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DEVELOPMENT OF 2X2 ASYMMETRICAL THERMOOPTIC SWITCH

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ABSTRACT

A 2x2 asymmetrical directional coupler based thermooptic switch utilizing polymer technology is reported. The index contrast of the upper cladding layer and the waveguiding layer is 0.03. The index contrast of the lateral section of the waveguiding region and lower cladding layer is 0.005. The asymmetrical fabricated switch exhibits very low switching power of 12.26 mW. The crosstalk level of -30 dB for the initial and switching states has been achieved. The response time measured is 7 ms.

1. INTRODUCTION

Waveguides based optical switches are the elementary components to perform the switching functions in all-optical networks. The application of optical switches is in network protection, routing of high bit rate optical signal and network reconfiguration. The recent progress in wavelength division multiplex (WDM) lightwave communication system will further increase the necessity of optical switch modules. Several optical switch architectures have been proposed and implemented in silica on silicon or glass substrates [1], Ti-$LiNbO_3$ [2] and semiconductors [3]. On the other hand, polymeric optical devices have attracted large attention recently because of low costs and high-speed possibilities as well as fabrication flexibility. Furthermore the polymer devices can be fabricated directly on electronic substrates and assembled with integrated circuits (ICs) to create a hybrid optoelectronic package [4].

There are only few reports on the devices based on hybrid polymer technology such as the balanced bridge Mach-Zehnder interferometer (MZI) switch incorporating 3-dB couplers [5]. The most important characteristics of polymer optical waveguides used in optoelectronic devices should be high thermal stability that will make them compatible with conventional fabrication processes [6]. Precise control of refractive index is essential for fabricating single mode channel optical waveguide. For optical telecommunication system, low optical loss at second and third window telecommunication wavelength is required.

In this paper we demonstrate an asymmetric 2x2 directional coupler based thermooptic (TO) switch using all polymer material. The TO effect, which means temperature dependence of the refractive index of a waveguide material. The polymer based waveguides with buried square core (BSC) structures have been adopted for polarization independence and single mode operation at 1550 nm wavelength. The temperature dependence of refractive index is achieved by heating one of the electrodes heater placed alongside the branches. The polymers type used are ZPU series curable polymers by Zenphotonics.

2. OPERATION PRINCIPLE

Fig. 1 shows a schematic view of the developed 2x2 directional coupler TO polymer switch (DCTOPS). It consists of two symmetric waveguides that are close together but separated by waveguide spacing of g. The center-to-center distance between the core and the heater electrode is d. The index contrast between the upper cladding and the waveguiding region is 0.03 and the index contrast between the lateral section of the waveguiding region and lower cladding is 0.005. The bend waveguides with curvature radius, R_c are connected to both the input and output port to form the directional coupler.

