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Inverse Design of a SOI T-junction Polarization Beamsplitter

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Abstract. A SOI T-junction polarization beamsplitter with an ultra-compact footprint of $2.8\times2.8\mu m^2$ is designed based on the method of inverse design. Simulated results show that the conversion efficiencies for TE and TM lights are 73.34% (simulated insertion loss of 2dB) and 80.4% (simulated insertion loss of 1.7dB) at 1550nm, respectively; the simulated extinction ratios for TE and TM lights are 19.3dB and 13.99dB at 1558nm, respectively.

1. Introduction

Recent development in optimization algorithm and computing power provides a broader way to improve the performance of on-chip integrated devices. Unfortunately, most optical devices are still designed by hand now. There is a creative device design method called inverse design [1], which can take advantage of the enormous available design space to design arbitrary high performances linear optical devices with ultra-compact footprints.

The polarization beamsplitter is an essential component in integrated on-chip photonics systems. It is widely used to separate different polarization states. However, most traditional PBS devices are fairly large [2], and there are strict requirements for wavelength sensitive due to the underlying phase-matching principle [3-4]. In contrast, inverse design method can design free-form PBS device with small footprints and wavelength insensitive performance. T-junction waveguide has been used to get ultra-compact footprints and high integration of on-chip silicon photonic devices. The original T-junction waveguide can be freely optimized enables ultimate devices that can be highly functional.

In this paper, we designed a compact T-junction PBS on a silicon-on-insulator (SOI) platform, with a compact footprint of $2.8\times2.8\mu m^2$, by using inverse-design method. The program exhibits TE and TM conversion efficiencies of 73.34% and 80.4% at 1550nm, and the FDTD solver shows low insertion losses (about 2dB for TE and 1.7dB for TM) and high extinction ratios, which is over 12dB in a wavelength range from 1545nm to 1567nm for TM and over 17dB for TE in entire C-band.

2. Device design

Fig.1 shows the initial scheme of the T-junction polarization beamsplitter, which consists of one input waveguide, two output waveguides and a square design region. The size of the design region is $2.8\times2.8\mu m^2$ with 70×70 pixels, the shape of each pixel is square with a size of $40\times40nm^2$. The input and output waveguides, with width of 500nm, are located at the center of their respective edge of the design region. The thickness of Si layer of the SOI wafer is 220nm. Refractive indices of $n_{Si} = 3.5$, $n_{SiO_2} = 1.5$ are used. The fundamental TE-polarized light and the fundamental TM-polarized light output through the bottom and top output waveguides.

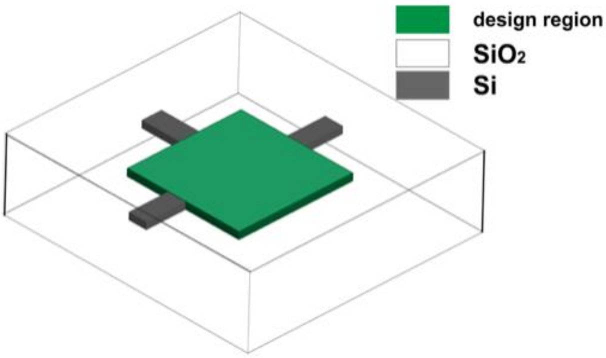

Figure 1. Initial scheme of the T-junction PBS.

Initially, we defined the waveguide mode and the mode conversion efficiency between input and output mode at a certain wavelength in order to specify the desired performance of our device. Next, inverse design optimization process was used to decide the permittivity distribution of design area [5-6]. The optimization process contains two stages, including: 1) an initial distribution of the permittivity in the design region is obtained by using alternating direction method of multipliers (ADMM) algorithm, which however is continuously distributed, impossible for fabrication; 2) the continuous permittivity is transformed to binary index by level-set method to ensure that device can be fabricated. With the help of GPU-based high performance computing, the T-junction PBS was designed in nearly 20h.

