High performance TM-pass polarizer via subwavelength grating bandgap engineering

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***Abstract*—Silicon photonics systems exhibit a strong birefringence which makes polarization management critical. Here we demonstrate, with full 3D-FDTD simulations, a TM-pass polarizer based on tilted subwavelength gratings that reflects the TE_0 mode into the TE_1 mode, which can then be easily eliminated. The polarizer achieves TM mode insertion losses below 0.4dB, reflections into the undesired fundamental TE mode of less than -20 dB, and an extinction ratio above 20 dB, over a 150 nm bandwidth around the wavelength of 1550 nm.**

I. Introduction

Silicon on insulator (SOI) is quickly becoming a mainstream platform for integrated optics. Its high-index contrast along with CMOS-like fabrication processes is enabling low-cost, large-scale production of chips with a high density of devices [1]. However, the large index contrast also leads to a strong birefringence. Therefore, polarization management in SOI becomes of great importance [2]. Different types of devices are employed to fulfill this task. Among them, polarizers are used to achieve high polarization purity for applications such as biosensing [3] or polarization multiplexing for high speed communications [4]. In the standard 220 nm SOI platform, TE-pass polarizers are significantly simpler to design than TM-pass polarizers, since the TE polarization is more confined than the TM polarization. For TM-pass polarizers several solutions have been proposed, but most of them require a complex fabrication process [5] or reflect the fundamental TE mode back into the system [6], which can have detrimental side-effects. Other approaches include using a polarization splitting mechanism with an air cladding, which can be problematic for integration [7], employing a Bragg grating with only 50 nm wide slots to radiate the TE polarization [8], or leveraging a directional coupler comprised of silicon and silicon nitride waveguides to couple only the TM mode [9].

Here, we propose a new TM-pass polarizer design for standard 220 nm silicon that exploits tilted subwavelength structures. This structure enables us to engineer the anisotropy of the structure by only affecting the TE-polarization [10], [11]. In addition, the proposed design can be fabricated with a single etch-step, achieving insertion losses below 0.4 dB, an extinction ratio above 20 dB and keeping the reflections into the undesired fundamental TE mode under -20 dB in the the 150 nm operational bandwidth.

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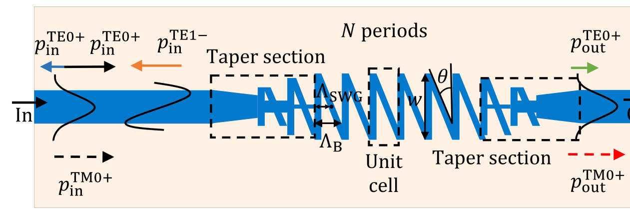

Fig. 1. Schematic of the TM-pass polarizer. For TE polarization the forward propagating fundamental mode is converted into the backward propagating first order mode as the periodic structure behaves as a reflector, whereas for TM polarization the structure behaves as an homogeneous subwavelength metamaterial.

II. Polarizer structure and design

The polarizer is comprised of a periodic structure, as shown in Fig. 1, and input/output taper sections. The device is designed to block the forward propagation TE_0^+ mode, reflecting it into the backward propagating TE_1^- mode, while allowing the forward propagatingTM_0^+ mode to pass through with negligible losses. Each second strips of this structure is tilted an angle θ, yielding a period $\Lambda_\mathrm{B} = 2\Lambda_\mathrm{SWG}$. This periodic perturbation will affect mainly the TE polarization, leaving the TM polarization almost untouched [12]. As a result the device operates as an (anti-symmetric) Bragg grating for TE polarization, and as a subwavelength structure for TM polarization [13].

In order to make the structure reflect the TE_0^+ mode into the TE_1^- mode, the pitch Λ_B must be chosen so that the phase matching condition between the modes is met: $k_0^+ + k_1^- = 2\pi/\Lambda_B$ [14]. Using the MPB software package [15], the pitch of the structure $\Lambda_\mathrm{B} = 440\,\mathrm{nm}$ is calculated to center the phase matching condition at a wavelength of $\lambda = 1550\,\mathrm{nm}$. The remaining geometric parameters of the device are then designed via MEEP [16], a 3D-FDTD open-source simulator, to minimize the insertion losses: $\mathrm{IL[dB]} = -10\log_{10}\left(p_\mathrm{out}^\mathrm{TM0+}\right)$ and the back-reflections into the fundamental mode: $\mathrm{BR0[dB]} = 10\log_{10}\left(p_\mathrm{in}^\mathrm{TE0-}\right)$, while maximizing the extinction ratio: $\mathrm{ER[dB]} = 10\log_{10}\left(p_\mathrm{out}^\mathrm{TM0+}/p_\mathrm{out}^\mathrm{TE0+}\right)$ and the back-reflections into the first order mode: $\mathrm{BR1[dB]} =$

