Fabrication of Two-Layer Microphotonic Structures without Planarization

Minghao Qi†, Michael R. Watts‡, Tymon Barwicz, Peter T. Rakich, Luciano Socci, Erich P. Ippen, and Henry I. Smith
Research Laboratory of Electronics, Massachusetts Institute of Technology, 77 Massachusetts Ave, Cambridge, Massachusetts 02139
†mqi@alum.mit.edu, ‡mwatts@alum.mit.edu

Abstract: A novel nanofabrication scheme for two-layer microphotonic structures were proposed and applied to the fabrication of integrated, mode-evolution-based polarization splitters and rotators. Prototype devices demonstrated effective splitting and rotating of polarization with low cross-talk.

OCIS codes: (230.3990) Microstructure devices; (230.3120) Integrated optics devices; (130.2790) Guided waves

1. Introduction

Future integrated microphotonic systems are likely to be multilayered (or 3D) structures [1]. However, due to challenges in fabrication, most microphotonic devices, especially high index contrast (HIC) structures or photonic crystals, are currently fabricated in one single layer. 3D fabrication typically requires planarization steps (Fig. 1b-1c) and multiple depositions of optical materials (Fig. 1d), which are time-consuming and yield-limiting. Fortunately, if the two layers of materials are the same, then fabrication of two-layer structures does not require planarization when the upper-layer pattern is a subset of the bottom one (Fig. 1g-1l). This can substantially simplify the prototyping and manufacturing of optical micro-/nanostructures, some of which may have important optical device applications, such as polarization splitting and rotation.

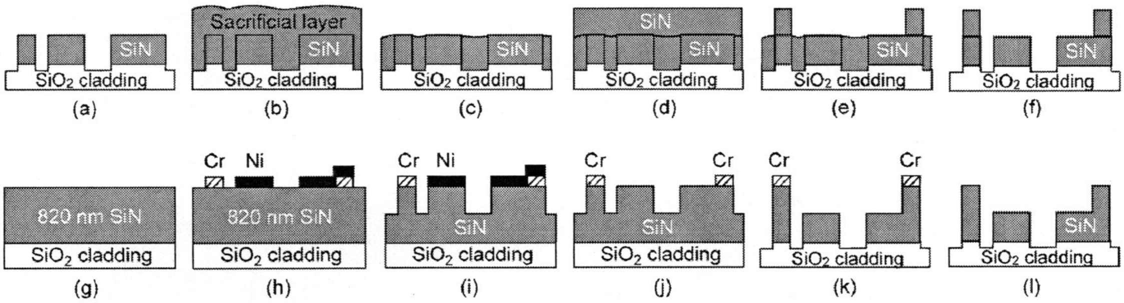


Fig. 1. Comparison of conventional (a-f) and new (g-l) fabrication strategy for two-layer nanostructures. (b) Gap filling via conformal deposition of a sacrificial layer; (c) Planarization, typically via chemical mechanical polishing; (d) deposition of another layer of optical materials, in this case silicon nitride (SiN) may be prohibitive due to contamination from the planarization step. The new strategy will be explained in the fabrication section.

Polarization has become an increasingly more critical issue in HIC microphotonics and/or photonic crystals because these devices exhibit significant polarization sensitivities. This is further complicated by the fact that polarization states from standard single-mode fibers are unpredictable. A practical solution is the polarization splitter and rotator (PSR), where an arbitrary polarization emanating from a fiber is split into orthogonal components (i.e. TE and TM), and then the TM mode is further rotated into TE mode. In this way the TE and TM components can be processed with two identical information-processing devices. For future integrated photonic systems, an on-chip PSR implementation is necessary. Moreover, an integrated approach allows the devices to be batch fabricated and the path lengths of the two arms to be matched through lithography.

2. Architecture of the polarization splitter and rotator

The polarization splitter and rotator were proposed and simulated by one of the authors (Michael Watts, [2-4]). The structures, depicted in Fig. 2a and 2d, consist of two silicon nitride core layers ($n_c = 2.2$), an under-cladding of thermal oxide ($n_{cl} = 1.445$) and an over-cladding of air. The operating principle of both devices is mode-evolution. In contrast to devices based on mode-coupling [5-8], these structures exhibit wavelength independence and fabrication tolerance. To minimize power exchange, a slow evolution of the structure is needed to allow the modes a chance to de-phase before substantial power exchange occurs. As a result the transition region (or the tapering) is much longer than what they appeared in the schematics.

