Ge-on-Si Waveguide Polarization Rotator Operating in the 8-14 μm Atmospheric Transmission Window

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Abstract: An ultra-broadband Ge-on-Si waveguide polarization rotator is experimentally demonstrated with a polarization extinction ratio of $\geq$ 15 dB over a 2 μm bandwidth (9-11 μm wavelength) with an insertion loss of $\leq$ 1 dB.

1. Introduction

There is substantial interest in developing integrated photonic circuits for molecular sensing in the 8 to 14 μm atmospheric transmission window. We recently demonstrated Ge-on-Si waveguides operating up to 11 μm wavelength with low propagation values ($\sim$ 1 dB/cm) [1]. A single chip sensor requires the integration of a source and detector. The most obvious candidate for the source is a quantum cascade laser (QCL). Since a QCL is a vertically linearly polarized emitting laser it will only couple to transverse magnetic (TM) waveguide modes. A waveguide polarization rotator would enable transverse electric (TE) operation with QCLs on-chip. The longest wavelength demonstration to-date has been below 6.15 μm [2]. Here we demonstrate the design, fabrication and characterization of a Ge-on-Si waveguide polarization rotator operating between 9 and 11 μm wavelength with a low insertion loss ($\leq$ 1 dB) and a high polarization extinction ratio ($\geq$ 15 dB).

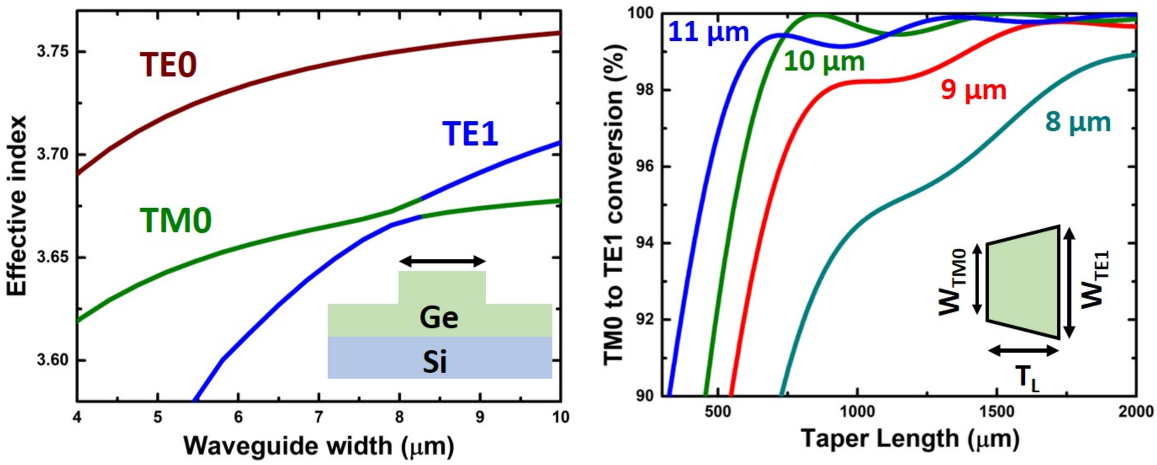

Fig. 1. (Left) The calculated modal indices versus the waveguide width for a Ge-on-Si rib waveguide at 8 μm wavelength. (Right) The modeled TM0 to TE1 mode conversion efficiency versus taper length for an input width of 7.7 to an output width of 8.7 μm, at 8, 9, 10 and 11 μm wavelength.

2. Modelling, Fabrication and Characterization

The waveguide polarization rotator is based on the mode evolution approach. A finite-difference eigenmode solver was used to calculate the supported eigenmodes versus the waveguide width of a 2 μm thick Ge-on-Si rib waveguide with a partial 1 μm. It is clear from Fig. 1 (Left) that there is an anti-crossing between the TM0 and TE1 modes at a waveguide width of $\sim$ 7.9 μm, which is indicative of mode hybridization. To enable broadband TM0 to TE1 mode conversion from 8-11 μm wavelength requires a taper design that has an input and output width that covers the mode hybridization points at the wavelength extremes. An eigenmode expansion solver (EME) was used to model a linear taper with an input and output width of 7.7 and 8.7 μm, respectively. The calculated TM0 to TE1 polarization conversion efficiency (PCE) for different wavelengths versus taper length is shown in Fig. 1 (right). It is clear that for a 2 mm long taper there is a PCE of $\geq$ 99 % over the full wavelength range.