$10\log_{10}\left(p_{\rm in}^{\rm TE1-}\right)$ in the broadest possible bandwidth. The resulting structure is $w = 1.1$ µm wide, has a tilt $\theta = 15°$ and is 20 periods long. Tapered input/output sections, shown in Fig. 1, are introduced to create a smooth transition between the access waveguide and the polarizer, reducing both the insertion losses and the undesired back-reflection into the fundamental mode. Indeed, as shown in Fig. 2(a) and (b), at the central wavelength ($\lambda = 1550\,\mathrm{nm}$), the TE_0 mode gets reflected into the TE_1 that propagates backwards, while the TM_0 propagates through the device with almost no losses. The performance of the device is summarized in Fig. 3, where it can be observed that the extinction ratio and insertion losses are above 20 dB and 0.4 dB, respectively, and the undesired back-reflections are below 20 dB in a bandwidth of 150 nm.

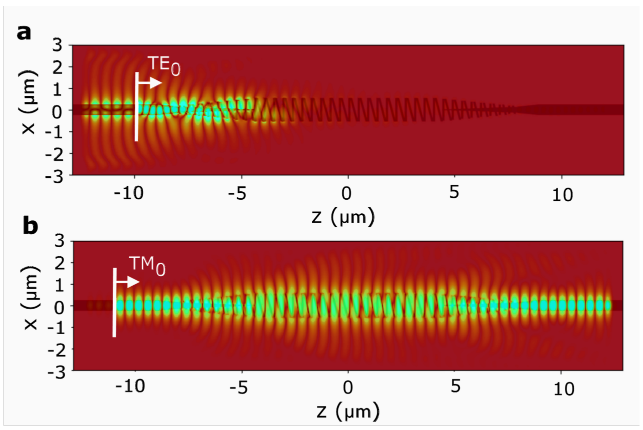

Fig. 2. Calculated propagation through the proposed structure of (a) $|E_x|$ of the fundamental TE mode and (b) $|E_y|$ of the fundamental TM mode via 3D FDTD simulations. The placement odf the source is indicated by the white line.

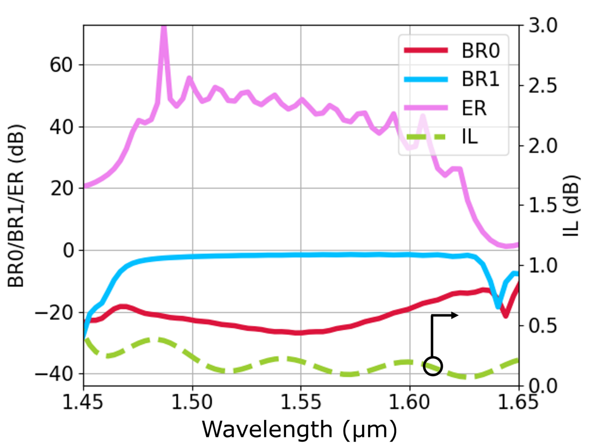

Fig. 3. Wavelength response of the structure calculated using 3D FDTD simulations. The extinction ratio (ER), back-reflection into the fundamental (BR0) and superior (BR1) modes are referenced to the left axis. The insertion losses (IL) in dashed lines is referenced to the right axis.

III. Conclusions

A novel topology for a TM-pass polarizer formed by tilted subwavelength gratings has been proposed and simulated via 3D FTDT simulations. The polarizer reflects the TE_0 mode into the TE_1 that can be readily eliminated, while letting the TM_0 mode through with almost no losses, achieving insertion losses below 0.4 dB, an extinction ratio above 20 dB and keeping the reflections into the undesired fundamental TE mode under -20 dB along the 150 nm operational bandwidth.

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