# High efficiency thermal optical switch based on suspended polymer waveguide

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***Abstract*—We propose and demonstrate a 2×2 Mach Zehnder Interferometer (MZI) thermo-optic switch based on suspended polymer waveguide with low power consumption of 1.8 mW and high extinction ratio of 34.2 dB.**

***Keywords—Polymer; Thermo optical switch; suspended waveguide;***

## I. Introduction

The 2×2 optical switch plays an important role in integrated optics. Polymer materials have the advantages of high thermo-optic (TO) coefficient, low cost, and the fabrication can be easily achieved by spin-coating and UV lithography without etching. Thus, polymer TO switch is widely used [1,2]. Polymer TO switches typically use polymer material as the waveguide core and $SiO_2$ material as the cladding. With regard to the commonly used structure of the switch, since the thermal conductivity of the air (0.026 W/mK) is much lower than that of the polymer (0.2 W/mK) and the $SiO_2$ (1.38 W/mK), etching air trenches around the waveguide is commonly used to limit the heat dissipation [1, 2], thus reducing the power consumption. In addition, by removing the bottom silicon part of the waveguide [3], heat dissipation will also be greatly inhibited. Mach-Zehnder interferometer (MZI) structure is widely used in TO switch [1,2], which mainly consists of two 3 dB couplers and two MZI arms. The 3 dB multimode interference (MMI) coupler, with the characteristics of large fabrication tolerance and compact structure [4], is suitable for application in optical switch. Hence, MMI-MZI structure is adopted in our design.

In this work, we propose and experimentally demonstrate a high efficiency optical switch based on suspended polymer MZI structure. Part of the $SiO_2$ on both sides of the waveguide together with the silicon below are etched to limit the transmission of heat and achieve low power consumption. Lateral heaters are introduced for the polymer waveguide with air upper cladding to reduce heating power and also accelerate the response speed.

## II. Design and analysis

Fig. 1 (a) shows the schematic structure of the TO switch. The switch is composed of MMI-MZI structure with suspended SU-8 core waveguide and lateral heaters. $SiO_2$ on silicon platform with coated SU-8 layer is utilized. The large refractive index difference between SU-8 and air is conducive to confine the optical mode field to reduce the size of the device. The buffered $SiO_2$ layer is chosen to be 2.8 µm, which is large enough to prevent the optical field leaking into silicon substrate.

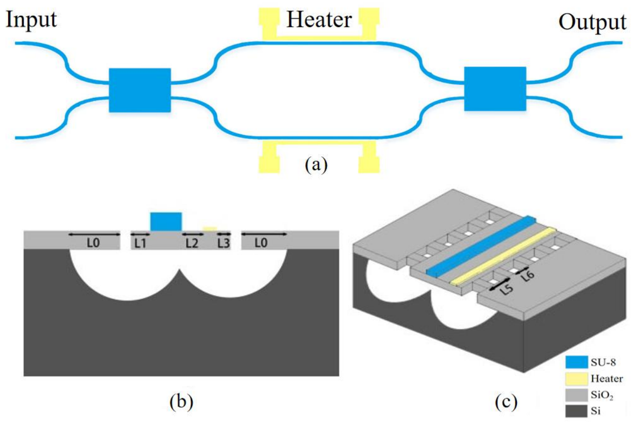


Fig. 1. (a) Schematic of the MMI-MZI switch. (b) 2D view and (c) 3D view of the switch suspended area.

The traditional polymer switch usually adopts the top heating method [2], and it's inevitable to introduce buffered thick $SiO_2$ or polymer layer to eliminate the optical loss by metal absorption, which leads to large power consumption and slow response. In this work, we proposed to have lateral heaters to reduce heating power and also accelerate the response speed. The large refractive index difference between the core and cladding strongly confine the mode filed in a small region, thus reducing the space between the waveguide and the metal heater. The distance between the waveguide and heater is then designed to be 2 µm considering optical absorption. At the same time, air hole is introduced below the heaters and waveguides. Since the thermal conductivity of air is lower than that of $SiO_2$, the most of heat is transferred through $SiO_2$ slab, which limits the diffusion of heat to the surrounding and reduce the power consumption. The switch increases the distance of the heat transferring to the silicon substrate, limits the heat dissipation and reduces the power consumption required for the switch.

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The width and height of the SU-8 waveguide is chosen to be 2 μm 1.5 μm to ensure single mode propagation. We use three-dimensional finite difference time-domain (3D-FDTD) for simulation. The width of MMI is chosen to be 18 μm to ensure enough excited mode, and the MMI length is determined to be 252 μm accordingly.

