WF4
9.15 - 9.30

# Simple and Compact InP Polarization Converter for Polarization-Multiplexed Photonic Integrated Circuits

T. Tanemura[1], T. Amemiya[2], K. Takeda[1], A. Higo[1], and Y. Nakano[1]

1) Research Center for Advanced Science and Technology, University of Tokyo, 4-6-1 Komaba, Meguro-Ku, Tokyo 153-8904, Japan
tanemura@ee.t.u-tokyo.ac.jp
2) Quantum Nanoelectronics Research Center, Tokyo Institute of Technology, 2-12-1 O-okayama, Meguro-ku, Tokyo 152-8552, Japan

***Abstract*— We propose and investigate a novel type of waveguide polarization converter, which is particularly suited for monolithic integration in InP photonic integrated circuits. Efficient mode conversion with 0.4-dB loss and 16.6-dB extinction is demonstrated numerically.**

## I. INTRODUCTION

Monolithically integrated optical transmitters based on InP photonic integrated circuits (PICs) have gained great interest, which can significantly reduce the number of optical components, complexity, and power consumption in the large-capacity wavelength-division-multiplexed (WDM) transmission systems. While quadrature phase-shift keying (QPSK) transmitters have been realized successfully on InP PICs, polarization-division multiplexing (PDM) is expected to be the next step to double the spectral efficiency [1]. To realize a monolithically integrated PDM transmitter, fully integratable InP waveguide polarization converter (PC) with simple fabrication process would be essential.

Various types of passive waveguide PCs have been proposed and demonstrated to date, based on periodically loaded waveguide [2], slanted sidewall [3,4], asymmetric trenches [5,6], and so on. These designs, however, require thin upper cladding and consequently have a difficulty in integrating and coupling with other active InP components, which typically have a thick cladding of more than 1 μm. Recently, Augustin, *et al.* have demonstrated a monolithically integrated InP PC with highly efficient coupling from/to standard ridge waveguides [7]. However, it required relatively complicated fabrication process with critical lithographical alignment, which might become the drawback in practical implementation.

In this paper, we propose a novel type of InP waveguide PC which is fully compatible with other InP components and can be fabricated with a simple self-aligned etching process. Efficient mode conversion between the transverse-electric (TE) and transverse-magnetic (TM) states is demonstrated numerically with insertion loss of 0.4 dB and extinction ratio of 16.6 dB.

## II. PRINCIPLE AND FABRICATION PROCESS

The sturucture of the proposed PC waveguide is shown in Fig. 1. It has a shallow-etched ridge structure on the one side (left side in Fig. 1) and a deep-etched high-mesa structure on the other (right side). Due to the asymmetric cross section, the two lowest-order eigenmodes are hybridized and their electric and magnetic fields are tilted from the vertical axis. As shown in Section III, with the proper optimization of waveguide parameters, these two modes can be rotated ±45° with respect to the $x$ and $y$ axes, in a similar way as the one with slanted sidewall [3]. In such a case, incident light with TE (or TM) polarization state excites the two modes with equal magnitudes, which, after the transmission of half beat length, recombine into TM (TE) polarization state. Owing to the thick cladding and half-ridge structure, these modes have large overlap with TE and TM modes of a symmetric ridge waveguide, which allows low-loss integration of the proposed structure into a standard ridge InP PIC.

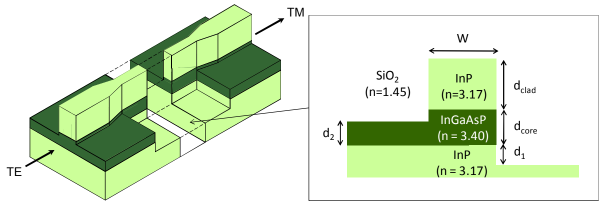


Figure 1: Schematic of the proposed waveguide PC integrated with standard ridge input/output waveguides.

