Ultra-compact Broadband TE-pass Polarizer Based on Vanadate-nanowire-integrated SOI Waveguides

Yusheng Bian, Lei Kang, Qiang Ren, Ping Werner and Douglas H. Werner*
Computational Electromagnetics and Antennas Research Lab (CEARL)
Department of Electrical Engineering, The Pennsylvania State University
University Park, PA, 16802, USA
*dhw@psu.edu

***Abstract*—An ultra-compact TE-pass polarizer is numerically demonstrated at telecommunication wavelengths by integrating a vanadate nanowire with a SOI platform. Results show that a device of 15 µm in length is capable of achieving a high extinction ratio of 22 ~ 34 dB, in conjunction with a low insertion loss of 0.18 ~ 0.23 dB in a wavelength range of 1.52 ~ 1.62 µm.**

Keywords—Polarizer; vanadate; transparent conducting material; silicon-on-insulator; polarization dependent loss

I. Introduction

The ability to precisely manage the polarization state of light is vital to maintaining the high performance of advanced optical systems, especially for those involving high-index-contrast silicon photonic components that are extremely polarization dependent [1]. Introducing a polarization diversity scheme into the system, for example, represents a feasible route toward polarization-transparent circuits, yet such a strategy inevitably adds significant complexities to the system, and meanwhile results in a considerably increased device footprint. Another commonly adopted, simpler and cost-effective approach is to utilize an optical polarizer to extinguish the unwanted polarization state. Recently, a significant amount of attention has been devoted to this field, leading to a wide variety of compact, silicon-on-insulator (SOI)-compatible integrated polarizers. For instance, a 1 mm-long TE-pass polarizer based on shallowly etched SOI waveguides was shown to enable an extinction ratio of 25 dB over a 100 nm wavelength range [2]. By exploiting a hybrid configuration with lossy metal involved, the length of the polarizer can be reduced down to 30 µm, while maintaining a high extinction ratio (22 ~ 28 dB) and a moderate insertion loss (2 ~ 3 dB) [3]. Further reduction of the device footprint can be enabled through leveraging the mode cutoff in a Si-based hybrid nanoplasmonic slot waveguide, which, however, comes at a price of degraded performance with a limited extinction ratio around 16 dB [4]. A high-performance polarizer capable of striking a good balance between device footprint and optical performance has yet to be demonstrated. Here, by integrating a vanadate nanostructure with a SOI platform, an ultra-compact and highly-efficient TE-pass polarizer is developed at telecom wavelengths. Featuring only 15 µm in length, the device achieves both high extinction ratio and low-insertion loss over a broadband wavelength range.

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II. Optical performance of the TE-pass polarizer

Vanadates ($CaVO_3$, $SrVO_3$, etc.), which are capable of satisfying the competing demands of high optical transparency and high electrical conductivity in the visible spectrum, have been identified quite recently as promising alternatives to their traditional transparent conducting oxide counterparts such as ITO [5]. In addition to their remarkable opto-electronic properties, the involvement of vanadate nanostructures in planar photonic waveguides can also lead to interesting guiding properties according to our studies. In sharp contrast to the waveguides involving noble metals like Ag, guided modes in hybrid composites incorporating $CaVO_3$ feature unique dispersion relationships at optical and near-infrared frequencies. For the fundamental modes at $CaVO_3$/dielectric interfaces, the significant dispersion red-shift, the dramatically increased attenuation, as well as the enhanced field localization are observable as compared to the modes in Ag/dielectric structures. Leveraging these unique properties may allow us to further control the optical performance of hybrid waveguides and related devices.

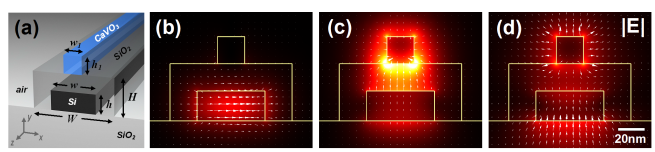

Fig. 1. (a) Sketch of the hybrid $CaVO_3$ waveguide. (b)-(d) Electric field distributions of the quasi-TE, fundamental and higher-order quasi-TM modes in a typical configuration at a 1.55 µm. Waveguide dimensions are chosen as w = 500 nm, h = 220 nm, w_l = h_l = 200 nm, W = 900 nm and H = 420 nm to ensure low insertion loss, high extinction ratio and high efficiency excitation of the guided modes. The complex refractive indices of the three modes are 2.44+0.0003i, 2.04+0.15i and 1.59+0.056i, respectively.

Here we look into the properties of the guided modes in a hybrid configuration consisting of a $CaVO_3$ nanowire located above a SiO_2-coated Si ridge waveguide (Fig. 1(a)). To accurately analyze the modal characteristics and find optimal waveguide configurations, a full-vectorial eigenmode solver based on COMSOL^{TM} is utilized. Results indicate that the modal losses are highly polarization dependent: the quasi-TE mode features an ultra-low-loss and a high n_{eff}, whereas both the fundamental and higher-order quasi-TM modes are extremely lossy. The fundamental TM mode has a high n_{eff}, and its modal field has little overlap with that of the Si waveguide (Fig. 1(c)), making it difficult to be directly excited using the photonic mode. In contrast, the higher order quasi-TM mode has a much smaller n_{eff}, close to that of the TM Si mode, and offers sufficient modal overlap with the Si region (Fig. 1(d)), which greatly facilitates its excitation. By leveraging the loss contrast between the TE and higher-order TM modes, we are able to build an efficient TE-pass polarizer with both low insertion loss and high extinction ratio.