3. Fabrication and experimental results

A novel "one deposition and two-step etching" process was applied to avoid the planarization step (Fig. 1g-1l)). First, 820nm of silicon nitride (SiN, n = 2.2) was deposited via low-temperature chemical vapor deposition (Fig. 1g). Second, two hard masks were created with electron-beam lithography and lift-off (Fig. 1h). The first hard mask was 50-nm thick chromium (Cr), defining the pattern of tall waveguides. The second one, 50-nm thick nickel (Ni), defined the short waveguides and was properly aligned to the first one. Third, the waveguide patterns were transferred into SiN via reactive-ion-etching, using a mixture of CHF_3 and O_2. The etching was divided into two steps to properly define waveguides of different heights. The first etch stopped when 410 nm of SiN was removed (Fig. 1i). One type of the hard masks, namely Ni, was selectively removed (Fig. 1j) and the second etch removed the remaining 410nm of SiN, as well as an additional 70 nm of SiO_2 underneath, to ensure that SiN was completely etched through (Fig. 1k). The short waveguides, without the protection of hard masks, preserved the height and cross-sections, while their vertical location recessed 410 nm as a result of the second-step etch. The tall waveguides, protected by Cr, had a full height of 820 nm. The fourth and final step was the removal of Cr via wet-etch (Fig. 1l). The fabricated structures are shown in Fig. 2 with minimum feature sizes down to 25 nm. This fabrication method can also be applied to more than two layers of structures in a straightforward manner.

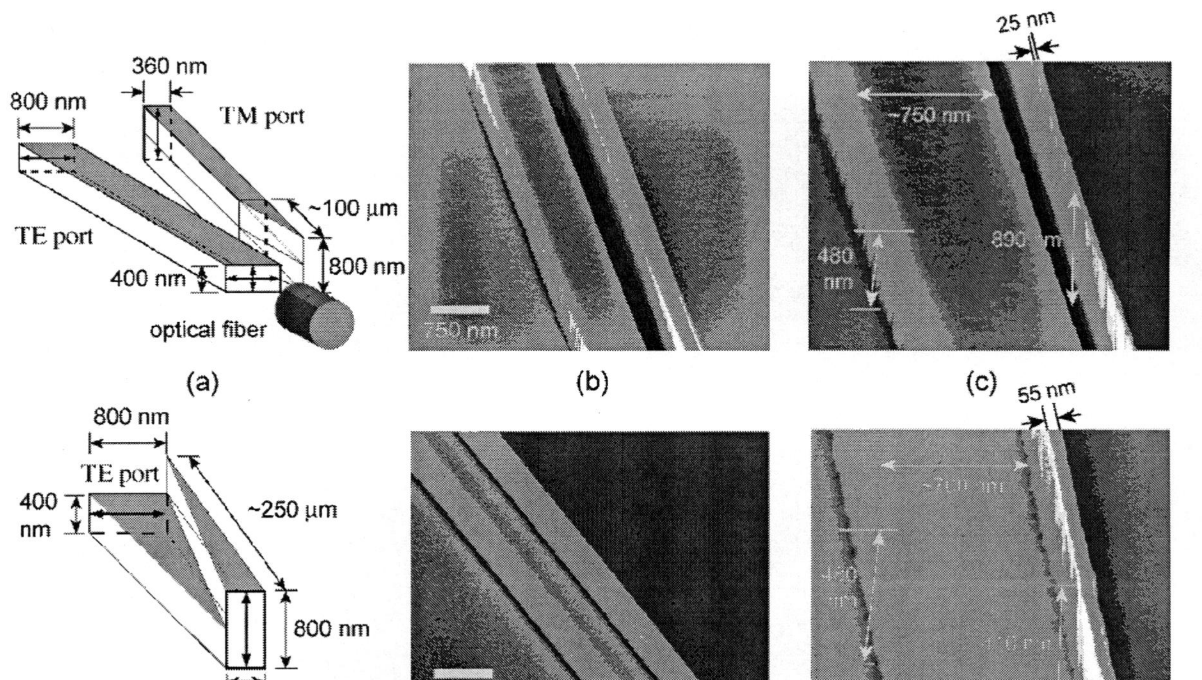
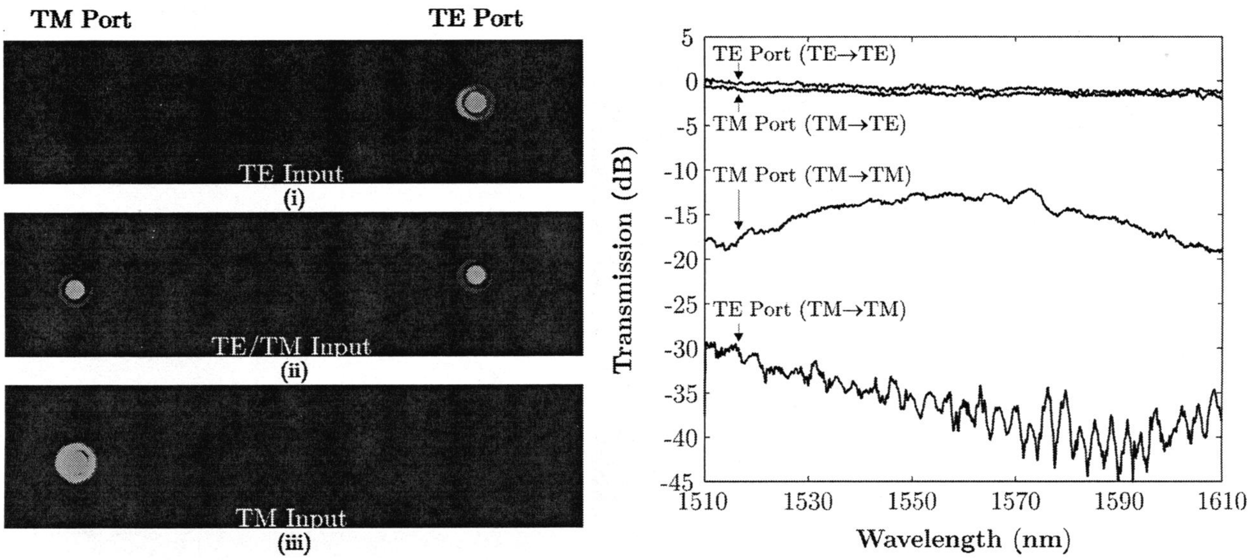


