# A Broadband Optical Switch Based on Adiabatic Couplers

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***Abstract***
**We designed and fabricated a broadband thermo-optic Mach-Zehnder Interferometer switch using two 3-dB adiabatic couplers on the 500 nm Silicon-On-Insulator platform. The fabricated switch has shown 120 nm optical bandwidth with more than 15 dB extinction ratios.**

***Keywords — broadband; coupler; optical switch; silicon photonics***

## I. MOTIVATION

A broadband optical switch is of great interest in alignment-free optical networks with large optical bandwidth or a wavelength division multiplexing system [1]. Mach-Zehnder Interferometer (MZI) switch is widely used in an integrated photonic system because of its simplicity and compactness in design and fabrication. However, the optical power couplers in the MZI switch are required to maintain a 50% splitting ratio over a broad wavelength range in order to reach a broadband operation of the switch. Multimode interferometer (MMI) or directional coupler (DC) are commonly used as a 3-dB coupler in a MZI. However, MMIs may cause undesired reflection back to light source [2] while DCs have a relatively strong wavelength dependence due to the optical dispersion of the waveguides [3]. A number of designs have been proposed and demonstrated to achieve broadband switch, with an MZI-based power splitter [3] or a bent directional coupler [4]. However, those designs are sensitive to fabrication imperfections and require a high accuracy in the design and processing.

In this work, we demonstrate a robust MZI switch design with 3-dB adiabatic couplers. A 3-dB adiabatic coupler has been shown to be inherently 50% power splitting and highly insensitive to wavelengths [5-7]; therefore, they have great fabrication tolerance and reproducibility. The MZI switch with adiabatic couplers in this report showed a high extinction ratios over 120 nm wavelength range over the C-band.

## II. DESIGN AND FABRICATION OF THE BROADBAND MZI OPTICAL SWITCH

### *A. Adiabatic 3-dB coupler on 500 nm SOI platform*

The basic working principle of a 3-dB adiabatic coupler can be found elsewhere [5-7]. In this work, our adiabatic 3-dB coupler is designed on a silicon on insulator (SOI) substrate with 500 nm device layer and 1 μm buried oxide. The coupler comprises three following sections: the first section (300 μm long) where the two waveguides (500 nm and 700 nm wide) slowly come close to each other through S-bends, the coupling section (500 μm) where the two asymmetric waveguides are linearly tapered to 600 nm wide waveguides at the end, and the third section (300 μm) where each 600 nm wide waveguide is guided to one of the output waveguides by two other S-bends (Fig. 1). A commercial software (FIMMPROP, Photon Design, UK) employing a Finite Difference Method [8] was used to simulate the propagation of the modes through the adiabatic coupler. Figure 2 shows, as an example, the process in which the mode propagating and splitting through the coupler when light is input to the 700 nm wide waveguide. The input mode first excites the fundamental (even) mode of the coupler modes, then this even mode transmits adiabatically to the even mode of the symmetric 600 nm wide waveguides at the end of the coupling section, and in the end, the power then splits equally to the two output waveguides. The experimental data shown in Fig. 3 shows the inherently 50:50 splitting ratio of the

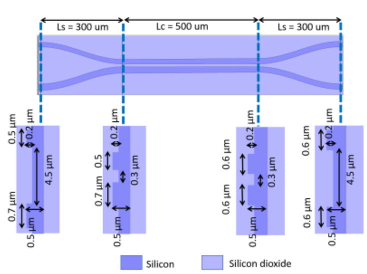


**Fig. 1. Schematic of the adiabatic 3-dB coupler and waveguide structures.**

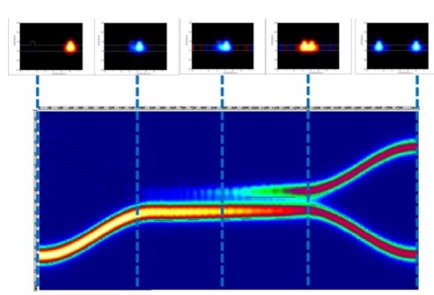

**Fig. 2. Simulation of the power transverse in the adiabatic 3-dB coupler. The optical modes along the coupler are shown on the**

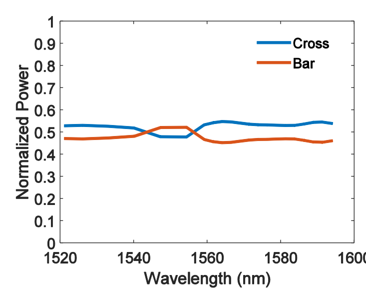


**Fig. 3. Experimental measurement of the transmission spectra of the fabricated 3-dB adiabatic coupler.**

adiabatic coupler over a broad wavelength range.

