High Efficiency Silicon-on-Insulator based Corner Turning Mirrors

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(An oral presentation is preferred)

Abstract: Low propagation loss and low turning loss are very important for photonic integrated circuits. In this work, the silicon-on-insulator based corner mirrors having high optical transfer efficiency optimized in previous numerical calculation are further validated with FDTD simulation and then fabrication and test. An experimental optical access loss of 0.8dB is obtained.

Keywords: Silicon-on-insulator, corner turning mirror, optical transfer efficiency, optical access loss

I. Introduction

Photonic network systems, especially those using reconfigurable optical add-drop multiplexing (ROADM), have led to the need for larger-scale photonic integrated circuits (PIC) [1]. As a result, silicon-on-insulator (SOI) waveguide is a maturing technology and its inherent capabilities and advances are encouraging intensive research on the hybrid integration of active/passive components on one chip [1-3]. However, the minimum tolerable radius curvature of a conventional rib waveguide bend is still quite large, so the development of a low-loss compact SOI waveguide corner turning mirror is a paramount research topic [4]. In this work, we optimized the SOI waveguide corner mirrors with our numerical theory and commercial software tools, and then validated the predictions with experiments.

II. Numerical Modeling and Performance Simulation

Figure 1(a) schematically shows the corner mirror structure of SOI rib waveguide and Fig. 1(b) is the cross-sectional view of SOI rib waveguide. This corner mirror structure is formed by an input waveguide channel, an output waveguide channel and a reflector. Certainly the angle between the input and the output waveguide channels θ meet the total internal reflection (TIR) at the interface of the waveguide and reflector materials. H is the silicon film thickness, h is the rib height and W is the rib width; n_1 and n_2 are the refractive indices of the core and the cladding of the effective channel waveguide, respectively, and n_m is the refractive index of the reflector material.

In this TIR process between the reflector material and waveguide material, the Goos-Hanchen effect results in shift of the effective reflecting interface from the real mirror interface, which impact the transfer efficiency. The Goos-Hanchen shift (GHS) is defined as [5]:

$$d_{TE} = \frac{1}{k_0[n_1^2 \sin^2(\frac{\theta}{2}+\varphi) - n_m^2]^{1/2}} \qquad (1a)$$

$$d_{TM} = \frac{n_m^2}{n_1^2 \sin^2(\frac{\theta}{2}+\varphi) - n_m^2 \cos^2(\frac{\theta}{2}+\varphi)} \qquad (1b)$$

where d_{TE} and d_{TM} are the GHS for TE and TM polarization states, respectively, and φ is the tilt-angle of mirror plane. Our numerical calculation shows the GHS in this structure has a bearing upon the transfer efficiency of a corner mirror [5]. Namely, if the mirror plane has a negative shift to compensate the GHS, this structure has the best transfer performance to the optical guided mode and is more robust to impaired surface roughness and mirror plane tilt angle errors.

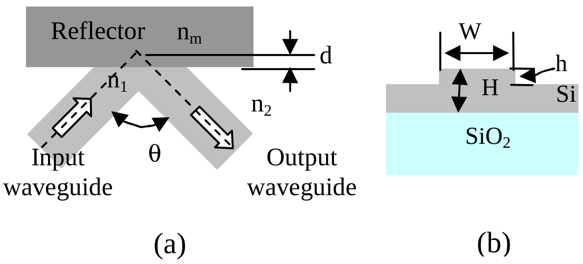


Figure 1: (a) Schematic geometry of SOI based corner mirror; (b) cross-sectional view of SOI rib waveguide

This work is sponsored by the Ontario Centre for Excellences (CR-60017-08) of Canada, D&T Photonics, and benefited from a Fabrication Grant IPDTTDTP provided by CMC Microsystems.

