yields the waveguide supporting two orthogonal hybrid modes with their optical axes rotated 45 degrees with respect to the TE/TM axes. The difference in the propagation constants (β_1, β_2) of the two hybrid modes results in full polarization conversion (TE to TM, or vice versa) after a half-beat length $L_{1/2}=\pi/(\beta_1-\beta_2)$.

Full mode hybridization can be achieved with different combinations of trench widths and depths, as shown in Fig. 1b. However, only a subset of these solutions can be physically implemented, being restricted by the etch depth dependence on the feature size for the Inductively Coupled Plasma (ICP) Reactive Ion Etch (RIE) fabrication process. Experimental characterization from a set of reference trenches showed that, for a 260 nm thick silicon wafer, the wafer is fully etched for features with widths larger than 140 nm. For smaller features, the actual etch depth progressively decreases, thus determining a set of depth and width combinations suitable for fabrication.

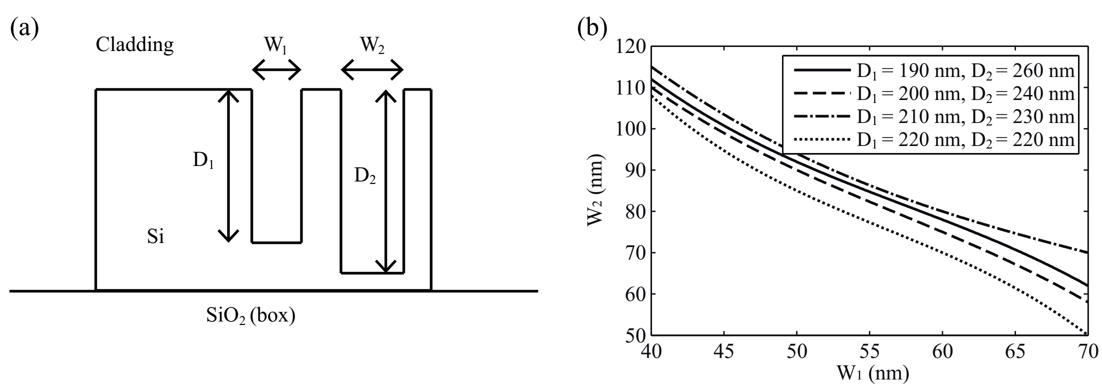

Fig. 1. (a) Polarization mode converter schematics. (b) Combinations of trench widths (W_1, W_2) and depths (D_1, D_2) that result in hybrid modes with a 45º effective polarization angle

A 450 nm wide waveguide was chosen for single mode operation at the design wavelength of 1.5 μm. The optimized design parameters, compatible with RIE lag experimental calibration, were trench widths $W_1 = 60$ nm and $W_2 = 85$ nm; with the corresponding etch depths $D_1 = 210$ nm and $D_2 = 230$ nm. Mode adaptation sections were included at both ends of the device in order to smoothen the transition between the input and output waveguides and the polarization rotator section with the subwavelength trenches while at the same time ensuring equal excitation of both hybrid modes.

3. Experimental results

Fig 2a shows the conversion efficiency η of the fabricated device, measured with a tunable laser with polarization control optics, according to the following equation:

$$\eta_{TE-TM} = \frac{P_{TM}}{P_{TM} + P_{TE}} \times 100\% \qquad (1)$$

where P_{TE} and P_{TM} are the output powers of the TE and TM polarized fundamental modes, respectively, after compensating for the difference in propagation and coupling losses. A maximum TE to TM efficiency of 97.5% was measured, which corresponds to an extinction ratio of 16 dB ($ER_{TE\text{-}TM} = 10 \times \log[P_{TM}/P_{TE}]$. A conversion efficiency in excess of 90% is achieved for a spectral bandwidth of 47 nm. Measured intrinsic losses of the device are 0.7 dB.

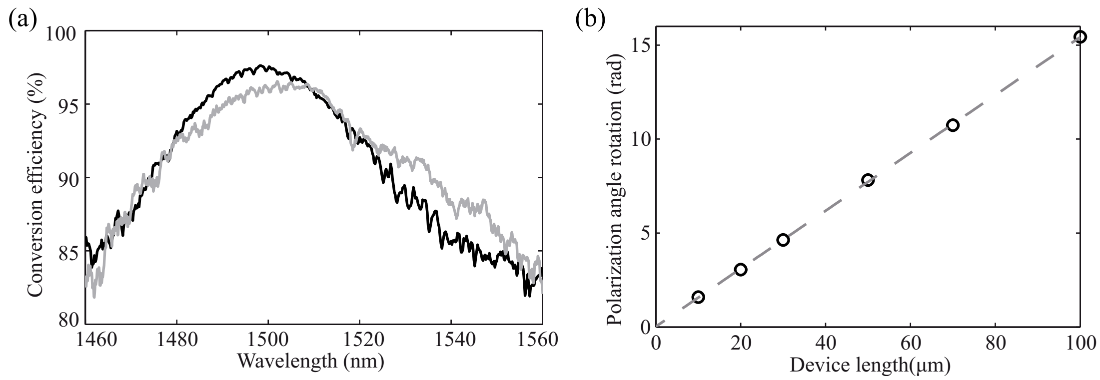

Fig. 2. (a) Measured conversion efficiency TE to TM (black) and TM to TE (grey). (b) Polarization rotation angle dependence on device length.

In order to determine the amount of polarization rotation caused by the adaptation sections, several devices with different lengths and the same adaptation sections were characterized. Linear regression was applied to the measured polarization rotation angles of the devices, as shown in Fig. 2b, presenting a good fit with a mean relative error below 1%. From the resulting offset, we determined a polarization rotation in the adaptation stage of less than 2º and the length of the rotator section was slightly reduced accordingly (by 0.22 μm).

4. Conclusions

We demonstrated an ultra-compact polarization mode converter in a silicon wire waveguide, fabricated in a single etch step. The measured extinction ratio was 16 dB in a device as short as 10 μm.

5. References

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