Fig. 2. (a)-(c): Schematic and fabricated structures of the polarization splitter; (d)-(f): Schematic and fabricated structures of the polarization rotator.

Devices with various parameters were fabricated to accommodate many fabrication uncertainties. Most notably, the transition lengths of the rotators are 192 μm and 384 μm long; and the transition lengths for splitters are 75 μm and 150 μm. Both standalone and integrated devices were made. The transmission spectra for an integrated polarization splitter and rotator (i.e. rotator attached to the TM output arm of the polarization splitter) were measured using a tunable laser across the 1.51-1.61 μm band. Despite the intentional width variations and misalignments of the layers, nearly all of the fabricated devices, splitters, rotators and integrated splitters and rotators demonstrated broadband low cross-talk (< 10dB) performance. The performance of a representative integrated polarization splitter and rotator is depicted in Fig. 3a and Fig. 3b. The results in Fig. 3b were normalized to the respective straight waveguide losses and chip couplings. The performance of the integrated polarization splitter and rotator qualitatively matches simulation results. The structure exhibits broadband low cross-talk performance. The cross-talk level below -30 dB in the TE port and -11 dB in the TM port across the measured spectrum. Other PSRs exhibited more impressive performance, but had noncontiguous waveguides making it difficult to normalize out the data. The low cross-talk level in the TE port indicates that the polarization splitter in the PSR is working near the theoretical limit. The modest cross-talk in the TM port indicates that the polarization rotator in the PSR is working only moderately well. The best standalone polarization rotator exhibited less -18 dB cross-talk across the band while the best polarization splitter exhibited -20 dB cross-talk across the band. As a result of noncontiguous waveguides and imperfect chip facets it is difficult to ascertain the losses. However, the device losses do not appear to be significant.



(a) (b)

Fig. 3. (a) Infrared image of PSR output for (i) TE, (ii) TE/TM, and (iii) TM inputs, and (b) Measured performance across 1510 – 1610 nm. Note: The TM port should (and does) possess a TE polarization as a result of the polarization rotator.

4. Conclusions

A novel fabrication strategy for two-layer microphotonic devices without planarization is proposed and applied to the fabrication of integrated PSRs. The standalone splitters and rotators exhibited as low as -20 dB and -18 dB cross-talk, respectively in a broad wavelength region of 1510 nm to 1610 nm. To our knowledge, this is the first demonstration of an integrated, wavelength independent, and CMOS compatible integrated polarization splitter and rotator.

References

[1] M. Qi, *et al.* "A three-dimensional optical photonic crystal with designed point defects," *Nature*, **429**, 538-542, 2004

[2] M.R. Watts, H.A. Haus, G. Gorni, and M. Cherchi, "Polarization splitting and rotating through adiabatic transitions," *Proceedings of Integrated Photonics Research Conference 2003 (IPR 2003)*, pp. 26-28, 2003.

[3] M. R. Watts and H. A. Haus, "Integrated mode-evolution-based polarization rotators," *Optics Letters, to be published, 2005*

[4] M. R. Watts, H. A. Haus, and E. P. Ippen, "An integrated mode-evolution-based polarization splitter," *submitted Optics Letters*

[5] M. R. Watts, "Wavelength switching and routing through evanescently induced absorption," MS Thesis, Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology, Cambridge, MA, 2001.

[6] J. J. G. M. van der Tol and J. H. Laarhuis, "A short polarization splitter without metal overlays on InGaAsP-InP," *J. Lightwave Tech.* **9**, 879 (1991).

[7] J. Z. Huang, R. Scarmozzino, G. Nagy, M. J. Steel, and R. M. Osgood, "Realization of a compact and single-mode optical passive polarization converter," *IEEE Photon. Technol. Lett.* 12, 317-319, March 2000.

[8] V. P. Tzolov and M. Fontaine, "A passive polarization converter free of longitudinally periodic structure," *Optics Communications* 127, 7-13, Jun. 1996.