# Polarization Independent Adiabatic 3-dB Coupler for Silicon-on-Insulator

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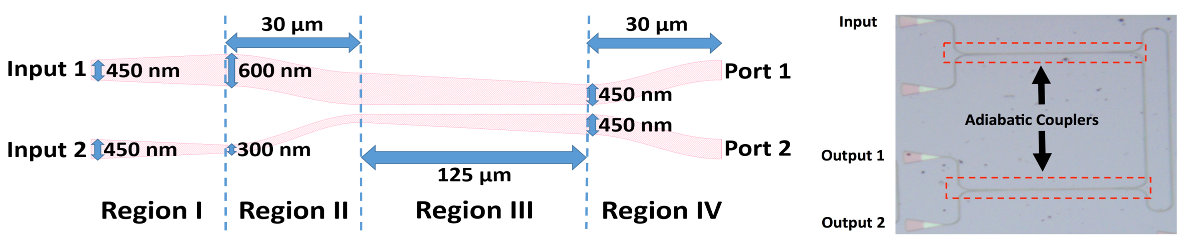
**Abstract:** We demonstrate a polarization independent adiabatic 3-dB coupler for the silicon-on-insulator platform, with a measured bandwidth of 100 nm and power splitting ratios of $3 \pm 0.7$dB for both the transverse electric and transverse magnetic modes.


**OCIS codes:** (130.3120) Integrated optics devices; (230.7370) Waveguides.

## 1. Introduction

Adiabatic couplers have been widely used in photonic integrated circuits (PICs) as optical power splitters and combiners [1, 2]. As compared to directional couplers and multimode interference couplers, adiabatic couplers are less wavelength dependent and more tolerant to fabrication imperfections [3]. In principle, adiabatic couplers can be both wavelength and polarization independent [4]. So far, wavelength independent adiabatic 3-dB couplers have been demonstrated for the transverse electric (TE) mode and the transverse magnetic (TM) mode separately for the silicon-on-insulator (SOI) platform [5]. In this work, we demonstrate an adiabatic 3-dB coupler that is both wavelength and polarization independent operating over 100 nm, including the entire C-band. Our adiabatic 3-dB coupler is designed for SOI wafers with 220 nm silicon layer and 3 µm buried oxide. A schematic of our adiabatic 3-dB coupler is shown in Fig. 1(a).

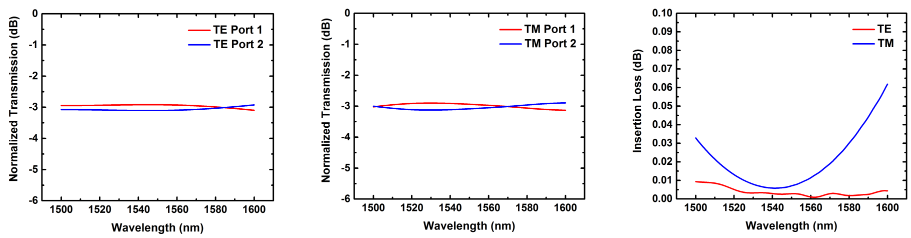



(a) (b)

Fig. 1. (a) Schematic of the adiabatic 3-dB coupler; (b) microimages of an unbalanced MZI test structure with two adiabatic 3-dB couplers.

## 2. Design and Simulation

Our adiabatic coupler consists of four regions, as shown in Fig. 1(a). In Region I, two parallel waveguides, with waveguide widths of 450 nm and a spacing of 2.5 µm, are linearly tapered to 600 nm and 300 nm, respectively. The asymmetry of the two waveguides is introduced to avoid the excitation of higher order modes. In Region II, the two waveguides are brought together with a gap of 100 nm using two S-bend waveguides. The bend radii of the two S-bend waveguides were chosen to be large enough to minimize the bending loss. Region III is the coupling region, where the two waveguides are linearly tapered from 600 nm and 300 nm to 450 nm, while maintaining a constant gap of 100 nm. The coupling length of 125 µm was chosen to ensure the mode change adiabatically. In Region IV, two S-bend waveguides are used to decouple the two parallel waveguides. As a result of the parameters chosen above, when light is injected from Input 1, only the fundamental mode of the two waveguides system is excited. The fundamental mode is preserved and no higher order modes are excited throughout Region III due to the slow transition of the waveguide geometry. At the end of Region III, the optical power distributes equally in the two waveguides due to the fact that the two waveguides are identical, which leads to a 3-dB power splitting ratio at the two output ports. Similarly, when light is injected from Input 2, only the first order mode of the two waveguides system is excited. The first order mode is preserved throughout the coupling region and at the end of Region III, the optical power distributes equally in the two waveguides, which again leads to a 3-dB power splitting ratio at the two output ports. It should be noted that when the light is injected from Input1, there is no phase difference between the two optical modes from the two output ports, while there is a $\pi$ phase difference between them when the light is injected from Input 2. Three-dimensional finite-difference time-domain (3D FDTD) simulations were used to design and optimize the adiabatic couplers. The simulated transmission spectra of our adiabatic 3-dB coupler with the TE and the TM modes as inputs are shown in Fig. 2(a) and (b), respectively. Within a bandwidth of 100 nm, from 1500 nm to 1600 nm, the designed adiabatic 3-dB couplers have simulated power splitting ratios of $3 \pm 0.11$ dB for the TE mode and $3 \pm 0.13$ dB for the TM mode. The simulated insertion losses (IL) for the TE and the TM modes are shown in Fig. 2(c), which are below 0.1 dB for both the TE and the TM modes.

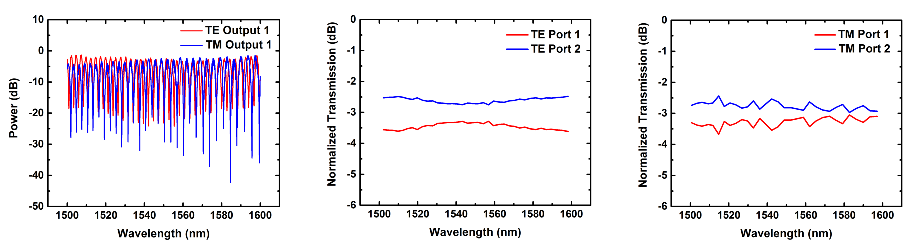



(a) (b) (c)

Fig. 2. Simulated transmission spectra of the adiabatic 3-dB coupler with (a) the TE mode, and (b) the TM mode as input; (c) simulated ILs for the TE and the TM modes.

## 3. Fabrication and Experimental Results

A waveguide-based Mach-Zehnder interferometer (MZI) was used to characterize the actual power splitting ratios of the fabricated adiabatic 3-dB couplers, as shown in Fig. 1(b). Broadband sub-wavelength grating couplers were used to couple light into and out of the test structures [6]. The test structures of our adiabatic 3-dB couplers were fabricated using electron beam lithography at Applied Nanotools Inc. Figure 3(a) shows the measured spectra from the Output 1, shown in Fig. 1(b), for test structures with the TE and the TM modes as inputs, respectively, where the ILs from the grating couplers have been calibrated out. Figures 3(b) and (c) show the calculated power splitting ratios of the measured adiabatic 3-dB couplers based on the wavelength dependent extinction ratios of the spectra shown in Fig. 3(a). The measured adiabatic 3-dB couplers cover a bandwidth of 100 nm with power splitting ratios of $3 \pm 0.7$ dB for both the TE and the TM modes.




(a) (b) (c)

Fig. 3. (a) Measured spectra for test structures of adiabatic 3-dB couplers with TE and TM input; calculated power splitting ratios with (b) TE input, and (c) TM input.

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