High Extinction, Broadband, and Low Loss Planar Waveguide Polarizers

Jared F. Bauters, Martijn J. R. Heck, Daoxin Dai, Demis D. John, Jonathon S. Barton, Daniel J. Blumenthal, and John E. Bowers
Engineering Science Building, University of California, Santa Barbara, CA 93106, U.S.A.
jbauters@ece.ucsb.edu

Abstract: A technique for making high extinction and broadband polarizers in a low loss planar waveguide platform is presented and characterized. Extinction greater than 78 dB is obtained with low loss for the desired polarization.

OCIS codes: (130.0130) Integrated Optics; (130.5440) Polarization-selective devices; (230.7390) Waveguides, planar.

1. Introduction

Many photonic communication and sensor systems require tight control of the optical polarization [1]. A planar waveguide polarizer, therefore, is an important component for enabling the integration of such systems. In combination with quarter and half-wave phase retarders, a polarizer can also make up other important photonic system components, such as isolators and polarization rotators [2]. In this work, we demonstrate high extinction (>78 dB) and broadband (1.50-1.62 µm) polarizers fabricated with a low loss planar silica waveguide platform for photonic integration on Si substrates. Such devices enable the integration of high performance interferometric sensors, such as optical gyroscopes, on a chip.

2. Highly Birefringent Planar Waveguides

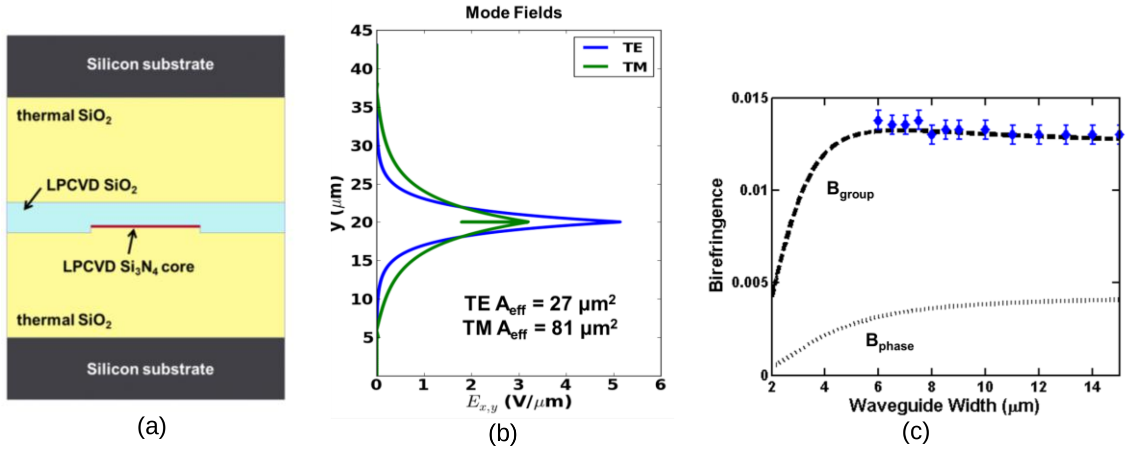


Fig. 1. a) Cross-section of waveguide structure and b) simulated fundamental TE and TM modes for a 7-µm-wide core at λ_0 = 1.55 µm. c) Calculated group and phase birefringence with measured values for various core widths.

Fig. 1a shows the dielectric layer structure used in the planar waveguide polarizers. The core layer of 40-nm-thick stoichiometric Si_3N_4 (n = 1.98) is deposited with LPCVD on a 15 µm SiO_2 (n = 1.45) lower cladding layer thermally grown on a Si substrate. The upper cladding is composed of a 3 µm LPCVD SiO_2 planarization layer and a wafer-bonded 15 µm thermal SiO_2 wafer (more fabrication details are found in [3]). The cores are etched to widths ranging from 2-15 µm. As seen in Fig. 1b, the high aspect ratio of the core yields large TE and TM mode areas. The TM mode, however, is less confined and has an effective mode area 3 times larger than that of the TE mode, resulting in a large polarization birefringence. The dashed lines in Fig. 1c give the group and phase birefringence values calculated with the FIMMWAVE mode solver for various core widths averaged over the 1.525-1.61 µm wavelength range. The markers show that the group birefringence values measured with optical frequency domain reflectometry (OFDR) agree well with the calculated values for the 6-15 µm range of core widths. The group birefringence for narrower core widths could not be obtained with OFDR due to the high loss of the TM mode.

As demonstrated by Varnham, et al. with an optical fiber coil [4], a disparity in TE and TM bend radiation losses exists in such a highly birefringent waveguide, and this property can be used along with a careful choice of waveguide bend radius to make a high extinction polarizer. This bend loss difference, discussed in [5] for 100 nm Si_3N_4 cores, is the main operating principle for the polarizers in this work. It can be seen in Fig. 1b, however, that the TM mode field has a larger amplitude than the TE mode near the upper and lower Si substrates. A resulting substrate leakage loss difference adds to the polarization extinction of the waveguide. The operating principle in this case is similar to that of the polished fiber cladding polarizer presented in [6].

