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POLYMER BASED DIRECTIONAL COUPLER THERMOOPTIC OPTICAL SWITCH

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Abstract. The optimization of 2×2 polymer based directional coupler (DC) thermooptic (TO) optical switch (DCTOPS) using Prometheus software has been demonstrated. The coupling length variations as a function of waveguide dimension, waveguide gap, and effective index difference have been studied. The position of the electrode heater, which maximizes the effective index difference between branches have been optimized. With the index contrast of 0.005 between the core and the cladding, the crosstalk level of –40 dB and –37 dB for the cross state and the bar state of TO switch can be achieved respectively.

Keywords: Thermooptic optical switch, directional coupler, crosstalk, waveguide gap, coupling length

Abstrak. Pengoptimuman bagi satu suis optik termooptik polimer 2×2 berasaskan pengganding berarah menggunakan perisian Prometheus telah dilakukan. Perubahan panjang gandingan terhadap fungsi dimensi pandu gelombang, sela jarak pandu gelombang dan perbezaan indek berkesan telah dikaji. Kedudukan elektrod pemanas, di mana pemaksimuman perbezaan indek berkesan di antara cabang telah dioptimumkan. Dengan indek beza jelas 0.005 di antara teras dan penyalutan, aras cakap silang –40 dB dan –37 dB bagi keadaan silang dan bar masing-masing telah dicapai.

Kata kunci: Suis optik termooptik, pengganding berarah, cakap silang, sela jarak pandu gelombang, panjang gandingan

1.0 INTRODUCTION

In recent years, the increasing demand for bandwidth by consumer leads to a much stronger need for efficient use of the immense bandwith of optical networks. One of the most common ways of transportation in optical networks nowadays is wavelength division multiplexing (WDM) [1]. A large core WDM ring network uses add-drop multiplexers (ADM), which connect the core network to a smaller subnetwork or to individual users. Useful functions of the ADM are the dropping of signals from the core network to the subnetwork and simultaneously adding signals from the subnetwork to the core network. The core networks can be made very flexible when they are reconfigurable because in that case, they can be adapted to specific consumer needs. Therefore, these type of networks will become very important. For a reconfigurable

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WDM network, wavelengths have to be reallocated and rerouted. This can be achieved by using flexible ADMs.

Various approaches had already been demonstrated in the past in integrated optics, like arrayed waveguide gratings (AWG) or Mach-Zehnder interferometers (MZI) [2, 3]. Each approach has its own advantages and disadvantages and therefore, research still continues. In any case, when all channels from the core network have been demultiplex, a 2×2 switching matrix is needed to perform the add-drop function for each channel. This switch matrix decides which channel will be added-dropped to-from the core network.

This paper describes the design of a 2×2 polymer based switch, which is the building block for the switch matrix to perform the formerly defined function. This 2×2 switch is a directional coupler (DC) based thermooptic (TO) polymer switch, with buried square core (BSC) waveguides structure for monomode operation at the third telecommunication window, with a central wavelength of 1550 nm. The TO effect, which results from the fact that the refractive indices are temperature dependent is achieved by heating one of the heater electrodes placed alongside the branches.

2.0 GEOMETRY OF THE OPTICAL SWITCH

Figure 1 shows a vertical cross-section of the design of DC optical switch. The dimensions of the BSC waveguides channel need to be optimized to get the optimum coupling loss of the modes.

The effective index contrast between the wave guiding region, and the lower and upper cladding regions have been optimized for monomode operation at third telecommunication window wavelength. The thermal conductivity for both of the polymer layers of the wave guiding and claddings are taken to be 0.17 W/m/K [4], and

