Low-Reflection Ultrahigh-extinction-ratio All-silicon TM-pass Polarizer covering E to U optical communication bands

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Abstract: We design and demonstrate a low-reflection TM-pass polarizer with high polarization extinction ratio > 30 dB over a 260 nm bandwidth. The fabricated polarizer exhibits excess loss < 0.9 dB for 1410-1700 nm wavelength range.

1. Introduction

Photonic integrated circuits based on silicon-on-insulator (SOI) platform have received great attention due to the advantages of high confinement of light and integration density. However, high index contrast of the SOI usually makes the device polarization-dependent, especially for the most widely used 220-nm thick SOI platform. Therefore, on-chip polarization management using polarizers, polarization beam splitters, or polarization rotators is highly desired [1]. Among them, the polarizers are used to block the unwanted polarization and minimize the polarization crosstalk. There have been various schemes to achieve broadband on-chip polarizers with high polarization extinction ratios (PERs), such as those based on shallow etched ridge waveguide [2], silicon hybrid plasmonic structure [3], graphene materials [4], antisymmetric directional couplers [5], anisotropic metamaterials [6] and Bragg gratings [7]. All-silicon polarizers with high performances are preferred in terms of fabrication complexity and compatibility. TE-pass polarizers based on anisotropic metamaterials could provide bandwidth > 415 nm and excess loss (EL) < 1 dB, as well as PER > 20 dB. As for the TM mode, very recent work demonstrates an excellent polarizer with 415 nm bandwidth (PER > 25 dB) using a double slot Euler waveguide bending on an air-clad SOI platform [8]. However, the use of air claddings is not practical for packaging. Alternatively, a TM polarizer with higher PER (> 30 dB) could be achieved using Bragg grating waveguides [9], but its single working bandwidth is limited to only ~100 nm and usually suffers from high back-reflection.

In this paper, we propose and demonstrate a novel low-reflection all-silicon TM-pass polarizer based on a multimode anti-symmetric apodized Bragg grating (MASABG) and a triple-core adiabatic taper. The MASABG works as a Bragg reflector to convert forward TE_0 to backward TE_1 mode, and then the reflected TE_1 gradually evolves into the TE_0 mode in the waveguide B and C and eventually leaks out through the tapered waveguides, as shown in Fig. 1 (a). The device is designed on a standard 220-nm SOI wafer and requires only one etch step. The proposed TM-pass polarizer shows an ultrahigh theoretical PER of ~60 dB and a very low EL of < 0.2 dB near 1550 nm. The calculated bandwidths for PER > 30 dB and >40 dB are 275 nm and 268 nm, respectively. The reflection of undesired TE polarization can be reduced to below -12dB for the 1410-1700 nm wavelength range. The fabricated device achieves broadband bandwidths of PER > 30 dB and >40 dB over 260 nm and 150 nm, respectively. The measured EL is < 0.9 dB for the entire working bandwidth.

2. Design and simulation

The proposed TM-pass polarizer consists of a single mode input waveguide, a triple-core adiabatic taper, a MASABG, and a single mode output waveguide. As shown in Fig. 1 (a), a triple-core adiabatic taper includes three waveguides to form a mode filter where forward TE_0/TM_0 mode could pass through waveguide taper A but backward TE_1 mode is converted into TE_0 mode from waveguide taper B and C. The MASABG structure gradually converts forward TE_0 into backward TE_1 mode through Bragg reflection. On the contrary, for TM_0 mode, the MASABG is equivalent to a dielectric waveguide according to the subwavelength-guided wave propagation. As a result, a TM-pass polarizer based on the MASABG supports single TM polarization transmission. Compared to sidewall multimode anti-symmetric Bragg grating (MASBG), introducing rectangle holes inside the waveguide can produce stronger modulation, which results in a much wider stopband [9].

Our device is based on a 220-nm SOI platform with a 1-µm thick upper SiO_2 cladding layer. The Bragg grating region is designed based on the phase matching condition between the forward TE_0 mode and the backward TE_1 mode. Here, the phase-matching condition is given as $n_0 + n_1 = \lambda_B/\Lambda$, where n_0 and n_1 are the effective index of TE_0 and TE_1 mode in the Bragg gratings, respectively, λ_B is the Bragg wavelength, and Λ is the Bragg period. In our design, both ends of the uniform MASBG are connected with an apodized MASBG to form the MASABG, as depicted in Fig. 1 (c). This can not only reduce the scattering loss caused by mode mismatch but also provide effective coupling between forward TE_0 mode and backward TE_1 mode in the short wavelength region, thus increasing the reflection bandwidth of TE_0 mode.

