

An Accurate Characterization Method for Polarization Converters on the Indium Phosphide Membrane on Silicon Platform

(Student Paper)

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ABSTRACT

In this paper, an accurate characterization method for characterization of the conversion efficiency of polarization converters on the InP-membrane-on-silicon (IMOS) platform is demonstrated. The method is insensitive to propagation losses, device insertion loss and grating coupler insertion loss. Circuits for demonstration of the method with polarization converters with various parameters are fabricated. A conversion efficiency as high as $97.5 \pm 0.7\%$ is experimentally shown using the proposed method. The high-efficiency polarization converter is only 4.1 microns long.

Keywords: Indium phosphide, nanophotonics, polarization converter, membranes, characterization.

1 INTRODUCTION

The demand for higher bandwidths in optical fiber technologies is ever-increasing. To satisfy this demand, every degree of freedom in the communication technologies is being exploited. A commonly used technique is wavelength division multiplexing (WDM), enabling multiple data channels to be submitted over a single fiber using different wavelengths. Spatial division multiplexing (SDM) exploits the spatial modes in few-mode or multicore fibers to further increase the number of channels that can be submitted over a single fiber. The polarization state of the light can be exploited to increase the capacity of a single fiber with a factor two, by simply using the two orthogonal polarization states: the EH and the HE modes. Furthermore, polarization can be used to employ more complex modulation formats, e.g. Stokes vector modulation (SVM). SVM enables multilevel modulation formats without the requirement of increasing the optical power. To reduce the cost of the transceivers, it is desirable to have the full circuit integrated in one chip. To achieve on-chip polarization handling, components that can manipulate polarization are of key importance. It is crucial to be able to characterize these devices accurately. Reported performances are commonly obtained by direct measurement of the devices under test. The main disadvantage of this method is the sensitivity to calibration of the measurement with respect to the insertion losses and polarization dependent losses of the fiber coupling and other components in the measurement setup.

We demonstrate a characterization method to accurately measure the polarization conversion efficiency of an integrated polarization converter. The method is insensitive to device insertion losses and propagation losses.

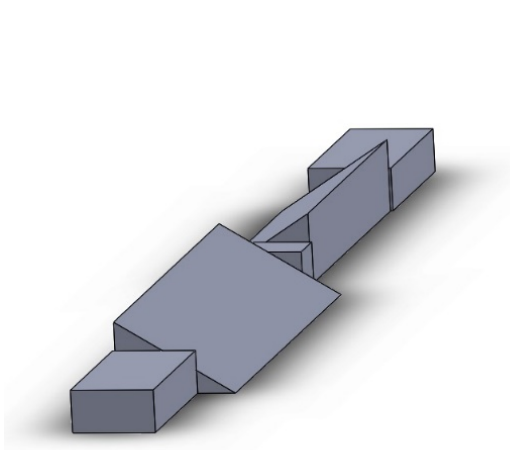


Figure 1. Cartoon of the polarization converter design.

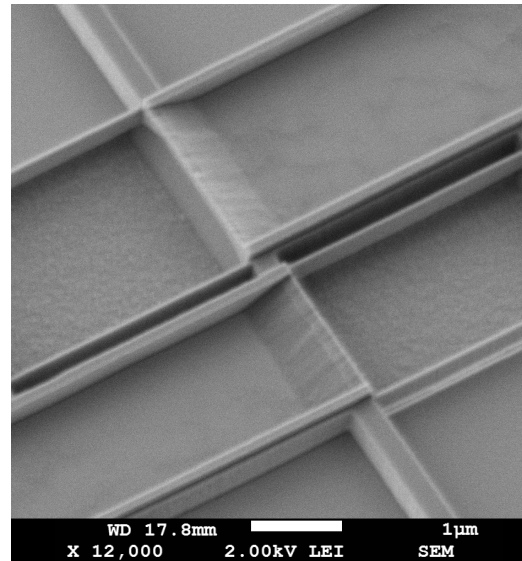


Figure 2. Scanning electron microscope picture of a polarization converter fabricated on the IMOS platform (before bonding).

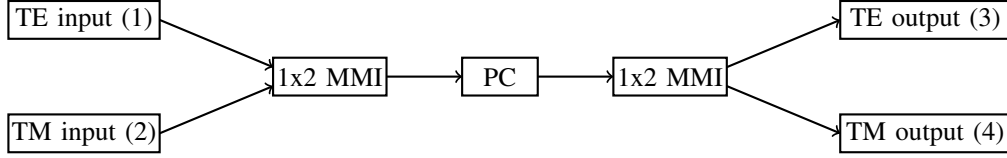


Figure 3. Schematic of characterization circuit for the characterization of polarization converters.