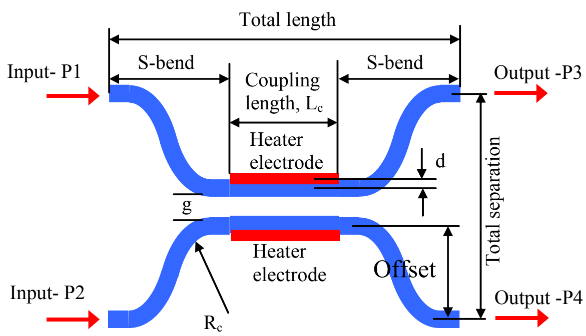

Fig. 1 A schematic view of 2x2 DCTOPS

In its simplest form, the directional coupler consists of two parallel waveguides placed close to each other. Light is launched into one of the waveguides and its optical energy is transferred synchronously back and forth between the guides by optical tunneling. In this work an active optical switch, the basic operation principles are as follows. At first, in two well separated waveguide regions, there are two uncoupled waveguide modes with the same propagation constant. In the interaction region, the two waveguides modes are symmetric and asymmetric modes with propagation constant β_{sym} and β_{asym} respectively. While light is propagating through the interaction region, the phase differences of the two eigenmodes increase due to the difference in their propagation constant. Interference of the two modes allows light power to transfer between the two channels. In other words the change in propagation constants leads to a change in the coupling length, L_c which is the minimum length of interacting waveguides required to obtain complete crossover or cross state. But the two waveguides in two distinct transition regions or taper regions start to couple and show a difference in their propagation constants when they are close enough. This coupling contributes to the power transfer as well. If low loss arc bend waveguides are used in the transition regions this contribution can be significant when the two channels are strongly coupled in the interaction region. Therefore the coupler has been designed with the tolerance of 200 μm such that slight change in ΔL_c suffices to drive the switch into a perfect cross state. When the voltage is applied to the heater electrode, the refractive index under the heater electrode is lowered due to the TO effect. Owing to the high thermal conductivity of the polymer used, the temperature of the right waveguide will be lowered even if only the left waveguide is heated. Therefore, the propagation constant of the waveguides will be changed almost synchronously to keep $\Delta\beta \approx 0$ as long as the applied voltage is maintained at a low level. By raising the applied voltage or heating power the resulting temperature difference between the two branches of the waveguides will induce an increasing mismatch $\Delta\beta$ of propagation constant and as a results the switch will behave asymmetrically to reach the bar state.

3. FABRICATION PROCEDURE

The device was fabricated on a 4-inch Si wafer, using standard polymer fabrication technology as shown in Fig. 2.

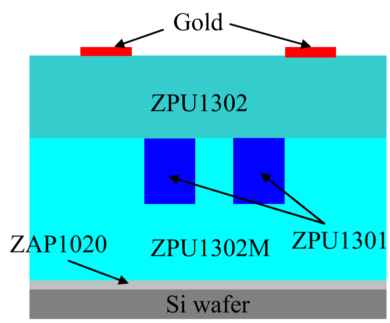

Fig. 2 Cross-section of fabricated 2x2 DCTOPS

A new technique of inverted channel structure using inductively coupled plasma (ICP) etching had been introduced for BSC waveguides definition. Before coating ZPU 1302M as under cladding polymer, an adhesion promoter ZAP1020 was spin coated because ZPU series polymer had weak adhesion to the Si wafer. Positive photoresist named, ATMR was used for waveguides patterning in the photolithography process. The photoresist was exposed with UV light while the wafer is in contact position with the mask. The developer for ATMR was AZ500MIF and used for 5 seconds, suffices to remove the illuminated photoresist. After having completed the photolithography process, the under cladding polymer was etched down for waveguide core definition using ICP etcher. The O_2 flow rate of 20 lpm was used as the etching gas. Thereafter the polymer, ZPU1301 waveguiding layer was deposited by spin coating. The thickness of the waveguiding layer needs to be controlled accurately to guarantee the designed switching behavior and therefore planarization technique was introduced and it had two folds benefits. First, to get rids of the 'dips', which occurred during the core layer coating due to inverted channel technique used. Second, for the accuracy of channel definition of step etch into the under cladding of ZPU1302M polymer. Subsequently the upper cladding ZPU1302 polymer layer was deposited and heating electrodes and pads were fabricated using e-beam evaporation and Au plating methods.

Fig. 3 shows the micrograph of the heater electrodes and heater pads after the seeds metal were removed. The bend waveguides of parallel BSC waveguides with the side linewidths of 7 µm with a waveguide gap spacing of 5 µm at the end of the coupling length could also be seen. The micrograph indicates that the side linewidths of the BSC waveguides were flat and the narrow gap spacing was completely parallel and well determined on top of under cladding layer. The thickness of the heater electrodes and heater pads were measured to be 0.4 µm and 3.2 µm, respectively. The resistance of the heater electrodes and the heater pads were measured to be 130 Ω and 10 Ω, respectively. This micrograph also indicate that the forming of heater electrodes and heater pads were well defined on top of the BSC waveguides structure.

