

# Experimental demonstration of an ultra compact SOI polarization rotator

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**Abstract**— We report the design, fabrication and characterization of a polarization rotator in SOI technology. The device is compact (26 $\mu\text{m}$ ), and features a measured crosstalk above 10dB, over a 35-nm bandwidth with a polarization conversion efficiency above 90%.

**Keywords**- Integrated optics; optical waveguides; polarization rotator; silicon on insulator technology

## I. INTRODUCTION

Silicon-on-Insulator (SOI) is being consolidated as the most promising technology to develop photonic devices for telecom applications with an ultra large scale of integration (ULSI) at a low cost [1] due to the high refractive index contrast between silicon ( $n \approx 3.45$ ) and silica ( $n \approx 1.45$ ) at  $\lambda = 1.55 \mu\text{m}$ , as well as its compatibility with Complementary Metal Oxide Semiconductor (CMOS) microelectronic tools.

For high index-contrast integrated waveguides, one of the main issues is their strong polarization dependence. To overcome this drawback, a polarization diversity system is required because it enables polarization-insensitivity to arbitrary polarized input light, but may require a polarization rotator as one of the core devices [2]. Several polarization rotators have been suggested but require a complicated fabrication process, due to slanting sidewalls [3], or the use of additional materials [4,5]. An alternative mode evolution approach based on a pair of two different waveguide core layers were proposed in [6] but a non standard 400nm silicon thickness was used in one of the layers and the minimum rotation length was 40 $\mu\text{m}$  [7]. Recently, a planar polarization rotator, whose conversion length was also above 40 $\mu\text{m}$ , has also been reported [8].

The silicon polarization rotator proposed here is based on a very compact design without slanted side wall, hence requiring less complex fabrication process, being fully compatible for co-integration with standard SOI wafers based on a 220nm thick silicon layer.

## II. POLARIZATION ROTATOR THEORY AND DESIGN

The proposed polarization rotator consists of a straight asymmetric structure shallow etched in a strip waveguide

configuration as depicted in Fig. 1a, which was also proposed in [9] but only theoretically analyzed and optimized with different parameters. Here, the chosen parameters are  $h = 220 \text{nm}$  (silicon thickness in standard SOI wafers), etch depth,  $ed = 70 \text{nm}$ , and fill factor of 25%,  $ff = 55 \text{nm}$ . The etch depth was chosen to facilitate the integration of the polarization rotator in devices that use conventional gratings to couple light from an external optical fiber [9]. A symmetric-asymmetric waveguide interface allows the excitation of two hybrid modes S1 and S2, depicted in Fig. 1b, with their principal axis tilted by 45 degrees. In order to achieve total polarization conversion, these hybrid modes must be excited equally. This condition is satisfied for a waveguide width of 220 nm, as shown in Fig. 2, taking into account the 25% fill factor.

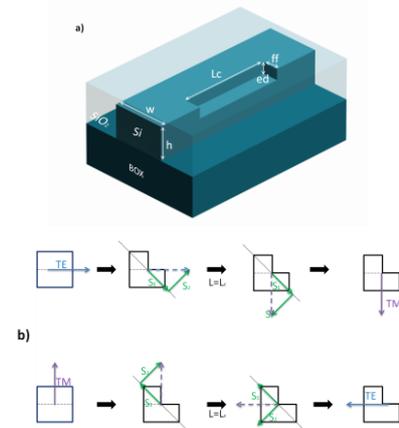


Figure 1. (a) Proposed SOI polarization rotator. (b) Optical axes rotation after propagating along  $L_c$

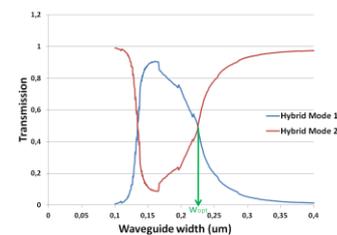


Figure 2. Width for which two hybrid modes are equally excited

Using the equation below, we find that the theoretical length to achieve polarization rotation is around 27  $\mu\text{m}$ .

$$L_c = \frac{\lambda}{2\Delta n_{eff}} \quad (1)$$

where the  $\Delta n_{eff}$  is the difference between effective indexes of the two hybrid modes. By using a simulation tool (FemSIM), we obtained that  $n_{eff0}=1.5121$  and  $n_{eff1}=1.4833$ , so  $L_c \approx 27 \mu\text{m}$  at  $\lambda=1.55\mu\text{m}$ . The polarization rotator was then analyzed by means of 3D-FDTD simulations. The figures below show normalized output powers for TE (Fig. 3a) and TM input polarizations (Fig. 3b). Knowing that the length of the input waveguide is about 3  $\mu\text{m}$ , the simulated length to achieve polarization rotation is close to 27  $\mu\text{m}$ , agreeing with the theoretical value.

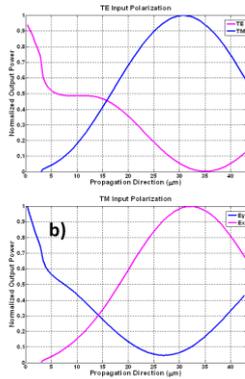


Figure 3. Normalized output power for (a) TE and (b) TM input polarization.

### III. FABRICATION AND EXPERIMENTAL RESULTS

The samples were fabricated in two steps. First, the waveguides were fabricated. A direct writing electron beam process was employed. The pattern was transferred into 100nm of HSQ negative resist employing a 30 KeV ebeam exposure. Then, the sample was etched by using an Inductive Coupled Plasma (ICP).

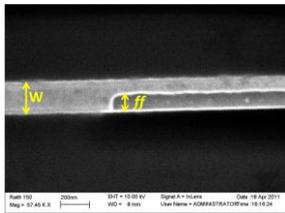


Figure 4. SEM image of fabricated polarization rotator

The second step was to remove the corresponding part of the waveguide to make the asymmetric structure. Once more, a direct e-beam writing process was employed but, in this case, on a patterned sample. So, previously exposed alignment marks were used to align the parts to be removed on the waveguides. This process was carried out by using PMMA positive resist which allows us to protect the rest of the sample during the etching process. The 70nm etching was again carried out by using an ICP system. Figure 4 shows the scanning electron microscope (SEM) image of the fabricated device.

Figure 5 shows experimental measurements. As depicted in Fig. 5a, we measured a 13.7dB crosstalk at  $\lambda=1.55\mu\text{m}$ . Moreover, the measured crosstalk remains above 10dB in a wavelength bandwidth of around 35nm, as shown in figure below. Fig. 5b shows the polarization conversion efficiency, which is larger than 95% at  $\lambda=1.55\mu\text{m}$

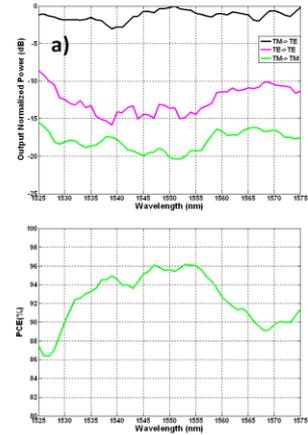


Figure 5. Measured (a) crosstalk and (b) polarization conversion efficiency for 26  $\mu\text{m}$ -long-rotator

### IV. CONCLUSION

In conclusion, an ultra compact and broadband polarization rotator in SOI technology has been designed, fabricated and experimentally characterized. The device features a polarization conversion efficiency of 95%, at  $\lambda=1.55\mu\text{m}$ , in a 26  $\mu\text{m}$ -long-device. The next step would be the combination of both the polarization splitter and rotator, in order to demonstrate the performance of polarization diversity schemes.

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