

## A THERMO-OPTIC POLYMER BASED 2×2 OPTICAL SWITCH

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### ABSTRACT

The major focus of this work was to design and simulate a 2×2 optical switch aiming to reduce insertion loss and switching power. For a directional coupler (DC) configured, thermo-optic (TO) polymer based 2×2 optical switch, the point-to-point insertion loss and switching power were found 0.85 dB and 1.75 mW respectively.

### 1. INTRODUCTION

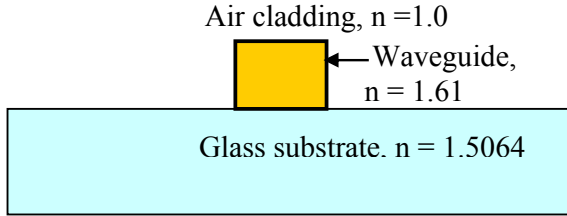
The main attraction of optical switching is that it enables routing of optical data signals without the need for conversion to electrical signals. The polymer waveguide technology has potential to meet the requirements of low power consumption, low insertion loss and low cross talk as well as high scale of integration on large substrates in a cost effective manner [1]. The concept of DC as a modulator (switch) was proposed first by Marcatili in 1969 [2]. Afterwards, in 1993 Yasuhiro et al. [3] demonstrated polymer TO 2×2 optical switch at the wavelength of 1.3 μm with switching power of 4.8 mW. In 1996 Keil et al. [4] reported DC configured TO polymer based 2×2 switch at 1.55 μm with insertion loss of 10 dB and switching power of 70 mW. In their next paper [5], they managed to reduce the power consumption to 30 mW and insertion loss to 9 dB. In 1996 elsewhere Keil et al. [6] demonstrated a 2×2 DC based optical switch, with reduced insertion loss of 6 dB, and switching power of 20 mW. In 1998, Oh et al. [7] described a TO polymer based 2×2 switch at 1.55 μm with insertion loss of 4.5 dB, switching power of 10 mW. In 2000 Keil et al. [8] reported a TO polymer based 1×2 vertical coupler switch (VCS) with insertion loss of 3.5 dB and power consumption of 80 mW using the polymer/silica hybrid integration approach. Recently Keil et al. modified the previous design of 1×2 VCS

[9] for reducing the insertion loss to 1.5 dB and power consumption to 30 mW. In 2001 Lee et al. [10] proposed a polymer based 2×2 switch at 1.3 μm with operating voltage of 8.5 V, and insertion loss of 14 dB. Recently Lee et al. [11] demonstrated a TO polymer based 2×2 switch at 1.55 μm, with insertion loss of 4 dB but power consumption was very high (250 mW). Thus, there is a scope to design 2×2 optical switch having low insertion loss and switching power.

In this work, a 2×2 optical switch was designed for the third transmission window aiming to reduce insertion loss less than 3 dB and switching power less than 2 mW. TO polymer waveguide technology, directional coupler configuration, strip waveguide structure, and square waveguide geometry were used for the design of the switch. HD 4000 polymer was used as the waveguide material on optical crown glass (OCG) as the substrate, and air was used as the cladding. The device parameters were simulated and optimized using Beam Propagation Method (BPM) modeling technique utilizing BPM\_CAD software. Heater electrodes were designed and simulated for optimum heater power, position, and dimension.

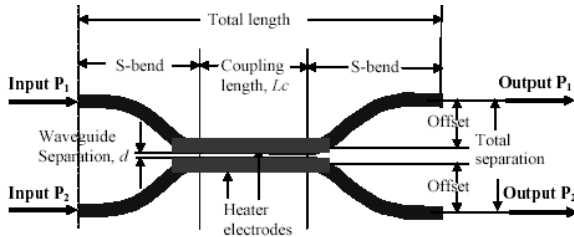
### 2. DESIGN AND SIMULATION

For low cost in house fabrication, the HD 4000 polymer was used as waveguide material on OCG, and air cladding was used to avoid involvement of another expensive polymer material. Air cladding is a new approach in this design. Square waveguide have the advantage of good fiber-to-waveguide coupling as modal field match and little polarization dependency than that of rectangular waveguides. The geometry of the designed square waveguides and material system are illustrated in Fig.1.



**Fig. 1** The schematic of the designed square waveguide geometry and material system.

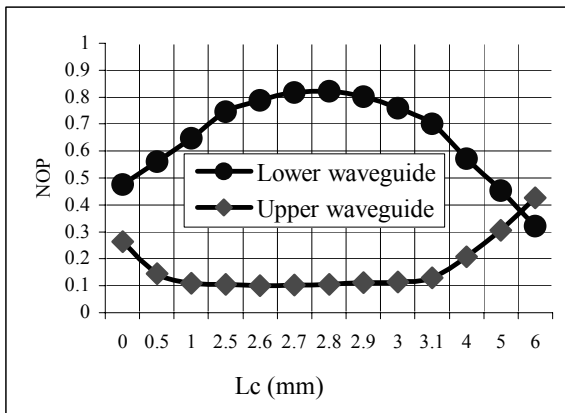
S-bend waveguides have been widely used in intergrated optics because they provide low transition loss between parallel waveguides with a lateral offset and is relatively easy to design and fabricate [12]. Therefore, S-bends were used for coupling between parallel waveguides and optical fibers. The schematic diagram of the designed switch with heater electrodes is illustrated in Fig. 2.