3. Broadband Polarization Extinction Measurements

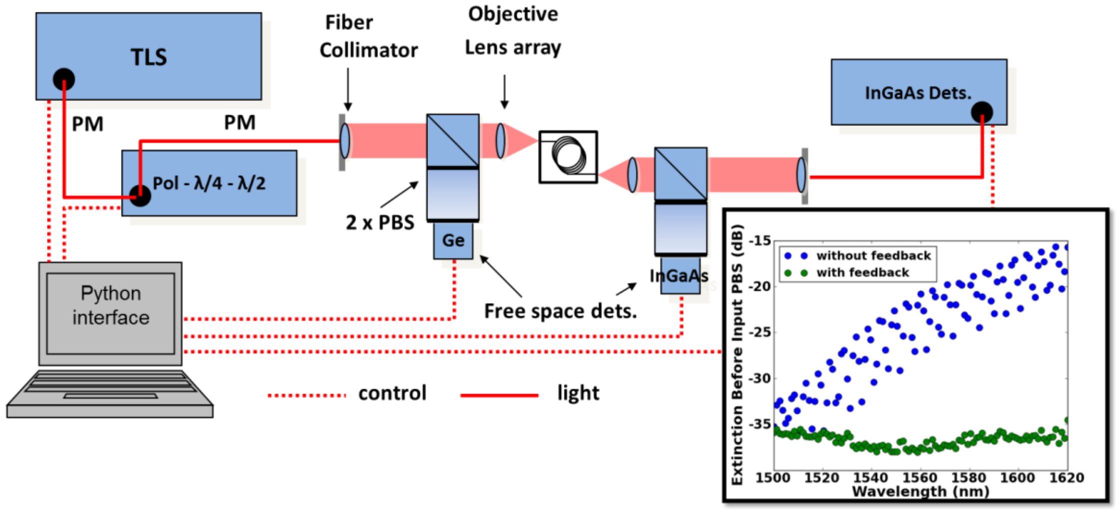


Fig. 2. A schematic of the setup used for the measurement of high polarization extinction. "PM" indicates polarization maintaining fiber. The inset shows how feedback is necessary to maintain high input polarization extinction during the wavelength sweep.

Fig. 2 shows a schematic of the setup used to measure the polarization extinction in high birefringence planar waveguide devices. Not including the device under test, three polarizers are employed in order to allow for the measurement of up to 78 dB of polarization extinction. The first polarization controller consists of a polarizer, a quarter-wave plate, and a half-wave plate in series. The angles of rotation for these free space optics are controlled with a computer. Two polarization beam splitting cubes are also placed in the light path before the input and after the output collimating lens arrays. The extinguished polarization power reflected by these cubes is monitored using two additional polarization beam splitter cubes as well as Ge and InGaAs free space detectors at the input and output. At the start of a wavelength sweep, the free space optics of the first polarizer are rotated to minimize the power incident on the input Ge detector, thereby maximizing the polarization extinction of the input light. Since the polarization state of the tunable laser source's output changes as the wavelength is swept, the power at the input Ge detector must be monitored and the positions of the free space optics must be updated in order to maintain the best polarization extinction of the input light throughout a wavelength sweep. The inset to Fig. 2 shows how the extinction degrades by about ~0.15 dB/nm during a sweep if the free space optics positions are not updated.

