Polarization beam splitter in the silicon nitride platform for the 1 µm wavelength band

(Student paper)

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Efficient and broadband devices able to control the polarizations state are an essential building block of any photonic integration platform. Here, we present the design and the experimental demonstration of an integrated polarization beam splitter realized in silicon nitride platform for the 1 µm optical wavelength band. The device has an experimental insertion loss smaller than 1 dB and a polarization extinction ratio of about 24 dB and 11 dB for TE and TM polarization, respectively.
Keywords: *integrated photonics, SiN platform, polarization*

INTRODUCTION

Silicon Nitride (SiN) photonic integrated circuits have attracted a strong interest in the last few years. The platform is especially interesting for quantum applications because it can offer ultra-low propagation losses, low non-linear losses, reduced birefringence, and a broadband transparency window from the visible to the upper part of the near infrared. Despite being less pronounced compared to the silicon-on-insulator platform, the dependence of the optical response of photonic devices to the polarization state of the light remains an issue also in the silicon nitride platform. For example, polarization control is critical in quantum key distribution to ensure the indistinguishability of the two transmitters [1]. Devices capable of controlling the polarization state (e.g., splitters or rotators) hence still play a key role [2,3]. So far, only a few devices have been demonstrated in silicon nitride, mostly using Mach-Zehnder interferometers or multi-mode interference couplers, but they tend to have relatively large insertion loss and footprint [4,5,6]. The need for high performance devices is particularly relevant at wavelengths shorter than the typical optical communication bands in the near infrared. This wavelength range has great interest for many applications such as free-space quantum communications in satellite networks [7] and single photon sources where single InAsP quantum dots has been demonstrated in the 1 µm wavelength band, achieving a very-pure single photon emission [8].

Here, we propose and experimentally demonstrate a SiN polarization beam splitter (PBS) realized by cascading two tapered asymmetric directional couplers. Our fabricated device shows high efficiency, a compact footprint and a broadband operation range in the 920 nm - 970 nm wavelength range.

RESULTS

The PBS is realized by cascading two tapered asymmetric directional couplers, as schematically represented in Fig. 1(a). The directional couplers are designed to ensure phase matching condition at a wavelength of 950 nm between the fundamental transverse-magnetic mode (TM0) of the waveguide WG1 (or WG3 for the second coupler) and the first-order transverse-magnetic mode (TM1) of the waveguide WG2. As a result, the TM0 mode in the input waveguide WG1 is efficiently couples to the TM1 mode in the central waveguide WG2. The TM1 in WG2 then couples back to TM0 in the output waveguide WG3 (cross port). At the same time, the device is ensured to be asynchronous for the transverse-electric (TE) modes in order to minimize coupling of the fundamental TE0 mode in WG1 to TE modes of WG2. The TE0 mode of the input waveguide WG1 hence remains in the waveguide WG1 and propagate to the through port. In addition, a linear tapered structure is introduced in the two directional couplers to increase the robustness of the device to wavelength variations and fabrication imperfections. The variation of the width in WG1 (WG3) and WG2 have opposite sign and the gap of the directional couplers is hence maintained constant. In the two coupling regions, the phase matching condition is fulfilled at the center of the two tapers. In the first coupler the width of the taper waveguide WG1 is decreased while the one of WG2 is increased, while the opposite occurs in the second coupler. With this structure, we can ensure that the phase matching condition will be respected in one point in the tapered region even with the presence of fabrication imperfection.

The fabricated device (as show Fig. 1(c)) has a SiN core with a thickness h = 400 nm, a 3-µm-thick SiO2 upper cladding and 4.5-µm-thick SiO2 buried oxide. A finite-difference eigenmode solver was used to choose the two widths w_1 and w_2 (as show Fig. 1(b)) that satisfy the phase matching condition. An eigenmode expansion solver was used to simulate the TM mode transmission to optimize the coupling length (Lc) and the width variation (Δw) (as show Fig. 1(a)). The gap (w_{gap}) between the two waveguides is fixed at w_{gap} = 0.35 µm. The phase matching condition is fulfilled for w_1 = 0.51 µm and w_2 = 1.28 µm. The maximum power conversion from TM0 to TM1 with was achieved with L_c = 111 µm and Δw = 0.03 µm. An S-bend of 100 µm radius is used to gently approach and separate WG1 from WG2 (and WG3 from WG2) to avoid back reflections that can occur by the abrupt introduction of the central waveguide WG2.