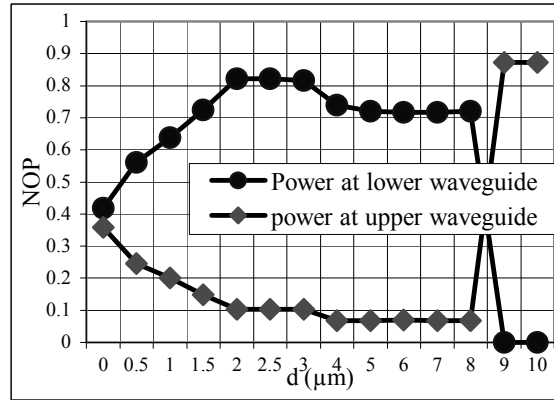
**Fig. 2** A schematic diagram of a DC configured TO polymer based 2×2 optical switch.

### 3. RESULTS AND DISCUSSION

Using BPM 3D software, the interaction length ( $L_c$ ) and separation distance ( $d$ ) of the parallel waveguides of the DC based 2×2 optical switch, were calculated. The simulated results of normalized output power (NOP) are shown in Fig. 3 and Fig.4.

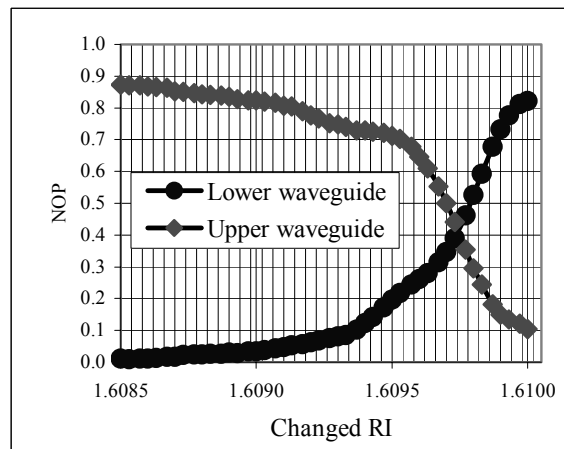


**Fig. 3** Simulated NOP versus  $L_c$  of the cross state of a DC configured 2×2 optical switch.



**Fig. 4** Simulated NOP versus  $d$  of the cross state of a DC configured 2×2 optical switch.

It is evident from Fig. 3 that the NOP is maximum and uncoupling NOP is minimum for the parallel waveguides at  $L_c$  of 2.8 mm. From Fig. 4 the maximum coupling (83%) is at  $d=2 \mu\text{m}$ . However,  $L_c$  of 2.8 mm and  $d$  of 2  $\mu\text{m}$  was selected with point-to-point insertion loss of 0.85 dB. Insertion loss was reported 6 dB [10], 10 dB [4], 9 dB [5], and 5 dB [13] but in this design total insertion loss is 2.85 dB including device coupling losses with fiber to waveguide (1 dB) and waveguide to fiber (1 dB). It was reported that for a DC based 2×2 coupler, coupling efficiency is less than 80% and interaction length is less than 3 mm with index contrast of 0.6% [14]. Total length of 7 mm was reported [6, 15] and 5 mm was also reported [4] for single mode structure but in this design the total length is 16.6 mm due to multimode structure. The variation of NOP with varying RI of the waveguides was plotted and is shown in Fig. 5.



**Fig. 5** Variation of NOP with varying RI of the bar state of a DC configured 2×2 optical switch.

It is evident from Fig. 5 that if the RI of lower waveguide decreases to 1.609 from 1.61 ( $\Delta n = 0.001$ ) then the power in upper waveguide is 83% and in lower waveguide is 3.3%. At this point coupling is acceptable compared with the cross state of this switch. Therefore  $\Delta n$  equal to 0.001 was selected for the minimum difference of RI required between the waveguides to achieve switching functionality. For the thermal analysis of the heater electrodes, the heat diffusion equations were solved using MATLAB. Chromium was selected for the heater material as chromium has been using for the thin film heater material of TO switches [3, 7]. The heater electrode used in this work has the dimension of  $25 \mu\text{m} \times 10.5 \text{ nm}$ , which was calculated using MATLAB. The heater width of  $50 \mu\text{m}$  and thickness of  $52 \text{ nm}$  was reported [7]; heater width of  $100 \mu\text{m}$  and thickness of  $60 \text{ nm}$  was also reported [16]. The calculated power for switching was  $1.75 \text{ mW}$ , with maximum wafer temperature of  $48 \text{ }^\circ\text{C}$ . The required switching power was reported  $45 \text{ mW}$  [1, 17],  $80 \text{ mW}$  [8, 9],  $20 \text{ mW}$  [6, 15],  $30 \text{ mW}$  [5], and  $4.5 \text{ mW}$  [3]. Thus, the insertion loss and switching power of the designed switch are superior to that of the reported works.

#### 4. CONCLUSION

TO polymer based  $2 \times 2$  optical switches were designed and simulated aiming to reduce insertion loss and switching power. DC configuration, strip waveguide structure, multimode square waveguide geometry were chosen for in-house fabrication. Simulations were done step by step, first parallel waveguides, followed by bend waveguides,  $2 \times 2$  DC, and  $2 \times 2$  optical switch using BPM\_CAD software. It was found through simulation that, the total length, insertion loss, and switching power of the designed  $2 \times 2$  optical switch were  $16.6 \text{ mm}$ ,  $2.85 \text{ dB}$ , and  $1.75 \text{ mW}$  respectively.

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