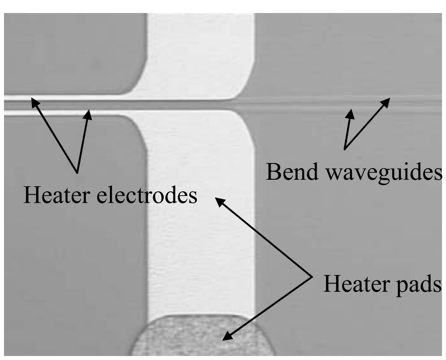

Fig. 3 Electrodes heater and heater pads after the seeds metal is removed (M100X)

3. EXPERIMENTAL RESULTS AND DISCUSSION

For ease of understanding in characterizing the switching characteristics of the fabricated 2x2 DCTOPS, the configuration of the switch is shown as depicted in Fig. 4.

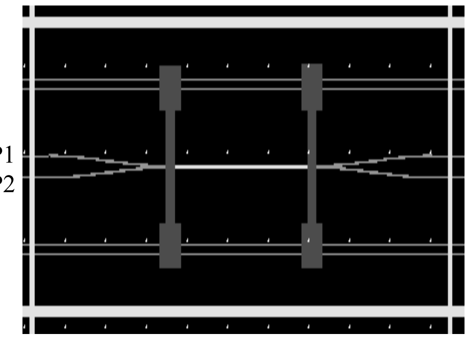

Fig. 4 2x2 DCTOPS configuration

The analysis of the switching characteristics has been performed using laser diode (LD) source at 1550 nm wavelength. Using LD at the input, IR camera and TV monitor at the output, the switching characteristics were analyzed by seeing the near field patterns either at initial state or at switching state. The near field patterns of the initial state and the switching state of 2x2 DCTOPS is shown in Fig. 5 and Fig. 6, respectively.

Fig. 5 Switching characteristic: Initial state

Fig. 6 Switching characteristic: Switching state

To characterize the switch, the switching curves were investigated using LD with a wavelength of 1550 nm for transverse magnetic (TM) modes polarizations. When light is launched into port P1, the switching curve was plotted for insertion loss (IL) in dB as a function of switching power in mW. The switching curve is shown in Fig. 7. At initial state or cross state; P1=>P3, the IL was –30.4 dB and P1=>P4, the IL was –2.01 dB, respectively. This corresponds to a crosstalk of –28.39 dB. At switching state or bar state; P1=>P4, the IL was –36 dB and P1=>P3, the IL was–1.7 dB, respectively. This corresponds to a crosstalk of –34.3 dB. The switching power required was 12.26 mW. The response time of the developed switch was measured to be 7 ms as depicted in Fig. 8.

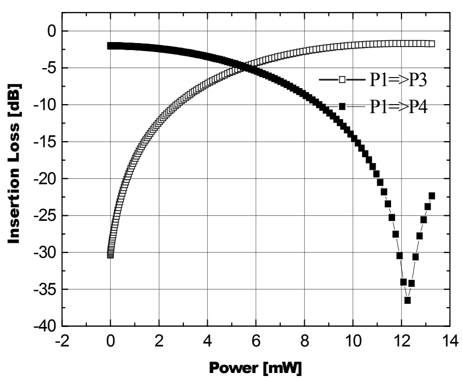

Fig. 7 Switching characteristic for 2x2 DCTOPS

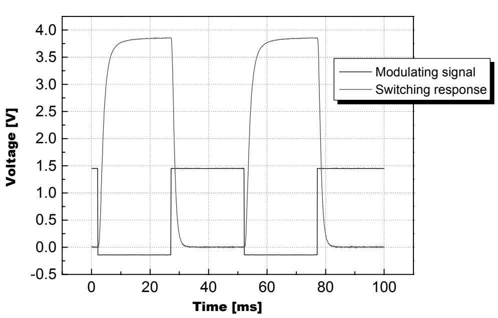

Fig. 8 Measured response time

4. CONCLUSIONS

We have demonstrated a new asymmetrical polymer based BSC 2x2 DCTOPS using polymeric materials. The asymmetrical switch configuration with an index contrast of 0.03 between the upper cladding layer and core layer has been realized and show very good performance in terms of the heating power required. This switch exhibits low IL of 2 dB and low power consumption of 12.26 mW at the 1550 nm wavelength window. The crosstalk level of -30 dB for the initial and switching states has been achieved successfully.

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