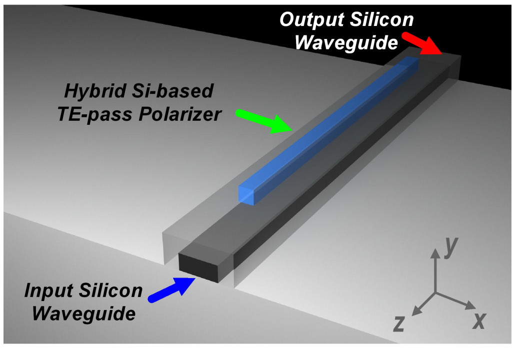

Fig. 2. Schematic of the proposed TE-pass polarizer integrated with Si waveguides. The lengths of both the input and output Si waveguides are 1 μm, whereas the hybrid polarizer is 15 μm long. The dimensions of the polarizer are exactly the same as the input and output waveguides except the $CaVO_3$ nanowire. Other geometric parameters are the same as those in Fig. 1.

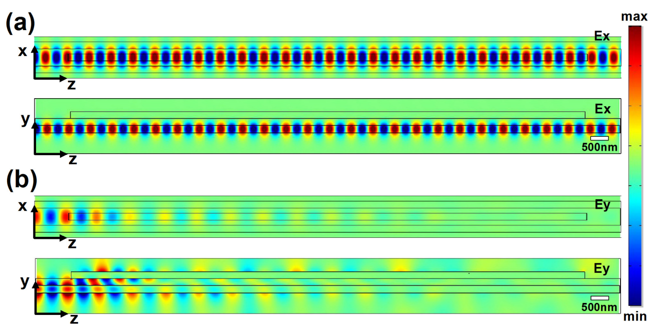

Fig. 3. Evolution of the electric fields for the (a) TE and (b) TM modes along the propagation direction through the polarizer at 1.55μm. The planes are cut along the centerlines of the Si waveguide.

3D full-wave FEM simulations are performed to reveal the optical performance of the polarizer shown in Fig. 2. Field evolution through the polarizer (see Fig. 3) reveals the significantly different behavior of the TE- and TM-polarized modes. For the TE polarization, the input Si photonic mode remains almost unaffected by the $CaVO_3$ nanowire and experiences negligible attenuation through the device. In contrast, the input TM Si photonic mode converts into a hybridized mode with a large attenuation, which decays dramatically along the propagation direction. The remarkable difference between the TE and TM insertion losses leads to an ultra-high extinction ratio of 30 dB at 1.55 μm. Performance comparisons shown in Table I indicate that our device features simultaneously smaller footprint, higher extinction ratio and lower insertion loss, relative to the previously reported state-of-the-art hybrid TE-pass polarizer.

TABLE I

Performance comparisons between the proposed device and the hybrid TE-pass polarizer reported in [3] at 1.55 μm

	Proposed Device	**Ref. [3]**
Device Length (μm)	15	30
Extinction Ratio (dB)	30	24
TE Insertion Loss (dB)	0.19	2

The proposed TE-pass polarizer also performs well over a broad wavelength range. As shown in Fig. 4, low insertion losses (0.18 ~ 0.23 dB), together with high extinction ratios (22 ~ 34 dB), are achievable within the wavelength range of 1.52 ~ 1.62 μm. In addition, our studies indicate that the device performance exhibits good tolerances to the possible fabrication imperfections as well, such as the deviation of the $CaVO_3$ nanowire along the horizontal direction, and slight variations in the dimensions of the Si and $CaVO_3$ nanostructures.

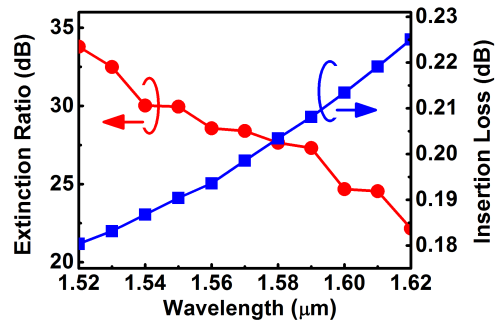

Fig. 4. Insertion loss and extinction ratio of the polarizer in the wavelength range of 1.52 ~ 1.62 μm.

III. Conclusion

In conclusion, an ultra-compact TE-pass polarizer based on a $CaVO_3$-integrated SOI platform is proposed and numerically investigated. Results show that an extinction ratio of 22 ~ 34 dB, together with a low insertion loss of < 0.23 dB is achieved by a 15 μm-long device over a bandwidth of 100 nm.

References

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