Here we use the Lumerical DEVICE Solutions to calculate the heating field distribution of the device. A metal heater is placed near the waveguide and transfers heat to the waveguide through the suspended buffered $SiO_2$ layer. The heater consists of three metal layers with 200 nm Ti, 10nm Au and 40 nm Al and the size of which is 1000 μm long and 2 μm wide. The optimized parameters are determined to be $L_1$=0.5 μm, $L_2$=2 μm, $L_3$=0.5 μm, $L_0$=5 μm, $L_6/L_5$=3/5, resulting a calculated power consumption ~ 2 mW, and a response time ~ 177 μs.

## III. Device Fabrication and Characterization

We then fabricate and characterize the device. Firstly, 2.8 μm thick $SiO_2$ film is deposited on silicon substrate by plasma enhanced chemical vapor deposition (PECVD). After that, the AZ5214 photoresist with a thickness of 1.3 μm is evenly spin-coated on the substrate and is exposured to obtain the mask for metal lift-off process. Then 200 nm Ti, 10 nm Au and 40 nm Al are evaporated on the chip as the metal heaters, where the top layer of Al is used as an anti-etching material. After evaporation, the metal heater is obtained by lift off process. Another AZ5214 layer is utilized as the etching mask for $SiO_2$ trench and silicon hole. $SiO_2$ trench is etched by inductively coupled plasma reactive ion etching (ICP-RIE) etching while silicon hole is etched by isotropic ICP etching to obtain suspended structure. Finally, SU-8 waveguide is formed by spin-coating and another UV lithography. Since the exposure dose is much smaller for SU-8 in the hole region compared with the top waveguide, the SU-8 in the hole region can be easily removed by developing solution.

As shown in Fig. 2, the metal heater width of the switch is 1.6 μm, the waveguide width is 1.7 μm, the electrode is basically adjacent to the etching trenches, and the duty ($L_6/L_5$) of the etching trench is about 8/10.

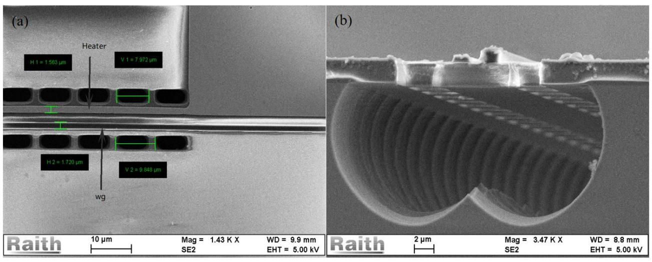


Fig. 2. (a) Top-view and (b) cross-sectional scanning electron microscopic (SEM) image of the switch suspended area.

## IV. Measurement and Result

The SLD1310 (Thorlabs S5FC1021P) light source, polarization controller, sourcemeter (Keithley 2400) and optical spectrum analyzer (OSA, Yokogawa AQ6371C) are used to measure the transmission spectrum of the switch. The lensed fiber is used for coupling. The response time of the switch is measured by using the functional signal generator (Siglent SDG6012X-E), the photodiode (PD, Thorlabs DET10D/M) and the oscilloscope (Keysight DSO7032B).

The insertion loss of the switch is about 3.4 dB by subtracting the maximum output of the switch signal from the maximum output of the reference waveguide. The extinction ratio of the cross port is 34.2 dB, the extinction ratio of the bar port is 24.6 dB, and the power consumption of the switch is 1.8 mW. The measured rise time is 218.7 μs, and the fall time is 274 μs.

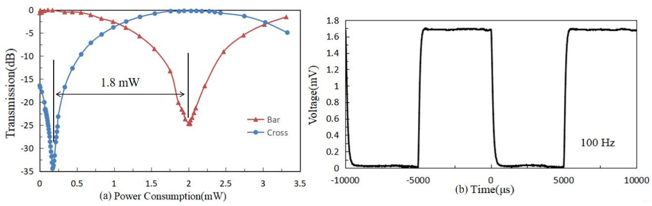


Fig. 3. (a) Measured transmission of cross and bar ports of the switch. (b) Switching response at 100 Hz square wave.

TABLE I. Performance Comparison of Other Polymer Thermo-Optic Switches

| Work | PC(mW) | ER(dB) | RT(μs) | FT(μs) |
|---|---|---|---|---|
| N. Xie[1] | 3.5 | 25 | 200 | \ |
| Yu-Fen Liu[2] | 3.4 | 29.6 | 183.1 | 139.9 |
| This work | 1.8 | 34.2 | 218.7 | 274 |

## V. Conclusion

We designed, fabricated and characterized a high efficiency switch by utilizing the suspended polymer waveguide. Low power consumption of 1.8 mW and high extinction ratio of 34.2 dB can be realized. Such device will prompt the development of energy-efficient optical routers.

## References

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