Dual-polarization O-band silicon nitride Bragg filters with high extinction ration

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ABSTRACT

Silicon nitride (SiN) photonic circuits operating in the original communication band (O-band) have a great potential to complement the Silicon (Si) photonic platform for the implementation of high-performance transceivers for Datacom applications. The low thermal coefficient, the reduced refractive index contrast, and the CMOS compatibility of SiN, make it an ideal solution to address certain key challenges in the Si photonic circuits. These particularly includes large thermal drift, tight fabrication tolerances, and strong polarization dependence. In this paper, we propose and experimentally demonstrate a SiN Bragg filter designed for dual-polarization operation. By optimizing the dimensions of a triangularly-shaped lateral corrugation, we yielded Bragg gratings with a quasi-square transversal geometry that minimizes filter birefringence. Exploiting this concept, we experimentally demonstrated SiN Bragg filters, fabricated with a single-etch step process in 300 mm Si photonics platform, exhibiting an experimental polarization independent rejection close to 40 dB in the O-band, with a bandwidth of 15 nm and negligible off-band excess loss.

Keywords: silicon nitride, silicon photonics, Bragg gratings, dual-polarization, wavelength filters

1. INTRODUCTION

Silicon photonics is being extensively developed for Datacom applications in big data centers. Following current standardization trends, this work is being focused on the O-band communications, at a wavelength of around 1310 nm. While Si photonics can benefit from large-volume fabrication processes in CMOS foundries, its performance may be limited by stringent requirements in terms of fabrication tolerances, temperature control, and polarization management. Silicon nitride (SiN), a CMOS compatible material, provides a seven-fold reduction in thermo-optic coefficient, compared to silicon [1,2], and a lower index contrast that substantially relaxes fabrication tolerances. Thus, SiN has been identified as a promising material choice to complement the Si photonics platform [3]. In addition, leveraging the reduced index contrast, proper geometry design can be exploited to reduce the birefringence of SiN devices, opening a new route to develop dual-polarization photonic circuits.

Here, we propose and experimentally demonstrate a novel SiN Bragg grating that provides high rejection simultaneously for both transverse electric (TE) and transverse magnetic (TM) polarizations, respectively. We implemented a triangularly-shaped lateral grating (see Fig. 1), with engineered corrugation dimensions to yield an average width that equals the SiN thickness. We also carried out a filter with an effectively square transversal geometry allowing a dual polarization behavior.

2. FILTER DESIGN

Bragg grating waveguides are a key component in the silicon photonics library, allowing the realization of wavelength filters [4], sensors [5], and advanced functionalities for dispersion engineering [6]. Bragg gratings rely on constructive interference of partial back-reflections in a periodic perturbation to implement a waveguide mirror. Bragg reflection occurs when the following phase-matching condition is met:

$$\lambda_c^{TE/TM} = \Lambda n_{BF}^{TE/TM}, \tag{1}$$

where the superscript denotes TE or TM polarization, $\lambda_c^{TE/TM}$ is the central Bragg wavelength, $n_{BF}^{TE/TM}$ is the effective index of the Bloch-Floquet mode that propagates along the periodic waveguide, and Λ is the grating period. From equation (1), it is evident that matching the central Bragg wavelength for TE and TM polarizations requires having similar Bloch-Floquet effective indices ($n_{BF}^{TE} \sim n_{BF}^{TM}$). One way to meet this requirement is to have

Bragg grating with square transversal geometry and homogeneous upper and bottom cladding, i.e. having the same index distribution along the horizontal (x) and vertical (y) axes.

For the filter design, we considered a 600-nm-thick SiN guiding layer surrounded by silicon dioxide (see Fig. 1a). To implement the Bragg grating, we used a triangularly-shaped lateral corrugation, depicted in Fig. 1b. We denote the filter period as Λ, the average grating waveguide width as W_{Ave} and the corrugation width as W_C. This geometry allows a single-etch process and relaxes minimum feature size requirements for short periods.

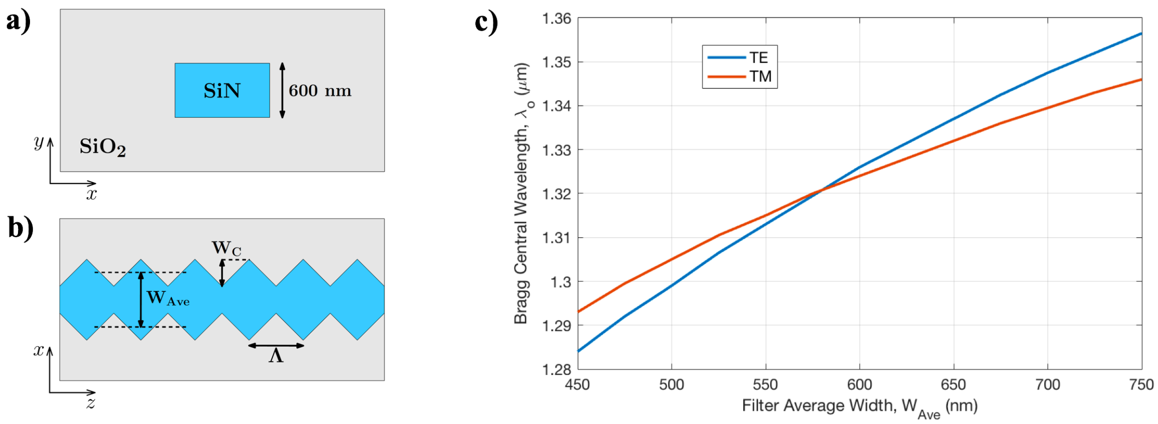

Figure 1. Schematic representation of a) transversal geometry of the strip waveguide, and b) longitudinal geometry of the proposed triangularly-corrugated Bragg filter. c) Central filter wavelength calculated with FDTD as a function of the filter average width (W_{Ave}) for a corrugation width of W_C = 200 nm, a period of Λ = 410 nm, and a total filter length of 20 µm.