3. Results

The ultimate designed T-junction PBS structure is shown in Figure 2(a). The input waveguide named port1 is either fundamental TE or TM polarized light. Then the TE and TM polarized lights couple into the bottom (named port2) and top (named port3) output waveguides, respectively. Figure 2(b)(c) illustrate the electric field intensity distributions for TE (b) and TM (c) polarized light at the design wavelength of 1550 nm. The inverse design programming figures out the conversion efficiencies into the port2 and port3 are 73.34% and 80.4% at 1550nm respectively.

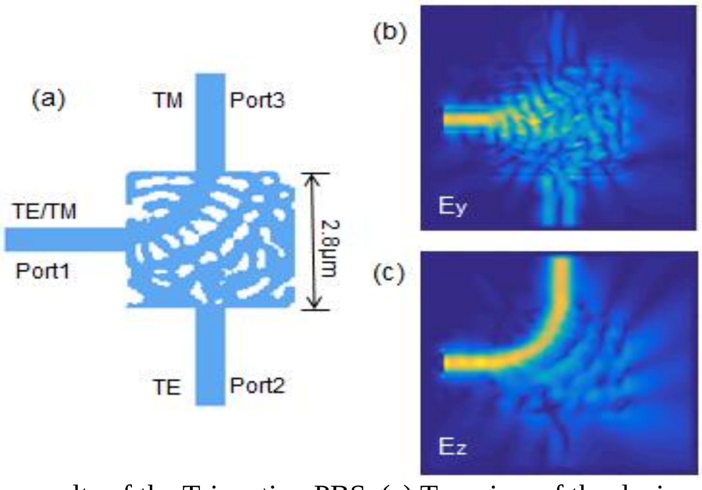

Figure 2. Simulation results of the T-junction PBS. (a) Top view of the device. (b) (c) Electric field intensity distributions for TE (E_y-dominant) and TM(E_z-dominant) inside the device.

To further verify this inverse-designed PBS, we used Lumerical Solutions Software to analyze the performance of the PBS by importing ultimate designed structure into the FDTD solver in Lumerical. The wavelengths of input lights with TE/TM-polarized varied from 1520nm to 1580nm. Figure 3 shows the broadband fluctuation of insertion losses and extinction ratio over 60nm. Simulation results show that the insertion losses of TE and TM lights are 1.93dB and 1.84dB and the extinction ratios are 19.3dB and 13.99dB at 1558nm. Figure 3(b) exhibits extinction ratios are higher than 12dB in a wavelength range of 22nm for TM, and higher than 17dB in total C-band for TE. The T-junction PBS verifies that inverse design can generate new generation of ultra-compact optical devices with novel functionality.

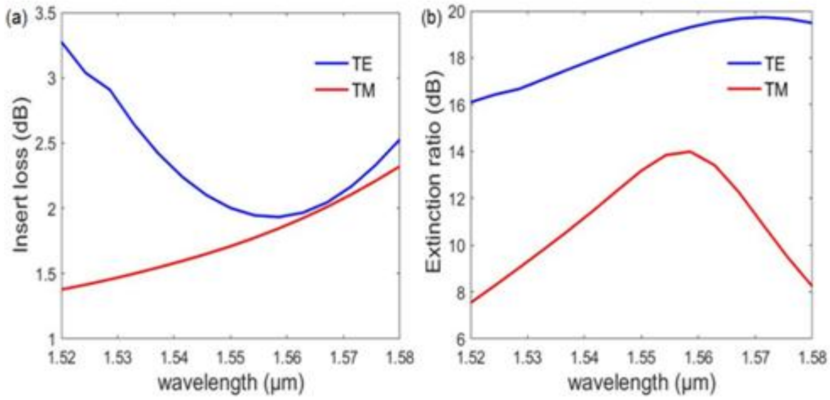

Figure 3 T-junction PBS insertion losses (a) and extinction ratios (b) as a function of wavelength.

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