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Fabrication and characterization of polymer thermo-optic switch based on mmi coupler

Abdulaziz M. Al-hetar [a,b,*], Abu Bakar Mohammad [b], Abu Sahmah M. Supa'at [b], Zaid A. Shamsan [a], Ian Yulianti [b]

[a] Communications and Computer Department, Faculty of Engineering and Information Technology, Taiz University, Taiz, Yemen
[b] Photonics Technology Center (PTC), Infocomm Research Alliance (IcRA), University Technology Malaysia (UTM), 81310 Johor, Malaysia

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ABSTRACT

The 2×2 polymer thermo-optic switch based on MMI coupler is realized. This device is fabricated using standard fabrication techniques such as coating, photolithography, and dry etching. A crosstalk level of −36.2 dB is achieved at cross and bar states. A power consumption of 1.85 mW is applied to change the state of the switch from the cross to the bar state. A switching time of less than 0.7 ms is traced to change a state of the realized switch.

1. Introduction

There is an increasing need for optical switch matrices for switching, protection switching, cross connection, and dynamic variable optical distribution. It is desirable that such switches have large optical bandwidth, small physical dimensions, large fabrication tolerances, and good performances. These properties are sought in order to reduce optical network system costs and improve efficiency. MMI couplers have compactness [1], relaxed fabrication tolerance, and suitability for device integration [2] which are the subject of interest in a high capacity WDM network.

The MMI switches based on the thermo-optic effect are very attractive due to their simplicity and flexibility. Polymer is the most attractive material to fabricate thermo-optic switches for its high thermo-optic coefficient. The thermo-optic effect refers to the variation of the refractive index of a heated dielectric material [3,4]. The thin-film heater is utilized to change the refractive index and propagation characteristics of the waveguide. The improvement of optical switches performance is crucial to fulfil the requirements of switching, protection switching, cross connection, and dynamic variable optical distribution applications.

In this work, a new structure has been used to realize a 2×2 MMI polymer thermo-optic switch. A strongly guiding ridge waveguide with deep etching in the lower cladding has been used. In addition, a ridge silicon is extended from the silicon substrate to the lower cladding and between heater electrodes. The main purpose behind this change in the substrate layer is to localize the heating at a heated region and limit the heat diffusion elsewhere [5,6]. The experimental results show that the 2×2 MMI polymer thermo-optic switch has a low switching power of less than 1.85 mW, a crosstalk at two states of less than −36.2 dB, and a switching speed of less than 0.7 ms.

This paper is organized as follows: in Section 2, the design and simulation of the 2×2 MMI polymer thermo-optic switch with new structures are presented. The fabrication steps are shown in Section 3. Finally, Section 4 is dedicated to describe the measurements and results.

2. Design and simulation

In the following simulation, we select the operation wavelength in free space $\lambda = 1550\ nm$, the core and cladding are ZPU12-480 and LRF378, their refractive indices are 1.48 and 1.378; respectively. ZPU12-480 and LRF378 are photoactive UV curable resins based on perfluorinated acrylate polymers. They have been synthesized at Chemoptics Co. Ltd. in South Korea and used in realizing the device. The electrode is made of aluminum (Al) and the substrate is Si wafer with a refractive index of 3.5.

The polarization sensitivity of a waveguide is typically characterized by its birefringence, which is the difference of the TE and TM effective refractive indices [7]. The birefringence values have been obtained by calculating the TE_0 and TM_0 effective refractive indices for various waveguide widths and thicknesses by using 3D Mode Solver BeamPROP, and noting that the smallest absolute value of a

* Corresponding author. Communications and Computer Department, Faculty of Engineering and Information Technology, Taiz University, Taiz, Yemen. Tel.: +967 777011750; fax: +967 4247515.
E-mail address: alhetar_aziz@yahoo.com (A.M. Al-hetar).

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birefringence is 7×10^{-6}, which occurs at a width of 2.5 μm and a thickness of 1 μm.

Fig. 1 shows the structural schematic of a 2×2 MMI thermo-optic switch which has been proposed with a silicon ridge at the substrate layer [5]. The silicon ridge is expanded from the silicon substrate layer to the lower cladding layer at the center of the MMI coupler and between two self-image areas as shown in Fig. 1. It acts as a heat sink [5,6]. The dimensions of the MMI coupler were calculated using the well known relation for general interference in the MMI waveguide [8]. The light coupled to the upper input waveguide will be imaged into the lower output waveguide during the cross state (initial state), as shown in Fig. 1(a).

The optical and thermal behaviors of the proposed 2×2 MMI thermo-optic switch were verified by BeamPROP, which is based on Finite Difference Beam Propagation Method (FD-BPM), and includes the effects of the heater. The changing phase is done by a certain value of applied power (1.35 mW) as shown in Fig. 4. The simulation result shows that the crosstalk (CT) of this structure is smaller than −39 dB at the cross state and the bar state.

3. Fabrication

Three different masks have been used in the fabrication process, one for the ridge silicon in the substrate layer, one for the heater electrodes and heater pads structure, and one for the ridge waveguide structure. The processes involved are depicted in Fig. 2.

