Low Power Consumption Thermooptic Switch Using Polymers

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Abstract - Thermooptic 2x2 switches utilizing polymer technology is reported. The devices made of ultraviolet curable fluorinated polymer are based on directional coupler. The waveguide is a rectangular buried channel type with 7x7 μm^2 and the effective index difference of the channel waveguide is about 0.5% for single mode operations. The crosstalk of the switching state is more than 36 dB. The fabricated switch exhibits very low switching power of 32.4 mW.

1. Introduction

Polymer based waveguides 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. Various types of 2x2 have been reported for protection switch and other application using optomechanical system, microelectromechanical systems (MEMS) and planar lightwave circuit (PLC) technology [1], [2], [3].

Recently many switches based on MEMS have been reported with good switching performance. Even though MEMS switches have a lot of advantages, they have a few drawbacks such as high operating voltage and the mechanical weakness by vibration. Therefore the thermooptic PLC-type switches are still very attractive due to their low driving voltage, no moving part and simple fabrication for low cost mass production. Furthermore the polymer devices can be fabricated directly on electronic substrates and assembled with integrated circuits (ICs) to create a hybrid optoelectronic package [4].

In this paper we demonstrate 2x2 directional coupler based thermooptic (TO) switch using all polymer 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 used are ZPU series curable polymers by Zenphotonics.

2. Device Structure and Operation Principle

The schematic diagram of the switch is shown in Figure 1.

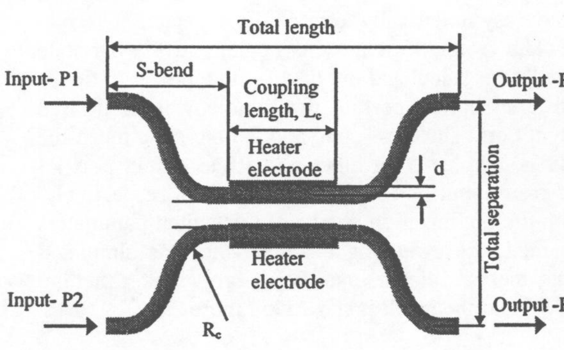

Figure 1: Schematic diagram of the proposed 2x2 switch.

The switch consists of a pair of singlemode straight buried square core (BSC) waveguiding channels, a pair of singlemode S-bend BSC waveguiding channels at the input and output ports to form a directional coupler, a pair of heating electrodes, heater pads, under cladding and upper cladding layers surrounding waveguiding channels. The heating electrodes were implemented to thermooptically control the phase matching condition of the coupling between the waveguiding channel and the cladding layers. The switch is characterized by the parameters of coupling length, L_c, waveguide spacing, g, center-to-center distance between the core and the heater electrode, d, and the bend waveguides with curvature radius, R_c, that connected to both the input and output ports.

When no voltage is applied to the heater, at the interaction region, the two waveguides modes are symmetric and asymmetric modes with propagation

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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. On the contrary, when the voltage is applied to the heater, the effective index under the heater electrode is lowered by negative thermooptic coefficient of polymer material. Owing to the high thermal conductivity of the polymer used, the temperature of the upper waveguide will be lowered even if only the lower waveguide is heated. Therefore, the propagation constant of the waveguides will be changed almost synchronously to keep the difference of the propagation constant, $\Delta\beta \approx 0$ 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.

The crosstalk of the cross-state and the bar-state have been calculated in dB for the power ratio of undesired output port to the total power of desired output port. The cross state and the bar state mean the light is coupled from input port P1 to output port P4 and from input port P1 to output port P3 respectively. With the optimization results of the switch parameters obtained, the switching characteristic was simulated using the two dimensional beam propagation method (BPM) and the result is shown in Figure 2.

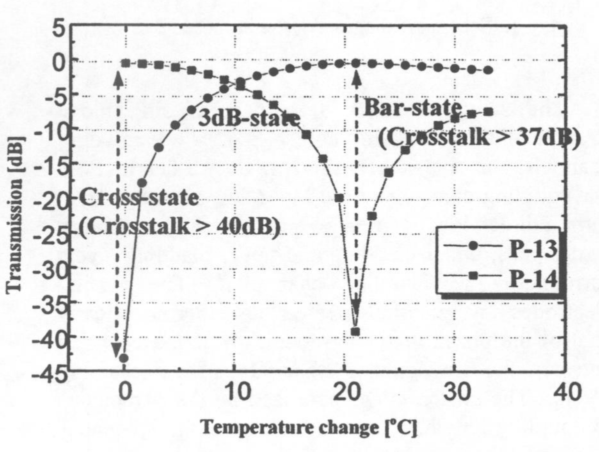

Figure 2: Switching characteristics as a function of temperature.

The simulation result shows that the crosstalk at the initial state is more than 40 dB. With the temperature change of 22 °C the switching state is in the bar sate. The crosstalk at the bar state is more than 35 dB. These results have been achieved when the optimum coupling length and the device length of the S-bend waveguide are 1.85 mm and 4 mm, respectively.

3. Device Fabrication

The device is fabricated on a 4-inch Si wafer. A new technique of inverted channel structure using inductively coupled plasma (ICP) etching had been introduced for BSC waveguides definition. The core and the clad materials are ZPU1301 and ZPU 1302M, respectively which are ultraviolet curable polymer based on perflourinated acrylate with low loss, low birefringence and good environment stability.