We have studied the performance of our filter using finite difference time domain (FDTD) tools [6]. In Fig. 1c, it is shown the central Bragg wavelength, calculated for both TE and TM polarizations as a function of the filter average width, W_{Ave}. We considered a corrugation width of W_C = 200 nm, a pitch of Λ = 410 nm, and a filter length of 20 µm. It can be seen that Bragg central wavelengths for TE and TM polarizations have similar values for filter average widths between 550 nm and 600 nm. This region corresponds to quasi-square filter transversal geometries, where the average grating width approaches the waveguide thickness of 600 nm.

3. EXPERIMENTAL RESULTS

The devices were fabricated on the 300 mm silicon photonics R&D platform DAPHNE in ST Crolles (France) [3,8], using Si wafers with a 1.4 µm-thick buried oxide (BOX) layer, and a 600-nm-thick SiN guiding layer, deposited at low temperature via Plasma Enhanced Chemical Vapor Deposition (PECVD). Input and output grating couplers, access and reference waveguides and triangular filters were defined with 248 nm deep-ultraviolet (deep-UV) optical photolithography and dry etching. Finally, the chip was encapsulated with a 1.5 µm-thick SiO_2 layer. Figure 2a shows the scanning electron microscope (SEM) image of one of the fabricated filters, without encapsulation.

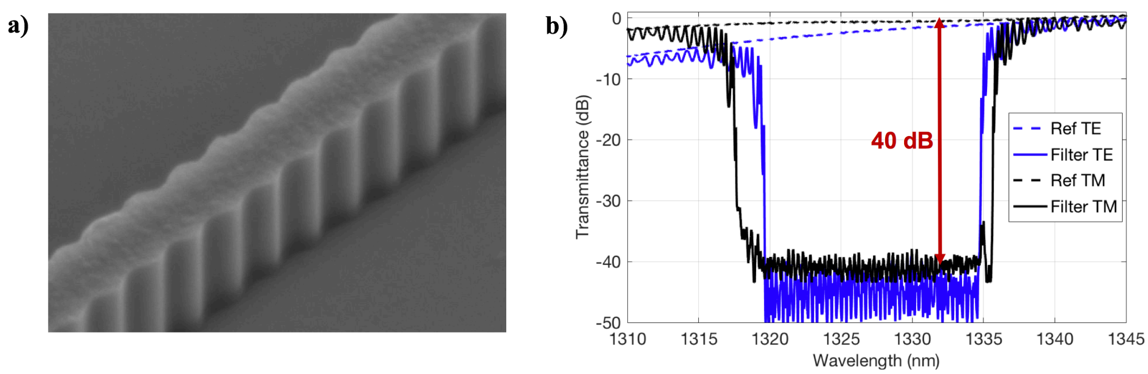

Figure 2. a) Scanning electron microscope (SEM) image of one of the fabricated filters, without encapsulation. b) Measured transmission spectrum for optimized triangular Bragg filter with 500 µm length, and reference strip waveguide.

The triangular filter has an average grating width of W_{Ave} = 600 nm, corrugation width of W_C = 200 nm, pitch of Λ = 410 nm, and length of 500 µm. Figure 2b shows the experimental response for both TE and TM polarizations for the same optimized Bragg filter, compared with a reference strip waveguide of the same length and corresponding polarization. We subtracted the insertion loss of the grating couplers. Our filter exhibits a polarization-independent extinction ratio close to 40 dB in a bandwidth of ~ 15 nm. The difference in bandwidth for TE and TM polarizations is only 3 nm. In addition, the filter shows negligible off-band excess propagation loss, compared to the reference strip waveguide.

4. CONCLUSIONS

In summary, we have designed and experimentally validated dual-polarization SiN Bragg filters operating in the O-band, based on a triangularly-shaped lateral corrugation geometry. We have shown by simulation that the difference between the central filter wavelength for TE and TM polarizations can be minimized by choosing an average filter width similar to the waveguide thickness, i.e. by implementing a quasi-square transversal filter geometry. We fabricated the filters in the 300 mm silicon photonics R&D platform DAPHNE in ST Crolles, using 248 nm deep-UV optical photolithography in a single-step etch process. We have experimentally demonstrated a polarization independent Bragg rejection of ~ 40 dB, with a 15 nm bandwidth around 1327 nm wavelength, and negligible off-band loss. These results open exciting perspectives for the realization of dual-polarization SiN photonic circuits with a great potential for Datacom applications.

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