Ultra-Compact Silicon TM-pass Polarizer with a Photonic Crystal Nanobeam Structure

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Abstract: An ultra-compact TM-pass polarizer is experimentally demonstrated by using PhC nanobeam structure. The TE mode is reflected with an extinction ratio over 20.4 dB, while the TM mode propagates through with a 0.7-dB insertion loss.

1. Introduction

Photonic integrated devices on the silicon-on-insulator (SOI) platform have drawn a lot of interests for their compact footprints, low power consumptions and compatibilities with the complementary-metal-oxide-semiconductor (CMOS) fabrication process. However, the high index contrast between the silicon waveguide and the SiO_2 cladding makes SOI platform highly polarization dependent. Polarization diversity scheme is a promising solution to eliminate the polarization sensitivity of silicon photonic circuits [1]. Various polarization handling devices, such as polarization beam splitters (PBSs) [2] and polarization rotators (PRs) [3] have been reported. In addition, a silicon polarizer, which can block the unwanted polarization state in an on-chip system, is highly desired.

Many configurations of TE-pass or TM-pass polarizers based on silicon hybrid plasmonic waveguide have been proposed with high extinction ratio [4-6]. However, these devices usually exhibit large excess losses and the metal-involved fabrication processes are relatively complicated. In comparison, a fully etched silicon waveguide polarizer is preferred. In [7], a TM-pass polarizer based on a 10-μm long narrow waveguide design was numerically proposed, the TE mode is scattered due to the cut-off condition. Xu et al. demonstrated a TE-pass polarizer using asymmetrical directional couplers with a device length of 29.4 μm [8]. To further shrink the device, a subwavelength grating structure-based TM-pass polarizer was implemented with a length of ~9 μm [9]; while the insertion loss is relatively high due to the scattering in the gratings.

In this paper, we propose an ultra-compact TM-pass polarizer by simply etching an array of circular holes to the silicon waveguide. The incident TE-polarized light is reflected due to the optical bandgap of the photonic crystal (PhC) nanobeam structure. The TM mode, however, is not well confined within the silicon waveguide so it becomes delocalized and propagates with low excess loss. The proposed TM-pass polarizer is very compact with a length of 7.25 μm. It can achieve relatively high extinction ratio over 20.4 dB and the insertion loss is only 0.7 dB in a broad bandwidth range from 1510 nm to 1570 nm.

2. Device design and simulation

The PhC nanobeam design for the polarizer is based on a 220-nm-thick, 0.5-μm-width silicon nanowire waveguide, the 3D view of the proposed device is shown in Fig. 1. SiO_2 is adopted as both top and bottom claddings. The nanobeam structure consists of a one-dimensional photonic crystal lattice patterned with circular holes. The

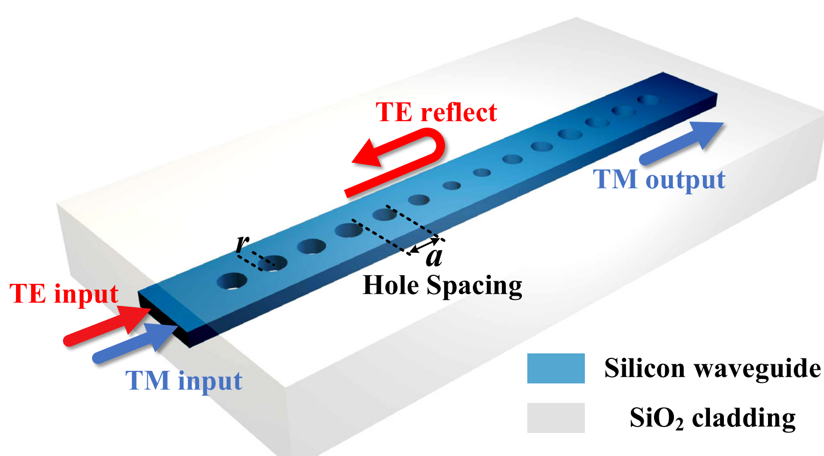

Fig. 1 Schematic configuration of the proposed nanobeam TM-pass polarizer.

nanobeam parameters, i.e. the hole spacing a and radius $r = 0.25a$, are chosen to satisfy the Bragg condition $n_{BL} = \lambda / 2a$ for TE mode. n_{BL} is the effective refractive index of the Bloch mode and λ is the center wavelength of the stop-band, which is chosen as 1550 nm. To minimize the light scattering outside the cavity, the PhC structure is adiabatically tapered [10] by linearly increasing the hole spacing from a = 250 nm in the center to a = 350 nm outward, by a step of 20 nm. The tapered region is followed by 7 identical holes on each side, serving as the Bragg mirror.