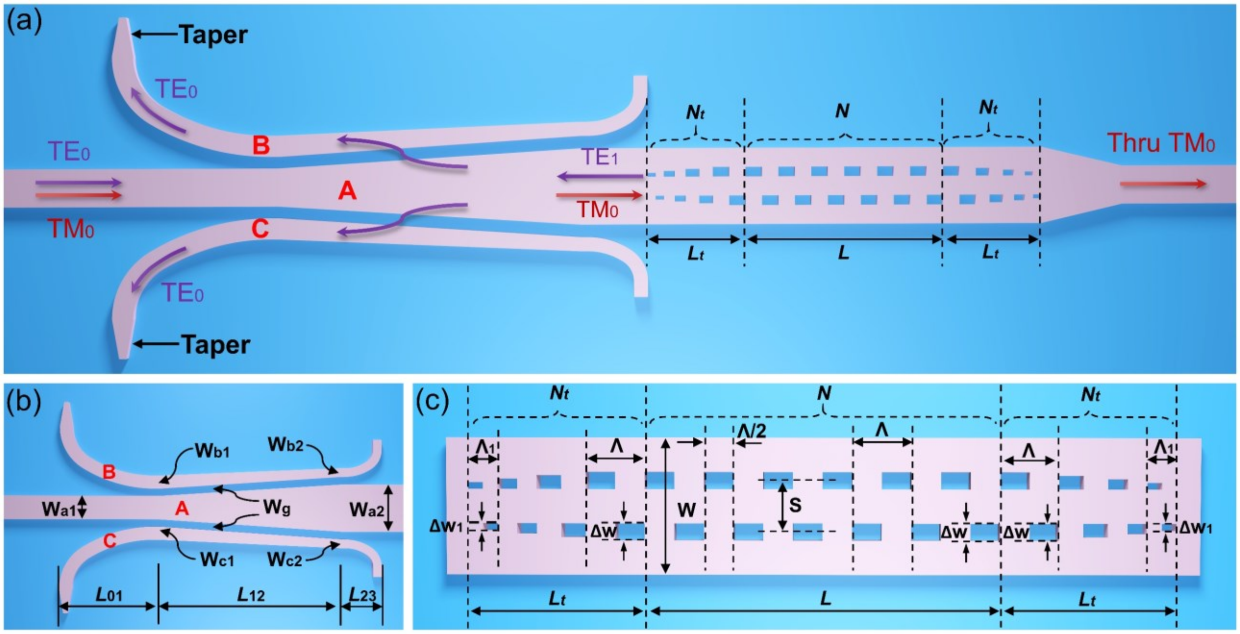

Fig. 1. (a) Top view of the proposed TM-pass polarizer bass on MASABG. The black dashed lines show the three parts of MASABG: one uniform Bragg grating and two apodized Bragg gratings. The purple arrows show the propagation of the TE_0 mode, and the red arrows represent the propagation of the TM_0 mode. (b) TE_1 mode filter based on a triple-core adiabatic taper. (c) MASABG with detailed parameters labeled.

The proposed TM-pass polarizer is then optimized through the three-dimensional finite difference time domain (3D-FDTD) method. Fig. 2 (a) shows the light propagation profiles for TE/TM polarization at wavelengths of 1410 nm, 1550 nm, and 1680 nm, respectively. From these profiles, the input TE_0 mode could be completely converted into TE_1 mode and eventually leaks out through the TE_1 mode filter, whereas the launched TM_0 mode passes through directly with low loss and finally outputs at the Thru-port. With a careful selection of all the parameters, the total length of the device is about 50 µm. The calculated PER is as high as 60 dB at around 1550 nm with a very low EL (<0.2 dB). The bandwidths for PER >30dB and >40dB are estimated to be 275 nm and 268 nm, respectively. More importantly, the undesired polarization is highly suppressed with < -12 dB reflection, as shown in Fig. 2 (c).

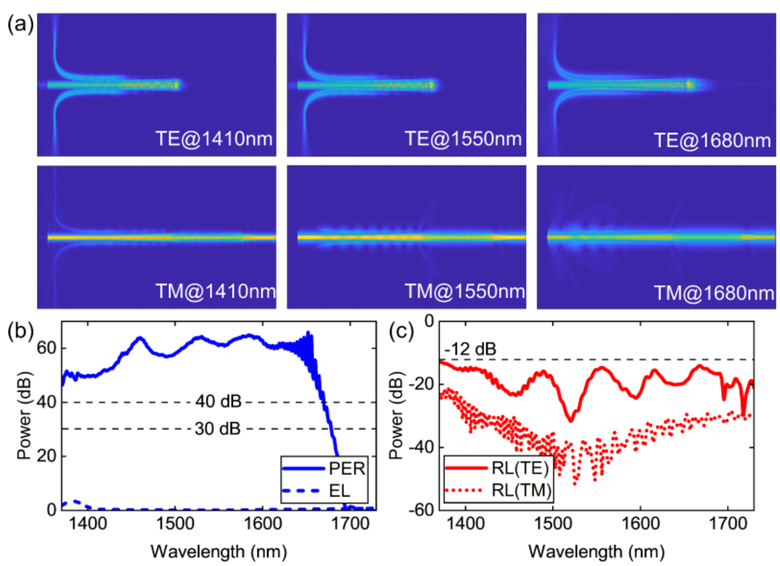

Fig. 2 (a) Calculated light propagation profiles when TE/TM polarization is launched. (b) Calculated PER and EL for the proposed TM polarizer at wavelengths range from 1400 to 1700 nm. (c) Calculated TE/TM reflections at wavelengths range from 1400 to 1700 nm.