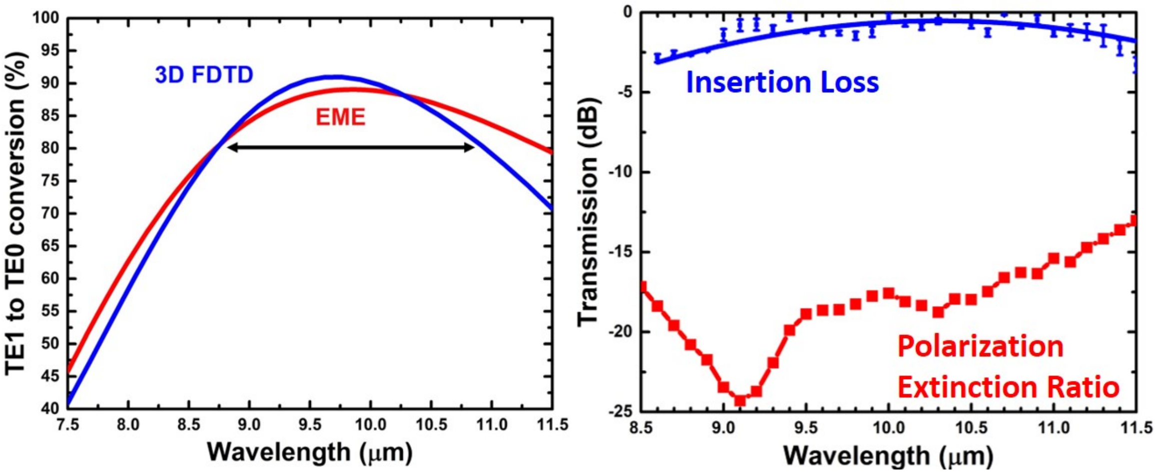

Fig. 2. (Left) The TE1 to TE0 mode conversion efficiency for the optimized higher order mode converter consisting of six asymmetric tapers modelled with the EME solver and 3D FDTD. (Right) The experimentally measured polarization extinction ratio and insertion loss as a function of the wavelength for the fabricated device.

Conversion between the TE1 and TE0 mode is normally achieved by using an asymmetric directional coupler. To provide broadband performance, however, the higher-order mode converters proposed by D.Chen et al. were utilized. [3] This asymmetric taper structure was optimized using EME and a particle swarm algorithm for a centre wavelength of 9.5 μm. Figure. 2 (Left) shows that after optimization $\geq$ 80 % conversion over a 2 μm bandwidth (9-11 μm) is achieved. A waveguide polarization rotator consisting of a 2 mm long linear taper for broadband TM0 to TE1 mode conversion followed by the optimized TE1 to TE0 higher order mode converter were microfabricated and experimentally characterized using previously described techniques [1]. A high extinction ratio ($\geq$ 40 dB) wire grid polarizer was used to ensure only a TM fundamental mode was excited at the input. At the output, the polarization axis of another identical polarizer was adjusted for the detection of the transmitted TE0 and TM0 modes by recording each spectrum on a mercury cadmium telluride detector. The ratio of these provides the polarization extinction ratio. The insertion loss was measured by comparing the transmittance of eight reference straight waveguides that had the same overall length. The fabricated device demonstrates a polarization extinction ratio of $\geq$ 15 dB and an insertion loss of $\leq$ 1 dB over the 9-11 μm wavelength region (see Fig. 2 (Right)).

3. Conclusion

A Ge-on-Si rib waveguide polarization rotator that operates between 9-11 μm wavelength with a low insertion loss ($\leq$ 1 dB) and a high polarization extinction ratio ($\geq$ 15 dB) was designed and demonstrated experimentally. The polarization rotator utilizes an intermediate polarization conversion between the TM0 to TE1 mode first by using an adiabatic linear taper before subsequent higher order TE1 to TE0 mode conversion is achieved by an asymmetric taper structure. The fabricated waveguide polarization rotators provide an order of magnitude increase in the operational bandwidth compared to previously demonstrated devices. This is the first experimental demonstration of a waveguide polarization rotator in the 8-14 μm atmospheric transmission window.

References

1. K. Gallacher, R. W. Millar, U. Griskeviciute, L. Baldassarre, M. Sorel, M. Ortolani, and D. J. Paul. Low loss Ge-on-Si waveguides operating in the 8-14 μm atmospheric transmission window. *Opt. Exp.*, 26(20):25667–25675, 2018.
2. C. J. Chung, J. Midkiff, K. M. Yoo, A. Rostamian, J. Guo, R. T. Chen, and S. Chakravarty. InP-based polarization rotator-splitter for mid-infrared photonic integration circuits. *AIP Adv.*, 9(1):6, 2019.
3. D. G. Chen, X. Xiao, L. Wang, Y. Yu, W. Liu, and Q. Yang. Low-loss and fabrication tolerant silicon mode-order converters based on novel compact tapers. *Opt. Exp.*, 23(9):11152–11159, 2015.