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Design of Integrated Visible-Light Polarization Rotators and Splitters

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Abstract: Integrated polarization rotators and splitters are designed for the first time at visible wavelengths. Specifically, an adiabatic polarization rotator, an off-axis polarization rotator, and a mode-coupling polarization splitter are designed in a silicon-nitride platform.

1. Introduction and Motivation for Integrated Polarization Control at Visible Wavelengths

Polarization control plays an important role in photonic integrated circuits (PICs), where it can enhance polarization-sensitive device performance as well as enable systems that can benefit from orthogonal modes, such as increased channel density for communications [1,2]. As such, there has been extensive research into integrated polarization rotators and splitters [2-6]; so far, however, they have only been shown at infrared (IR) wavelengths.

Recently, there has been a significant drive to develop PICs at visible wavelengths that require polarization manipulation, in particular for chip-scale atomic systems and qubit state preparation [6,7]. However, integrated polarization-control devices for these systems have yet to be developed, a particular challenge given the scaling of device dimensions with wavelength.

In this work, we demonstrate the design of the first integrated polarization rotators and splitters operating at visible wavelengths. Specifically, using combinations of single and dual silicon-nitride (SiN) waveguide sections, we show an adiabatic polarization rotator, a compact off-axis polarization rotator, and a mode-coupling polarization splitter all operating at a wavelength of 422nm.

2. Fabrication Process

The devices in this work were designed for fabrication compatibility with the MIT Lincoln Laboratory 200-mm wafer fabrication platform for ultraviolet to near-IR wavelengths [8], which consists of a 100-nm-thick alumina (Al_2O_3) layer and two 100-nm-thick silicon-nitride (Si_3N_4) layers separated by 90nm of silicon dioxide (SiO_2).

3. Adiabatic Polarization Rotator Design

First, we design an adiabatic polarization rotator which converts between the fundamental TE and TM modes on chip (Fig. 1a). This device begins with an asymmetric coupler that converts the input fundamental TE mode to the next higher order TE mode. The mode then enters an adiabatic taper, which passes through an anti-crossing between the higher order TE and fundamental TM modes, transferring power from one mode to the other. This anti-crossing is enabled by breaking the vertical symmetry via the dual SiN layer (Fig. 1a) [3]. By utilizing a three-stage taper that varies more rapidly on either side of the anti-crossing, the total device length is reduced without a significant sacrifice in performance. The total device length is 550μm, giving a simulated device efficiency of 93.78%, corresponding to an extinction ratio of 11.78 dB (Fig 1b).

4. Off-Axis Polarization Rotator Design

As a complement to the above device, it is useful to have a more compact polarization rotator that can be used in more densely integrated systems. To this end, we also design an off-axis rotator that works on the principle of mode coupling between the two lowest-order modes (Fig. 1c), which have a high coupling coefficient [4]. By horizontally offsetting two stacked waveguides appropriately in the coupling region, both the fundamental modes become quasi-TE and TM, corresponding to an effective optical axis oriented at 45°. As a result, the fundamental modes exhibit beating and, by appropriate choice of length, the input TE mode can be efficiently converted to TM [4]. Gradual tapers into and out of the coupling region minimize radiative losses due to mode mismatch. The total device length is only 111μm, achieving a simulated efficiency of 99.15%, corresponding to an extinction ratio of 20.7 dB (Fig. 1d).