We simulate the performance of the proposed TM-pass polarizer using the 3D finite-difference time domain (FDTD) method by launching a TE- or TM-polarized light and monitoring the output spectrum. The structural parameters are optimized through scanning the central hole spacing values, as shown in Figs. 2(a-b). The simulated power distributions at 1550 nm for TE and TM inputs, are illustrated in Figs. 2(c) and 2(d), respectively. It can be noted that the TE mode is reflected back while the TM mode propagates with no additional loss.

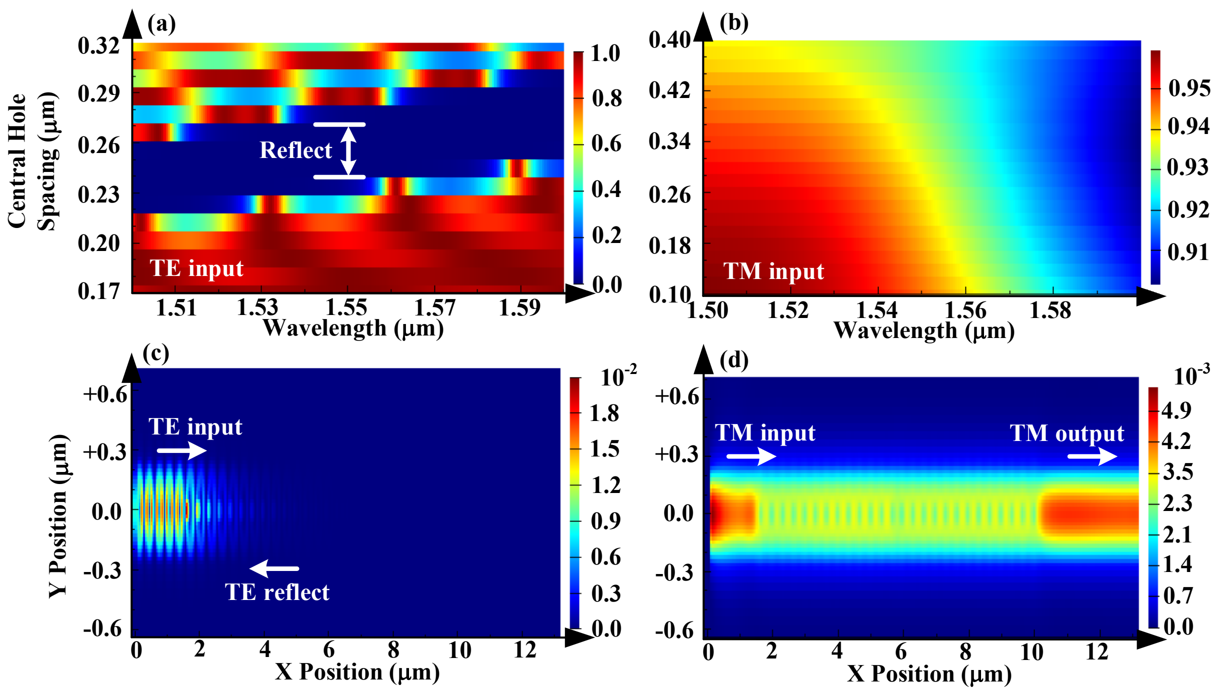

Fig. 2 Monitored spectrum using parametric scanning through 3D-FDTD method for (a) TE-, (b) TM-polarized light inputs, respectively. Simulated power distributions at 1550 nm for (c) TE, (d) TM mode inputs, respectively.

3. Device fabrication and measurement results

Multiple devices were fabricated on a SOI platform with a 220-nm-thick silicon on top of a 3-μm SiO_2 buried oxide with TE and TM grating couplers. Waveguides, PhC structures were patterned using electron beam lithography (Vistec EBPG-5200$^+$) and fully etched by inductively coupled plasma (ICP) etching. A 1-μm-thick SiO_2 cladding layer was then deposited on the devices by plasma-enhanced chemical vapor deposition (PECVD). The scanning electron microscope (SEM) image of a fabricated nanobeam TM-pass polarizer is shown in Fig. 3(b).