The fabrication of the investigated devices is carried out on the InP-membrane-on-silicon (IMOS) platform [1], which is a nanophotonic platform that provides tight optical confinement and miniaturization of components and waveguides. The tight optical confinement is achieved by adhesively bonding of the indium phosphide wafer to a silicon wafer with benzocyclobutene (BCB), and removing the substrate of the indium phosphide wafer. This results in an air cladding on one side and a BCB cladding on the other side. The core thickness of the photonic nanowires on the IMOS platform is 300 nm, and the typical waveguide width is 400 nm.

2 DEVICE DESIGN AND FABRICATION

The design of the polarization converter, shown in Fig. 1, is based on the design on a 250 nm thick InP membrane, reported in [2]. The current design is optimized for the 300 nm membrane thickness, enabling integration compatibility to the twin-guide active-passive integration scheme [3]. Furthermore, surface grating couplers capable of coupling both transverse electric (TE) and transverse magnetic (TM) polarized light are now available, which are required for directly measuring the polarization conversion. However, by doing this, one has to compensate for the polarization-dependent insertion losses of the surface grating couplers and other components, e.g. multi mode interference couplers (MMI), and the polarization-dependent propagation losses in the waveguides. In Section 3 we describe a 4-port measurement method which solves this issue.

The device was fabricated on the IMOS platform, and integrated with the standard process. To optimize the mode matching between the triangular sections and the rectangular waveguides, the triangles require a height of 460 nm. An extra quaternary etch-stop layer was introduced to provide the extra height for the triangular sections, as discussed in [3]. The vertical sidewalls of the triangular sections are patterned in the same step as the waveguide definition, while the slopes are created using a selective wet etch that stop on the (112) crystallographic plane of indium phosphide, providing a 35° slope with respect to the wafer surface. Since the tilt angle of the hybrid modes in the triangular sections is below 45°, two sections are required to obtain full polarization conversion. A scanning electron microscope (SEM) image of the fabricated device is shown in Fig. 2. All processing is performed prior to the wafer bonding, hence this image is taken before bonding the InP wafer to the silicon carrier wafer.

3 MEASUREMENT METHODOLOGY

The characterization circuit is schematically shown in Fig. 3. For further reference, the input and output ports have been numbered. We consider P_{ij} the measured power at output j when input i is used, which, for all combinations of inputs and outputs results in

$$P_{13} = \alpha_1 \alpha_3 \alpha_{\text{MMI}}^2 (1 - \eta) P_{\text{in}}, \quad (1)$$

$$P_{14} = \alpha_1 \alpha_4 \alpha_{\text{MMI}}^2 \eta P_{\text{in}}, \quad (2)$$

$$P_{23} = \alpha_2 \alpha_3 \alpha_{\text{MMI}}^2 \eta P_{\text{in}}, \quad (3)$$

$$P_{24} = \alpha_2 \alpha_4 \alpha_{\text{MMI}}^2 (1 - \eta) P_{\text{in}}, \quad (4)$$

where α_k is the loss in input arm k , α_{MMI} is the insertion loss of the MMI, η is the polarization conversion efficiency and P_{in} is the input power. These losses are polarization dependent, but are compensated in the next step. We then introduce the parameter C as

$$C = \frac{P_{13} P_{24}}{P_{14} P_{23}} = \frac{(1 - \eta)^2}{\eta^2}. \quad (5)$$

From Eq. 5 it can be seen the parameter C is independent of the insertion and propagation losses, and only depends on the polarization conversion efficiency η . Rewriting the equation gives

$$\eta = \frac{1}{1 + \sqrt{C}} = \frac{1}{1 + \sqrt{\frac{P_{13} P_{24}}{P_{14} P_{23}}}}. \quad (6)$$

The accuracy of a direct 2-port measurement method is limited by how accurately one can determine the insertion loss of the surface grating couplers, which typically gives an uncertainty of around 0.5 dB per grating coupler. This would already introduce an uncertainty of around 20% for this method, which diminishes the accuracy of the method.