Firstly, a 4-in Si wafer serves as a substrate which is covered by positive photoresist (Si-PR). After a soft bake (1 min at 90 °C), the ridge Si in the substrate is defined through a chromium mask at a wavelength of 410 nm (UV light). After development and a hard bake at 120 °C for 30 minutes, the wafer was etched to form a 3 μm ridge height by using Inductively Coupled Plasma Etcher (ICPE). Then LFR378 is spun-coated on the Si substrate as lower cladding. The LFR378 solution was dispensed onto the center of the ridge silicon, approximately 5 ml for a 4-in substrate. Then the substrate was spun at 300 rpm for approximately 3–5 s to spread the resin out from the center. The substrate was then spun for 20 s at spinning speed 2500 rpm to obtain the desired polymer thickness target at 6 μm. Next, ZPU12-480 is spun-coated on the lower cladding layer. The required thickness of this layer is 1 μm, so the second speed was 3000 rpm for 60 s to obtain that thickness. Then, LFR378 is spun-coated on the core layer as upper cladding. The required thickness of this layer is 2 μm. So the second speed was 3000 rpm for 40 s to obtain that thickness. After each spinning, the wafer was put in the UV chamber for UV curing.

To define the heater electrodes and heater pads, the wafer was covered by negative photoresist (AZ3612) which is the first step in the photolithography. The photoresist thickness must be thicker than the thickness of chromium (Cr) (the Cr layer was introduced as an adhesion) and Al. Then, the heater electrodes and heater pads were applied to the negative photoresist. The photoresist layer was patterned in a reverse pattern, i.e. the photoresist layer was removed from the area where the metals are to remain in the final structure as shown in Fig. 2. Then, the Cr and Al deposition were consecutively done by using an e-beam evaporation technique [9] over the masking layer and in openings through the masking layer. The lift-off was performed in a Micrchem Remover PG solution to remove the metals overlying the photoresist layer and leave the desired metal pattern on the underlying surface.

To define the ridge waveguide, the wafer was covered by photoresist which is the first step in the photolithography. Positive photoresist (Si-PR) has been spun at 3500 rpm for 20 s to form a layer of photoresist over the wafer. After a soft bake (1 min at 90 °C), the waveguide, heater electrodes, and heaters pads pattern or waveguide pattern was defined through a chromium mask by UV light. After development and a hard bake (30 min at 120 °C), the wafer was etching to form 4 μm of ridge height by using ICPE.

4. Measurements and discussion

The experimental setup that was used for all the measurements is shown in Fig. 3 The light originated from a tunable laser source (TLS) passed through a polarization controller to choose TE or TM mode and then the light was coupled to the fiber block. The device under test

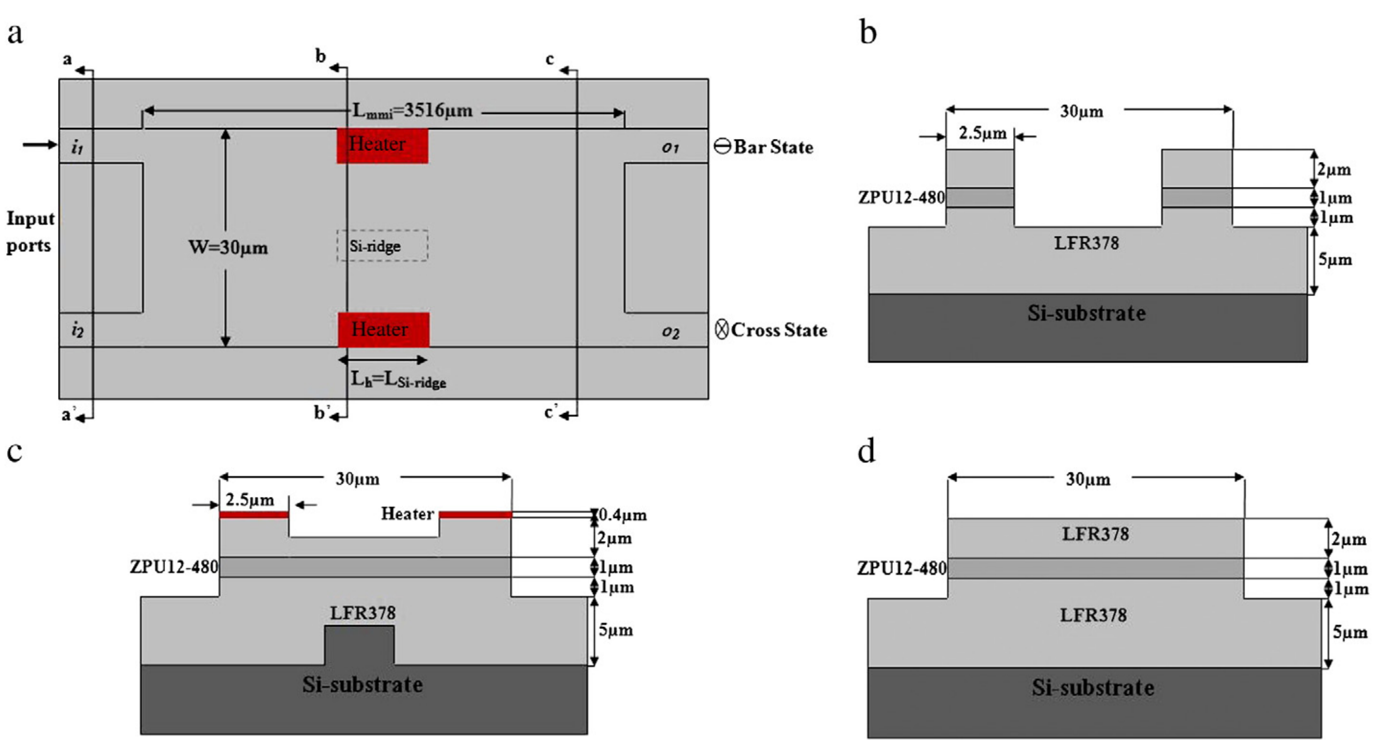

Fig. 1. (a) Schematic diagram of the MMI switch, (b) aa′ cross section, (c) bb′ cross section, and (d) cc′ cross section.