To characterize the performance of the TM-pass polarizer, we use a tunable continuous wave (CW) laser (Keysight 81960A) to launch a signal to the input port, and collect data from the output port, as shown in Fig. 3(a). Since there is a strong reflection at the input port of the device caused by the PhC structure, an optical circulator is introduced to avoid damage to the laser source. Grating couplers are employed to couple the TE- and TM-polarized lights. The periods of the TE and TM grating couplers are 630 and 980 nm, respectively, with the same filling factor of 46%. Both the grating couplers have an etching depth of 70 nm. Measured coupling losses of the TE- and TM-polarized grating couplers are 7.5 and 7.0 dB per facet, respectively. Two identical polarizers with different grating couplers were fabricated on the same wafer to measure the transmission responses for the TE- and TM-polarized light inputs, respectively.

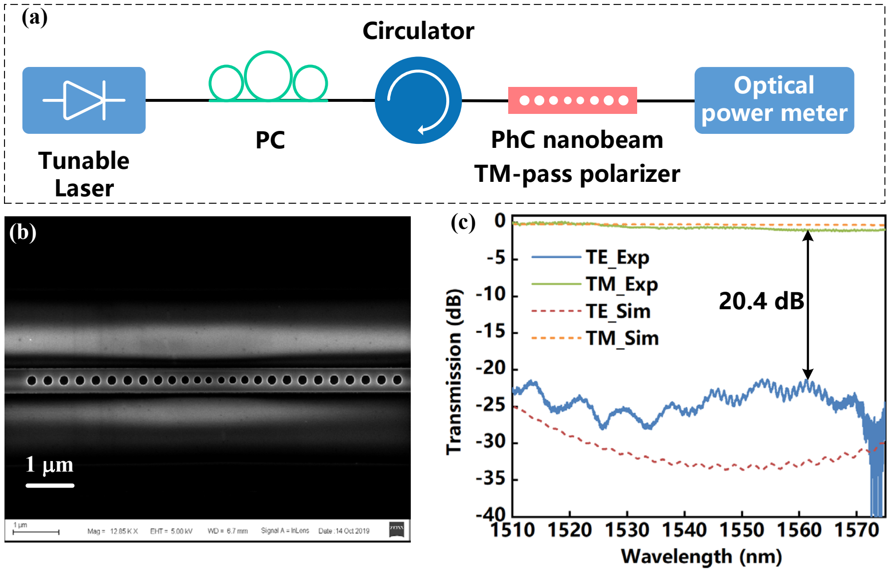

Fig. 3 (a) Experimental setup, (b) SEM image of a fabricated TM-pass polarizer, (c) Measured transmission responses for TE- and TM-polarized light inputs, respectively. The dashed curves show the simulation results as a reference.

The measured transmission responses for the TE- and TM-polarized light inputs are shown in Fig. 3(c). The transmission spectra of the TM-pass polarizer were normally calibrated to a straight waveguide fabricated on the same wafer. The insertion loss for the incident TM mode is < 0.7 dB and the extinction ratio for the TE mode is > 20.4 dB, in a broad bandwidth range from 1510 nm to 1570 nm. For comparison, the simulated transmission spectra are also presented, as shown by the dashed curves in Fig. 3(c). The crosstalk in the experiment is attributed to the imperfect Bragg condition caused by the fabrication process, which can be further optimized by improving the fabrication accuracy.

4. Conclusion and discussion

We have proposed and experimentally demonstrated an ultra-compact silicon TM-pass polarizer using a PhC nanobeam structure. The TE mode is reflected while the TM mode propagates with a low loss. In the wavelength range of 1510 nm to 1570 nm, the measured extinction ratio is > 20.4 dB, and the insertion loss is lower than 0.7 dB. The device length is only 7.25 µm. This TM-pass polarizer is compatible with SOI fabrication technology and can be easily integrated with other optical components. Moreover, the structure can be further extended to implement a PBS or a polarization splitter and rotator (PSR) by using a SiN/Si bi-layer coupler [11].

5. References

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