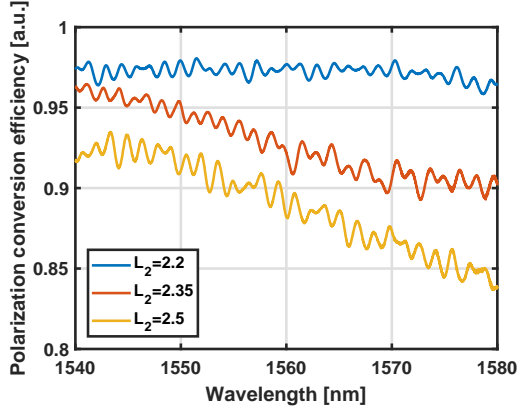


Figure 4. Measured polarization conversion efficiency versus wavelength for three lengths L_2 . L_1 is fixed at $1.7 \mu\text{m}$.

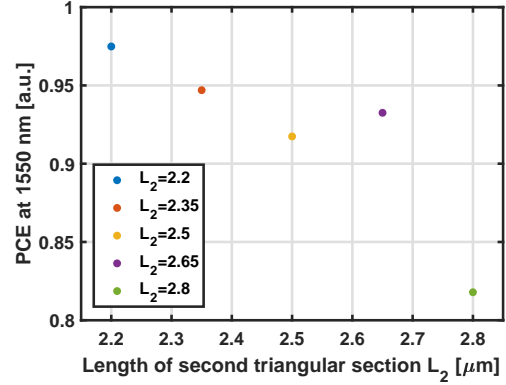


Figure 5. Measured PCE at 1550 nm for various lengths of the second triangular section. L_1 is fixed at $1.7 \mu\text{m}$.

4 MEASUREMENT RESULTS

The proposed measurement method is applied to the previously introduced polarization converters. Converters with length variations for both sections have been measured over a wavelength range such that both TE and TM surface grating couplers have reasonable coupling efficiency, which is 1540-1580 nm for this fabrication run. In Fig. 4, the measured polarization conversion efficiency (PCE) is shown. Almost $98 \pm 0.7\%$ PCE is achieved, which is comparable to the state-of-the-art in silicon photonics [4]–[6]. The ripple on the PCE is caused by reflections in the circuit. Reducing these reflections can improve the accuracy of the method further. The efficiency is above $96 \pm 0.7\%$ for 1540-1580 nm for a total device length of $4.1 \mu\text{m}$. In Fig. 5, the PCE at a wavelength of 1550 nm is shown for five devices with fixed L_1 and various L_2 . A sinusoidal trend is expected, however, there is a limited amount and range of points available and there is an anomaly for $L_2 = 2.65 \mu\text{m}$. After inspection of the structure, this is expected to be caused by residual InP after the wet etching of the triangular sections.

5 CONCLUSION

An accurate characterization method for the characterization of polarization converters has been experimentally demonstrated. Characterization circuits with polarization converters are fabricated on the IMOS platform, and the results are presented in this paper. A maximum conversion efficiency of $97.5 \pm 0.7\%$ is achieved and over $96 \pm 0.7\%$ is achieved over a wavelength range of 1540-1580 nm.

REFERENCES

- [1] J. J. van der Tol, Y. Jiao, L. Shen, A. Millan-Mejia, V. Pogoretskii, J. P. van Engelen, and M. K. Smit, "Indium Phosphide Integrated Photonics in Membranes," *IEEE Journal of Selected Topics in Quantum Electronics*, vol. 24, no. 1, pp. 1–9, 2018.
- [2] J. Pello, J. van der Tol, S. Keyvaninia, R. van Veldhoven, H. Ambrosius, G. Roelkens, and M. Smit, "High-efficiency ultrasmall polarization converter in InP membrane," *Optics Letters*, vol. 37, no. 17, p. 3711, 2012.
- [3] S. Reniers, V. Pogoretskiy, K. Williams, J. van der Tol, and Y. Jiao, "Towards the integration of an ultrashort polarization converter on the active-passive InP-membrane-on-silicon platform," *IEEE Photonics Benelux Symposium, Not Published*, 2019.
- [4] Y. Zhang, Y. He, X. Jiang, B. Liu, C. Qiu, Y. Su, and R. A. Soref, "Ultra-compact and highly efficient silicon polarization splitter and rotator," *APL Photonics*, vol. 1, no. 9, 2016.
- [5] D. Vermeulen, S. Selvaraja, P. Verheyen, W. Bogaerts, D. V. Thourhout, and G. Roelkens, "High Efficiency Broadband Polarization Rotator on," *Journal of the Optical Society of America*, pp. 42–44, 2010.
- [6] A. Xie, L. Zhou, J. Chen, and X. Li, "Efficient silicon polarization rotator based on mode-hybridization in a double-stair waveguide," *Optics Express*, vol. 23, no. 4, p. 3960, 2015.