3. Fabrication and results

The proposed MASABG-assisted TM-pass polarizer is fabricated on the 220 nm SOI wafer. The device layout is patterned by 100 keV electron beam lithography (Vistec EBPG 5000plus ES). One-step etching process is used to define all devices, followed by plasma-enhanced chemical vapor deposition (PECVD) of a 1-μm thick silicon dioxide film for the top silica cladding. Here, fully etched grating couplers (GCs) are used, thus the entire device requires the same etch depth which simplifies the fabrication process. However, it is quite difficult to use a single GC to measure the transmittance spectra over the 1400-1700 nm wavelength range due to the limited operating bandwidth. As a result, three sets of GCs with different center wavelengths are used to enable spectral measurements in the wavelength range from 1400 nm to 1700 nm. As shown in Fig. 3 (a), three sets of devices with the same polarizers but different GCs are fabricated for characterizations. TE-type GCs are attached to both ends of the TM-pass polarizer to measure the spectrum of the TE polarization after passing through the device. Similarly, TM-type GCs are connected at both ends of the polarizer to measure the spectrum of TM polarization after passing through the device. In order to measure the low ELs, ten TM-pass polarizers are cascaded, as shown in Fig. 3 (b). Fig. 3 (c) shows the Microscopic and the partial scanning electron microscope (SEM) image of the fabricated device. Straight single-mode waveguides are also fabricated on the same chip for normalization. A supercontinuum source and an optical spectrum analyzer are used to characterize the transmission responses. The measured PER and EL spectra are also recorded and plotted in Fig. 3 (d). At around 1550 nm, the measured PER is > 40 dB and the EL is around 0.6 dB. The measured bandwidths for PER >30 dB and > 40dB are 260 nm and 150 nm, respectively. In addition, the fabricated device shows a very low EL (<0.9 dB) in a wide wavelength range of 1410-1700nm, as shown in Fig. 3 (e).

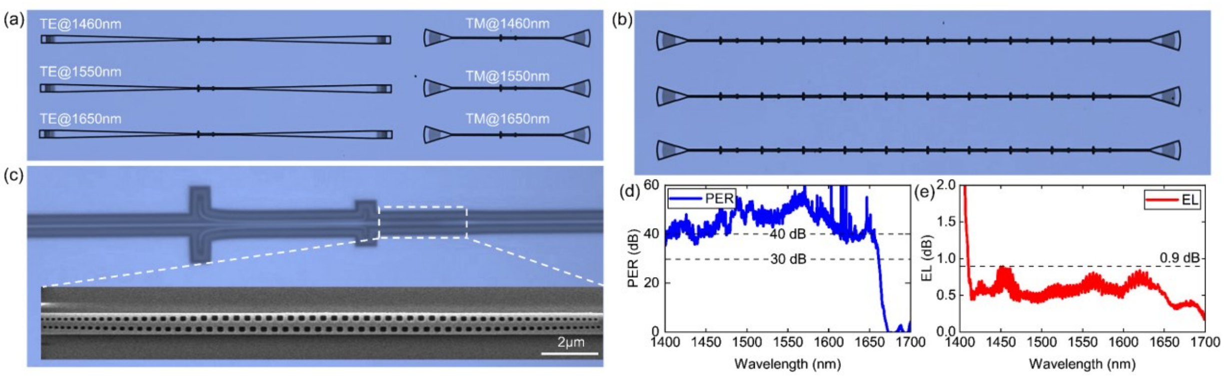

Fig. 3. (a) Microscopic image of fabricated three set devices for measurement. (b) Microscopic image of the 10 cascaded devices. (c) Microscopic image of fabricated device. Insets: partial SEM image of the Bragg grating. The measured PER (d) and EL (e) spectra for 1400-1700 nm.

4. Conclusion

In conclusion, we proposed and experimentally demonstrated a low-reflection and ultrahigh PER on-chip all-silicon TM-pass polarizer based on MASABG covering E to U optical communication bands. For the fabricated device, the EL is less than 0.9 dB in a wide wavelength range of 1410 - 1700 nm, and the measured bandwidth for PER >30 dB and >40 dB are 260 nm and 150 nm, respectively. The total length of the device is only 50 μm. We believe that our demonstrated high-performance TM-pass polarizer would find in applications for high-compacity optical communications and optical sensing.

5. Acknowledgements

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6. References

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