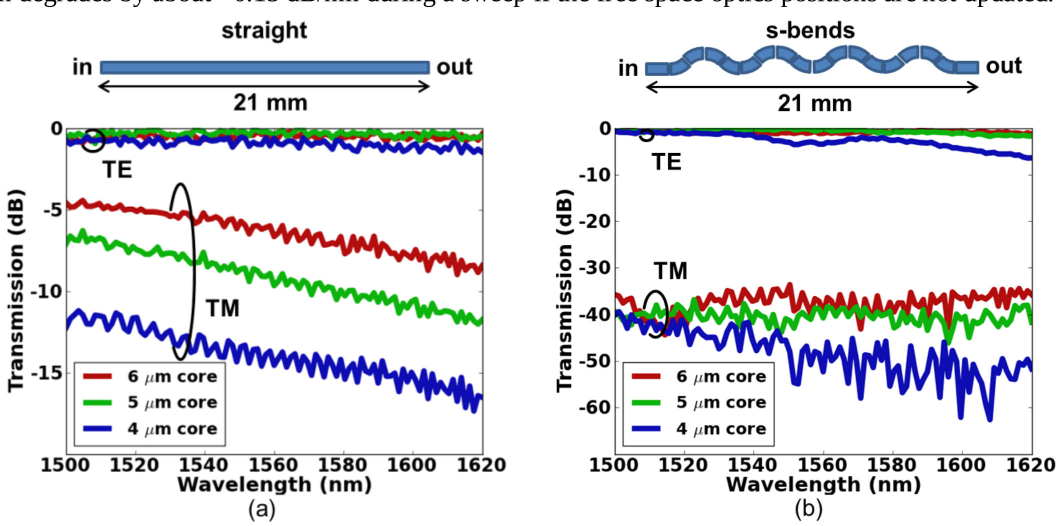
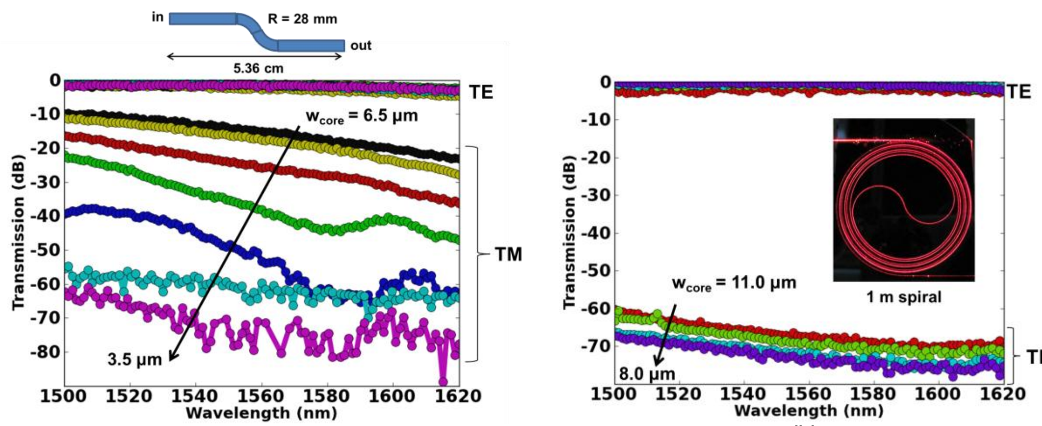


Fig. 3. a) The polarization extinction measured in straight waveguides and b) a series of R = 9.8 mm s-bends.

Fig. 3 compares the normalized transmission of the TE and TM polarized modes through (a) straight waveguides and (b) a series of s-bends. The waveguides have cores that are 40 nm thick by 4, 5, or 6 μm wide. The extinction of the TM mode after propagation through a 21 mm–long straight waveguide demonstrates the aforementioned substrate leakage loss differential. The highest extinction, seen at λ=1620 nm for the 4 μm wide core, is 15 dB. The high extinction of the TM mode after propagation through the S-bend structure seen in Fig. 3(b) is primarily due to the large bend loss difference for the TE and TM modes. The S-bends have 9.8 mm bend radii, and no offset is used for mode matching at the bend-to-bend or straight-to-bend interfaces. The 6 and 5 μm core structures are low loss for the TE mode, with the total loss dominated by the fiber-to-chip coupling losses of 1.5 and 1.4 dB per facet, and average extinctions of 36.8 and 39.8 dB are measured across the wavelength range. The 4μm-wide core has a larger average extinction of 45.6 dB, but the TE mode has greater bend loss at this core width, adding significant loss of 3 – 8 dB to the polarizer at wavelengths larger than 1530 nm.



(a) (b)

Fig. 4. a) Polarization extinction measured in a single s-bend of 28 mm bend radius for different waveguide core widths and b) polarization extinction measured in a 1 m spiral delay line for various core widths.

Fig 4 shows the polarization extinction measured from propagation through a single s-bend 28 mm bend radius. For a 7 μm core width, the polarization extinction is low around 10-15 dB. As the core width is narrowed, the leakage and radiation losses of the TM mode increase, resulting in a large and broadband polarization extinction of 61 to 78 dB from 1500 to 1620 nm for the 3.5-μm-wide core. The increased extinction compared to the S-bend structure shown in Fig. 3b is due to the increased length of bend and total propagation. The total insertion loss for the 3.5-μm-wide waveguide device of 2.6 dB is dominated by the fiber-to-chip coupling loss. It has been shown how this loss can be reduced to lower than 1 dB by tapering the waveguide core width to below 2 μm at the chip facet [3]. Fig. 6 shows the polarization extinction measured for a 1 meter spiral of waveguide with a central s-bend of 9.8 mm radius. More details for this structure, including TE propagation and coupling losses are found in [3]. For this structure, the extinction is greater than 60 dB even for the widest more highly confining waveguide cores. For cores narrower than 8 μm, the extinction is greater than the 78 dB measurable with our setup. The extinction is high across the entire 1500 to 1620 nm sweep range, making the waveguide a good candidate for applications requiring a single polarization channel.

4. Acknowledgements

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