For the waveguide fabrication, the lower clad and core layers are spin coated in thickness of 15 µm and 7 µm, respectively. After each spinning, layers are exposed to ultraviolet light for curing and baked at 160 °C for 1 hour. The waveguides are patterned by photolithography and ICP etching process using O_2 plasma. Next, the upper layer is spin coated and cured by the same process. By E-beam evaporation and gold plating technology, the heating electrode and heater pad are made of Cr and Au. The thickness of the heater electrode and heater pad is 0.4 µm and 3.2 µm, respectively. The resistance of the heater electrode and the heater pad is about 130 Ω and 10 Ω, respectively. Figure 3 shows the micrograph of the heater electrodes and heater pads after the seeds metal were removed.

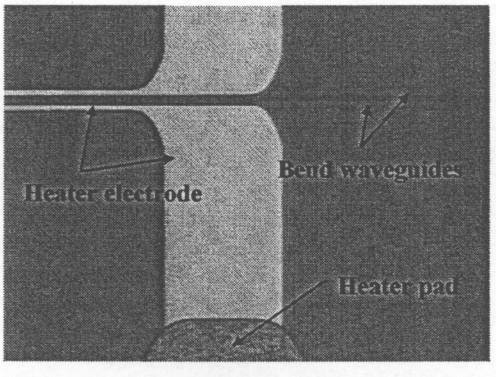

Figure 3: Heater electrode and heater pad (M100X).

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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. This micrograph also indicate that the forming of heater electrodes and heater pads were well defined on top of the BSC waveguides structure.

4. Experimental Results

The switching curves were investigated using LD with a wavelength of 1550 nm for TE and TM modes polarizations. The input power of the LD was fixed at 0.5 mW. Figure 4 and Figure 5 show switching curves for TM and TE polarizations, plotted for insertion loss (IL) in dB as a function of switching power in mW, respectively. At the initial state or cross state; P1=>P3, the IL for TM and TE modes were –28.32 dB and –28.12 dB, respectively and for P1=>P4, the IL for TM and TE modes were –1.31 dB and –1.51 dB, respectively. These correspond to the crosstalk of the switch as -28.32 dB and –26.61 dB for TM and TE modes, respectively. At the switching state or bar state; P1=>P4, the IL for TM and TE modes were –38.1 dB and –37.2 dB and P1=>P3, the IL for TM and TE modes were –1.71 dB and –1.81 dB, respectively. These correspond to the crosstalk of the switch as –38.1 dB and –37.82 dB for TM and TE modes, respectively. The switching power and switching voltage were 32.4 mW and 1.15 V for TM mode, respectively. For TE mode the switching power and switching voltage were 33.5 mW and 1.25 V, respectively. These data were summarized as depicted in the text boxes to explain the switching curves for TM and TE modes of Figure 4a and Figure 5a, respectively.

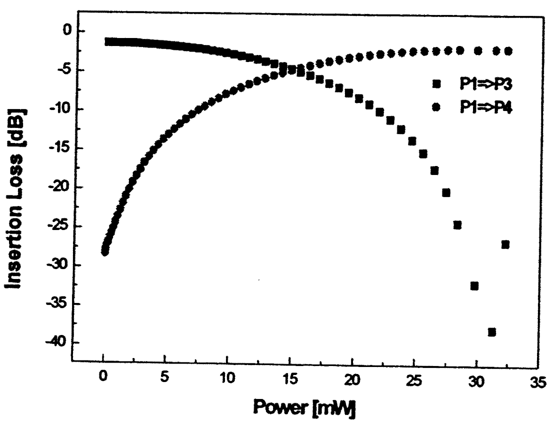

Figure 4: Measured switching curve 2x2 switch for TM mode.

Initial: cross state (IP1,TM)
IL ~ -28.32 dB (P1=>P3)
-1.31 dB (P1=>P4)
Crosstalk ~27.01 dB

Switching: bar state
IL ~ -1.71 dB (P1=>P3)
-38.1 dB (P1=>P4)
Crosstalk ~36.39 dB
Switching power ~ 32.4 mW
Switching voltage ~ 1.15 V

Figure 4a: Summary of switching curve of 2x2 switch for TM mode.

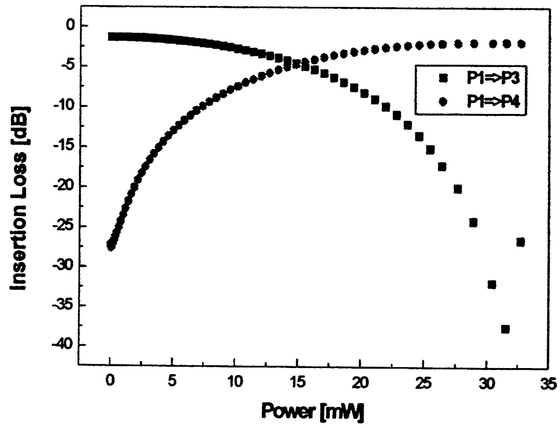

Figure 5: Measured switching curve 2x2 switch for TE mode.

Initial: cross state (IP1,TE)
IL ~ -28.12 dB (P1=>P3)
-1.51 dB (P1=>P4)
Crosstalk ~26.61 dB

Switching: bar state
IL ~ -1.81 dB (P1=>P3)
-37.82 dB (P1=>P4)
Crosstalk ~36.01 dB
Switching power ~ 33.5 mW
Switching voltage ~ 1.25 V

Figure 5a: Summary of switching curve of 2x2 switch for TE mode.

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5. Conclusion

2x2 thermooptic switch with low power consumption had been demonstrated using polymer PLC technology. The fabricated switch exhibits low switching power of 32.4 mW and more than 36 dB of the crosstalk at the switching state for TM mode polarization. The switch shows good potential for protection switching and switching function in the optical network.

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