5. Polarization Splitter Design

Third, we design an integrated asymmetric directional-coupler-based polarization splitter, using the dual SiN layers to maximize TM coupling into the tap port, while minimizing coupling of the TE mode (Fig. 1e). The device consists

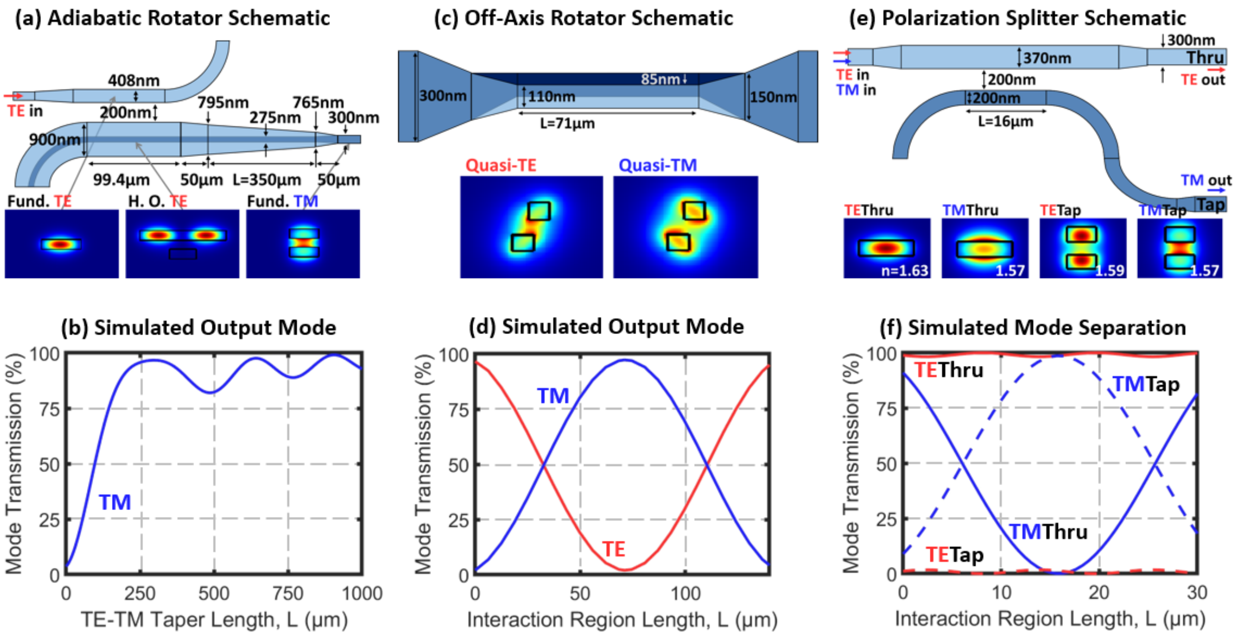

Fig. 1. (a) Schematic (not to scale) of the adiabatic rotator, with relevant mode profiles shown. (b) Mode conversion efficiency of the adiabatic rotator as a function of TE-TM taper length. (c) Schematic of the off-axis rotator, with mode profiles that demonstrate the 45° optical axis rotation of the fundamental modes in the interaction region. (d) Mode conversion efficiency of the off-axis rotator as a function of interaction length. (e) Schematic of the polarization splitter, with mode profiles demonstrating the effective index match and contrast between the fundamental TM and TE modes, respectively. (f) Mode splitting efficiencies for the thru and tap ports for the polarization splitter as a function of interaction length.

of a single-layer thru port and a dual-layer tap port, where the effective indices of the TM modes are matched between the two arms of the coupler. Due to their asymmetry, the two arms exhibit very different effective indices for TE [5] (Fig. 1e). As a result, the fundamental TM mode periodically strongly couples between the arms of the device along the length of the coupling region, while the TE mode exhibits only low-amplitude oscillations (Fig. 1f). The length of the coupling region of this device is only 16μm, providing a compact device that allows for extinction ratios of 46.3 dB for TM input and 18.7 dB for TE input for their respective ports.

6. Conclusions, Future Outlook, and Acknowledgements

In this work, we design the first integrated polarization rotators and splitter operating at visible wavelengths, enabling integrated polarization-diversity schemes, increased datacom channel density, and advanced chip-scale atomic systems. These designs are currently being fabricated at the MIT Lincoln Laboratory. Future work will include experimental demonstration of these devices and their implementation in application-specific systems for advanced integrated-photonics-based trapped-ion cooling [9].

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7. References

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