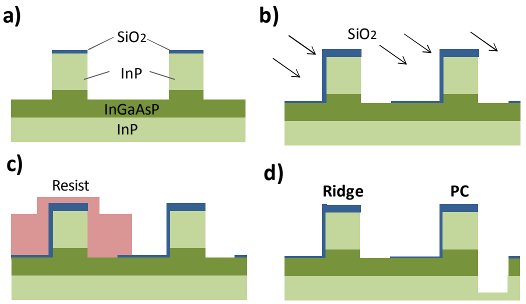
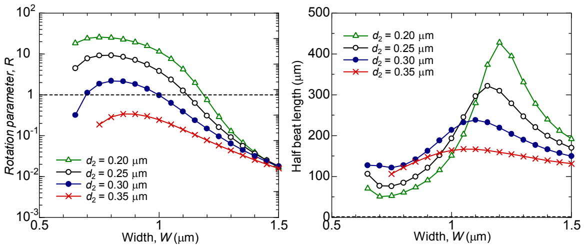


Figure 2: Proposed fabrication procedures. After the first dry-etching (a), SiO$_2$ is evaporated from an angled direction so that only the left side of the waveguide is covered (b). The symmetric ridge section is then masked selectively (c), followed by the second dry-etching process to form the asymmetric PC structure (d).

Fig. 2 shows the proposed fabrication procedures. After the formation of ridge waveguide (a), only one side of the waveguide is covered with SiO$_2$ (or any other masking material) by using electron-beam evaporation from an angled direction (b). The symmetric ridge sections are then masked

978-1-4244-3681-1/09/$25.00 ©2009 IEEE



(a) Rotation parameter (b) Half beat length

Figure 3: The rotation parameter (a) and half beat length (b) for various values of $d_2$ and $W$ ($d_{core}$ = 0.5 μm, $d_{clad}$ = 1 μm, $d_1$ = 0.5 μm).

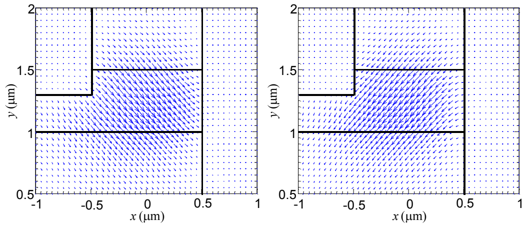


Figure 4: Magnetic fields of Mode 1 (left) and Mode 2 (right) for $d_{core}$ = 0.5 μm, $d_{clad}$ = 1 μm, $d_1$ = 0.5 μm, $d_2$ = 0.3 μm and $W$ = 1 μm

selectively by the photoresist (c), followed by the second dry-etching to form the asymmetric PC structure (d). Finally, the entire structure is covered with $SiO_2$ (or any other material such as polymide) to reduce the coupling loss from a symmetric ridge waveguide. Since there is no critical lithographical alignment, the procedure is relatively simple, and fully compatible with standard ridge laser fabrication process.

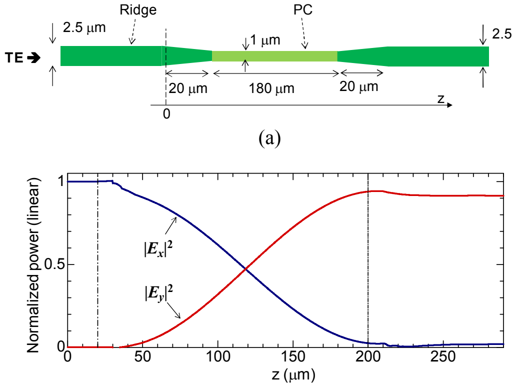
## III. NUMERICAL RESULTS

First, eigenmodes of the PC structure is solved numerically by using full-vector finite-different method (FV-FDM) [8]. As a measure of optical axis rotation of the eigenmodes, we define the rotation parameter as

$$R \equiv \iint |H_x|^2 \, dxdy \Big/ \iint |H_y|^2 \, dxdy \quad , \qquad (1)$$

where $H_x$ and $H_y$ are the $x$- and $y$-components of the magnetic fields, respectively. Fig. 3 shows the rotation parameter and half beat length calculated for $d_{core}$ = 0.5 μm, $d_{clad}$ = 1 μm, $d_1$ = 0.5 μm, and various values of $d_2$ and $W$. Definition of these parameters as well as refractive index of each layer is indicated in the inset of Fig. 1. When $d_2$ = 0.3 μm, $R$ approaches 1 with relatively small dependence on $W$. In particular, $R$ = 0.97 when $W$ = 1 μm, corresponding to nearly 45° rotation. Fig. 4 shows the magnetic fields of the fundamental mode (Mode 1) and second mode (Mode 2) for $d_2$ = 0.3 μm and $W$ = 1μm, which are indeed angled 45° to the $x$ and $y$ axes.