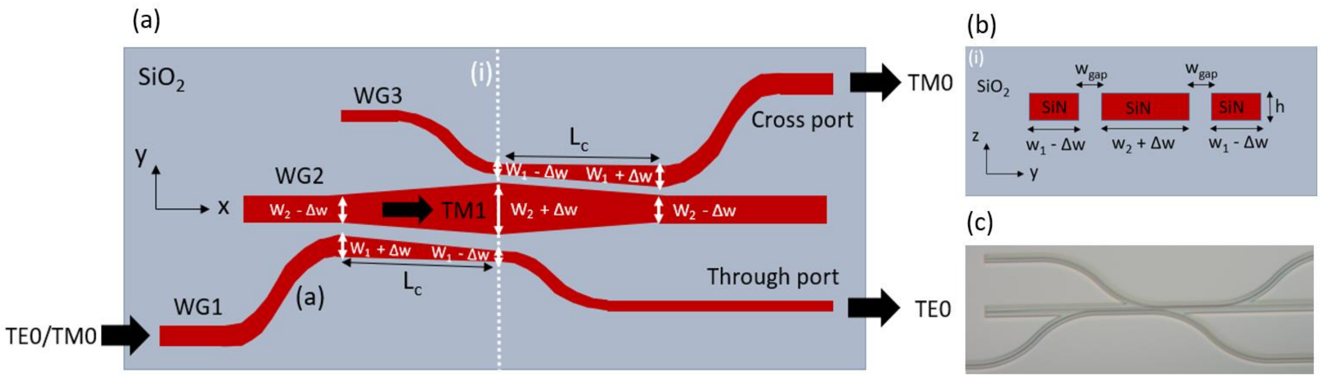

Fig. 1. (a) Schematic of the SiN polarization beam splitter. (b) Cross-sectional view of the directional coupler at the position (i) maked with the white dashed line in (a). (c) Microscopic image of the fabricated PBS.

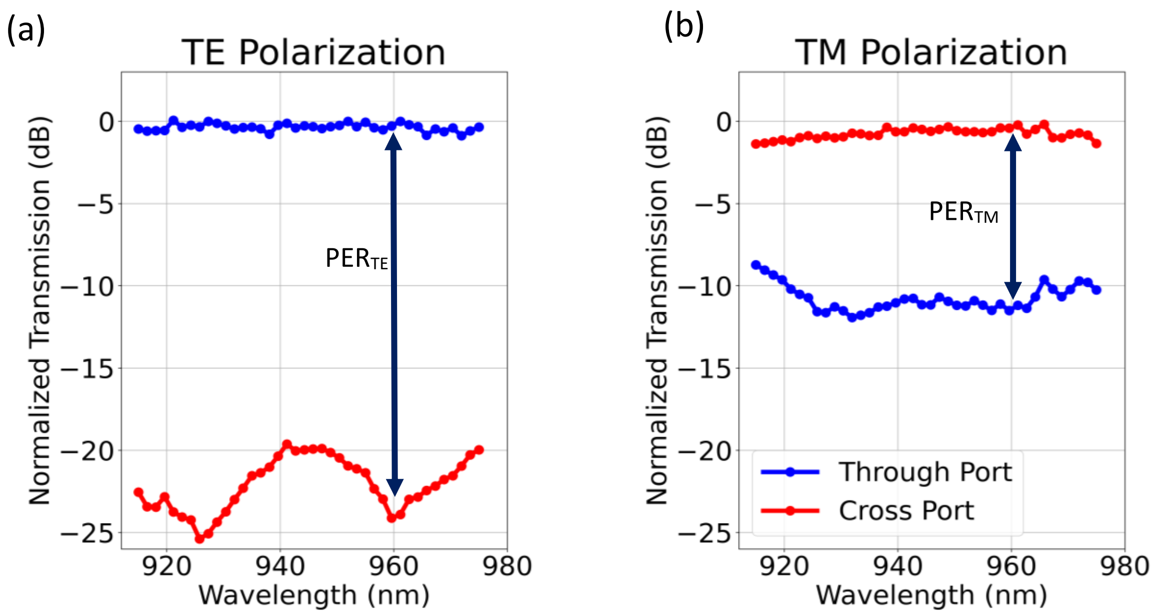

Fig. 2. Measured transmisions at the through and cross ports for (a) TE mode input and (b) TM mode input.

The PBS performance was measured by characterizing the polarization extinction ratio (PER) and insertion loss (IL), respectively defined as:

$$PER_{TE} = 10 \cdot \log_{10}\left(\frac{T_{through}}{T_{cross}}\right)$$

$$PER_{TM} = 10 \cdot \log_{10}\left(\frac{T_{cross}}{T_{through}}\right)$$

$$Il_{TE} = -10 \cdot \log_{10}(T_{through})$$

$$Il_{TM} = -10 \cdot \log_{10}(T_{crosss})$$

Here $T_{through}$ and T_{cross} are the normalized transmission from the input waveguide WG1 to the through and cross output port, respectively (see Fig. 1) The normalization is made with respect to the transmission of a reference waveguide without the PBS. The experimental transmission for the two polarizations over a wavelength range between 920 nm and 970 nm is reported in Fig. 2. When we excite the TE0 mode at the input port, negligible coupling occurs and as expected light ends up at the through port with an insertion loss IL_{TE} = 0.27 dB at λ = 950 nm. On the contrary, when the TM0 mode is excited at the input, the phase matching condition is fulfilled and the light couples efficiently in the two directional couplers and propagates to the cross port. Also in this case the PBS operates with low insertion losses of IL_{TM} = 0.53 dB at λ = 950 nm. In both cases, insertion losses remain smaller than 1 dB on the entire wavelength range between 920 nm and 970 nm. In the same range, PER_{TE} and PER_{TM} are higher than 19 dB and 10 dB, respectively. At the central wavelength λ = 950 nm, PER_{TE} = 20 dB and PER_{TM} = 11 dB.

DISCUSSION

In summary, a highly performing PBS in the silicon nitride platform was successfully demonstrated in the wavelength range around 950 nm using a cascade of two tapered asymmetrical directional couplers. The device has a compact footprint of about 222 µm with low insertion losses below than 1 dB and PER above 10 dB in the 920 nm – 970 nm band. Larger PER, especially for the TM polarizations, could be obtained either cascading multiple PBS or exploiting polarization filters.

Acknowledgements: This work has been supported by an Ideation Fund-Small Teams Initiative by the National Research Council Canada

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