*B. Mach-Zehnder optical switch based on adiabatic 3-dB couplers*

The 2×2 MZI switch is formed by cascading two adiabatic 3-dB couplers back to back with a phase tuner on one of the arm. It is worth to note that the two adiabatic couplers are arranged in such a way that both input and output sides are asymmetric (waveguides are 700 nm and 500 nm wide) while the two waveguide arms connecting the two couplers are both 600 nm wide as shown in Fig. 4. Theoretically, such configuration results in the switch being "normally off", *i.e.* no light goes through the cross-port when no extra phase difference is introduced to the MZI arms (see the simulation result at the Fig. 4 bottom). In this work, the phase is thermo-optically tuned with a heater on the top of one MZI arm.

The MZI switches were fabricated on 500 nm SOI with 1 μm buried oxide layer. The waveguides were patterned using 248 nm DUV lithography. The etch depth of silicon rib waveguide was 200 nm. A $SiO_2$ layer of 1 μm thickness was deposited on top of the waveguide to isolate the optical mode from the metal heater. The fabrication was completed with the last step of Ti/Pd deposition onto the top $SiO_2$ layer to make the heaters and probe pads.

## III. DEVICE CHARACTERIZATION

The input/output ports of the switch were coupled to the optical fibers by edged inverted tapers to allow the transmission measurement. Fig. 5 shows the transmission through the switch at "off" and "on" states. It clearly shows that the fabricated switch achieves > 15 dB extinction ratios between on and off states over 120 nm wavelength range (1460 -1580 nm) in both output ports.

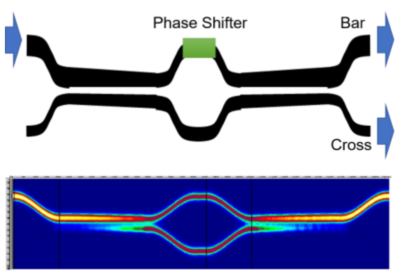


**Fig. 4. Schematic of the MZI switch based on adiabatic 3-dB couplers.**

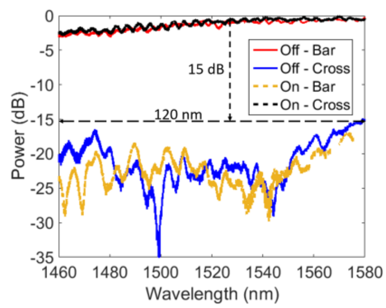


**Fig. 5. Normalized transmission spectra to the cross and bar ports at on and off**

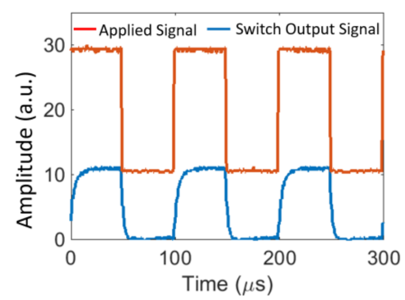


**Fig. 6. Optical switching response (to the bar port) to a 10 kHz square-wave signal.**

The dynamic switching operation of the device was also demonstrated with a 10 kHz square-wave voltage signal (as shown in Fig. 6). The response time is about 10 μs, which is typical for thermal switching in silicon [9]. The speed can be improved by using other phase-shifting mechanisms, such as carrier depletion.

## IV. CONCLUSION

We successfully demonstrated a thermo-optic MZI switch using 3-dB adiabatic couplers. The inherent 50% power splitting and wavelength insensitive properties of the adiabatic couplers results in a high extinction ratio over a broad bandwidth. This approach does lend itself to integration with sources and detectors, and we have integrated 15 such switches in a ring network on chip with WDM arrays of sources and detectors.

## ACKNOWLEDGEMENT

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