Finally, complete propagation including the coupling from/to 2.5-μm-wide symmetric ridge waveguides is simulated by using the 3D full-vector beam-propagation method (3D-FV-BPM) [9]. As shown in Fig. 5(a), 20-μm-long tapered structure is introduced at the transitions between the ridge and PC sections to reduce the coupling loss. Fig. 5(b) shows the calculated intensities of the $x$- and $y$- electric fields along the propagation length $z$. Using a 180-μm length of PC section, efficient conversion from TE to TM mode is achieved with the insertion loss of 0.4 dB and extinction ratio of 16.6 dB. We also confirm that the conversion efficiency is kept above -1 dB for a width deviation of ±50 nm.



(a)

(b)

Figure 5: (a) Design of integrated PC with symmetric ridge input/output waveguides. (b) Relative intensities of $x$- and $y$-electric fields calculated using 3D-FV-BPM as a function of the propagation distance z. The parameters for the PC section are same as those in Fig. 4.

## IV. CONCLUSIONS

We have proposed and designed a novel type of waveguide PC, which is particularly suited for monolithic integration in InP PICs. Owing to the thick upper cladding and half-ridge structure, the proposed PC structure has full compatibility and large mode overlap with a standard ridge waveguide. Efficient mode conversion between TE and TM modes is demonstrated in a 180-μm-long PC section with 0.4-dB insertion loss and 16.6-dB extinction ratio.

## REFERENCES

[1] M. Kato, *et al.*, "Transmitter PIC for 10-channel x 40Gb/s per channel polarization-multiplexed RZ-DQPSK modulation," *in Proc. Optical Fiber Communication Conference.*, OThN2, San Diego, Mar. 2009.

[2] Y. Shani, R. Alferness, T. Koch, U. Koren, M. Oron, B. I. Miller, and M. G. Young, "Polarization rotation in asymmetric periodic loaded rib waveguides," *Appl. Phys. Lett.*, vol .59, no. 11, pp.1278-1280, 1991.

[3] V. P. Tzolov and M. Fontaine, "A passive polarization converter free of longitudinally-periodic structure," *Opt. Comm.*, vol. 127, pp. 7-13, 1996.

[4] H. El-Rafaei, D. Yevick, and T. Jones, "Slanted-rib waveguide InGaAsP-InP polarization converters," *J. Lightwave Technol.*, vol. 22, no. 5, pp. 1352-1356, 2004.

[5] B. M. Holmes and D. C. Hutchings, "Realization of novel low-loss monolithically integrated passive waveguide mode converters," *IEEE Photon. Technol. Lett.*, vol. 18, no. 1, pp. 43-45, 2006.

[6] M. V. Kotlyar, L. Bolla, M. Midrio, L. O'Faolain, and T. F. Krauss, "Compact polarization converter in InP-based material," *Opt. Express,* vol. 13, no. 13, pp. 5040-5045, 2005.

[7] L. M. Augustin, J. J. G. M. fan der Tol, E. J. Geluk, and M. K. Smit, "Short polarization converter optimized for active-passive integration in InGaAsP-InP," *IEEE Photon. Technol. Lett.*, vol. 19, no. 20, pp. 1673-1675, 2007.

[8] P. Lüsse, P. Stuwe, J. Schüle, and H. G. Unger, "Analysis of vectorial mode fields in optical waveguides by a new finite difference method," *J. Lightwave Technol.*, vol. 12, no. 3, pp. 487-494, 1994.

[9] BeamPROP, software by RSoft Design Group, Inc, US.