By selecting the device parameters of a 90° corner turning mirror: H=1.5µm, h=0.5µm, and W=3.0µm, the refractive indices of Si and SiO_2 as 3.45 and 1.45, respectively, at wavelength λ=1550nm and TE polarization, we obtained the FDTD simulation result of beam propagation process and guided mode output with this corner turning mirror as shown in Fig. 2(a) and (b), respectively

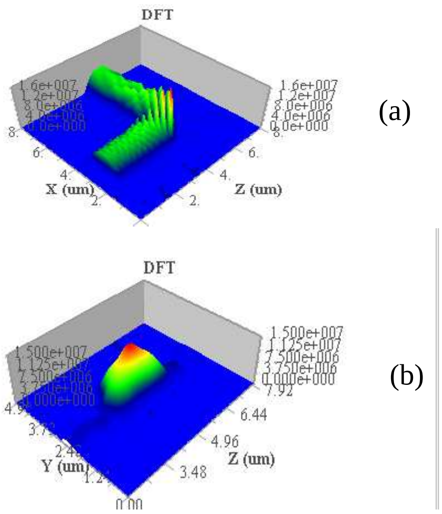
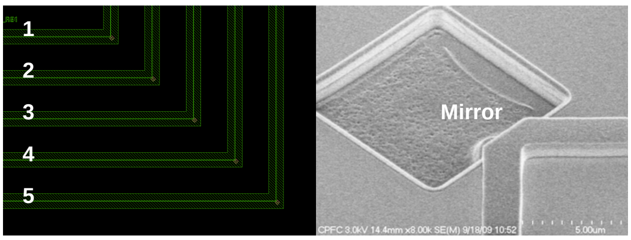


Figure 2: FDTD simulations with the selected corner mirror: (a) the propagation optical beam and (b) the output mode

III. FABRICATION AND EXPERIMENT

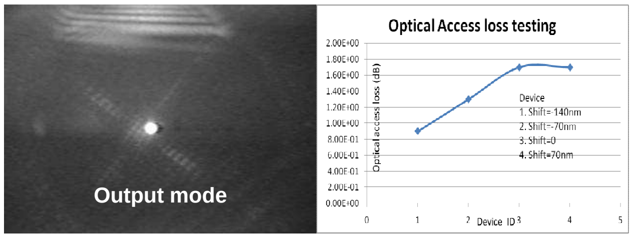
According to above optimization, we designed five corner mirror structures to correspond with the reflecting plane shift of -140, -70, 0, 70, and 140nm, then fabricated the corner turning mirror devices in Canadian Photonics Fabrication Centre (CPFC) with a fabrication grant of Canadian Microsystems Corporation (CMC). A SOI based device of corner turning mirror with incident/reflection waveguides was fabricated as shown in Fig. 3(b), where the mirror is the deep air trench. The measurement shows the sidewall verticality of the deep air trench has achieved 90±0.4°.



(a) **(b)**

Figure 3: (a) Five corner turning mirror devices having five different mirror plane shifts and (b) the SEM image of a mirror

With the fabricated device, at the wavelength of λ=1550nm, a guided mode output is observed as shown in Fig. 4(a), and the measured results of its optical access loss is shown in Fig. 4(b), the lowest value of 0.9dB is from the device with the shift of -140nm and this structure also gives a relatively lower polarization dependence of the optical access loss, which are completely consistent with the predictions of our previous work [5].



(a) **(b)**

Figure 4: (a) an experimental optical guided-mode output and (b) the measured values of optical access loss for four devices

IV. CONCLUSION

In accordance with our previous work on the modeling and numerical calculation, we further validated the optimization for the optical energy transfer efficiency of SOI waveguide corner mirrors with FDTD commercial software with a consideration of GHS. Then we fabricated a serial of corner turning mirror devices and finally obtained experimental results of guided mode output and optical access loss, which are agreeable with the values obtained in both numerical calculation and simulations.

ACKNOWLEDGMENT

Authors would like to thank Professor Pierre Berini of the School of Information Technology & Engineering and his group members: Ewa Lisicka, Asad Sadkhan and Fan Hui for their kind help to the experimental/testing work of this project. Authors also thank Professor Karin Hinzer and her group Ph.D student Simon Chow for their assistanc. Mr. Peng Liu of D&T Photonics is acknowledge for his support of this project.

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