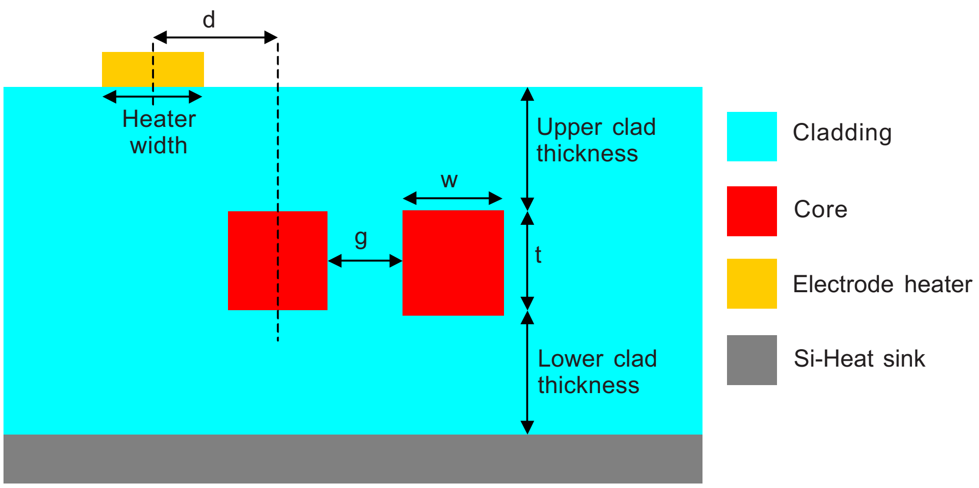

Figure 1 Vertical cross-section of DC based optical switch

for the silicon (Si), the thermal conductivity is 0.015 W/m/K [5]. The Si substrate is treated as a perfect heat sink with zero temperature. The TO coefficient for both polymer layers are taken to be -1.2×10^{-4} 1/K [4]. The electrode heater width is chosen identical to the width of the waveguides. The upper and lower cladding thickness is taken to be rather thick, 15 μm respectively. The center-to-center distance between the core and the heater electrode is d. The gap, g, is the waveguide spacing between the two waveguides core.

3.0 THERMAL ANALYSIS

The temperature profiles within a body depends upon the rate of its internally generated heat, the capacity to store some of this heat, and the rate of thermal conduction to its boundaries, where the heat is transferred to the surrounding environment. Based on the structure shown in Figure 1, we consider the heat conduction as the only heat transport mechanism, which will be accounted on the influence of temperature profiles in the optical waveguides, for which, Wang *et al*., [5] and Kokkas [6] also used this approach. Mathematically, this can be stated by the heat equation [7]:

$$\nabla^2 T - \frac{1}{\alpha}\frac{\partial T}{\partial t} = -\frac{Q_{gen}}{k} \qquad (1)$$

where T is the temperature, Q is the power generated per unit volume, k is the thermal conductivity of the material, and α is the thermal diffusivity. In this problem, we will seek solutions for the temperature profile in two-dimensional region with specified boundary conditions. This can be done as the dimension of the heater in the direction of propagation is in the order of millimeters and the other dimensions are in the order of microns. Considering the steady state heat conduction, equation (1) can be written as:

$$\nabla^2 T + \frac{Q_{gen}}{k} = 0 \qquad (2)$$

4.0 OPTIMUM POSITION OF THE HEATER ELECTRODE RELATIVE TO THE WAVEGUIDES CORE

In DC based TO optical switch, the difference in effective index between the two identical and parallel waveguide branches are achieved through TO coefficient of the wave guiding material by heating up one of the branches. This heating is achieved by means of a heater electrode placed alongside the branch. As the temperature is increased, the effective index contrast between the waveguides will increase, causing a gradual shift of power from one branch to another. Therefore, the position of the heater electrode, d, which maximizes the effective index difference between branches, should be optimized. Figure 2 presents effective index as a function of the distance, d.

Figure 3 shows the effective index difference between the branches for various waveguide gap, g, which is obtained by using Figure 2. It is readily seen that for every given waveguide gap, g, there is an electrode position that maximizes the index contrast. As a rule of thumb, it can be expressed that for the given geometry, this position is on average at d = 4 µm from the heated core.

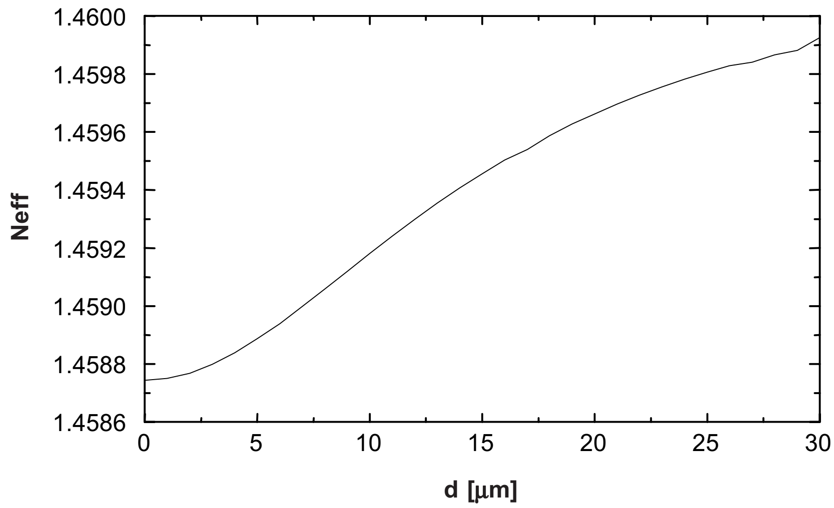

Figure 2 Effective index as a function of electrode heater position, d (@ ΔT = 30°C)

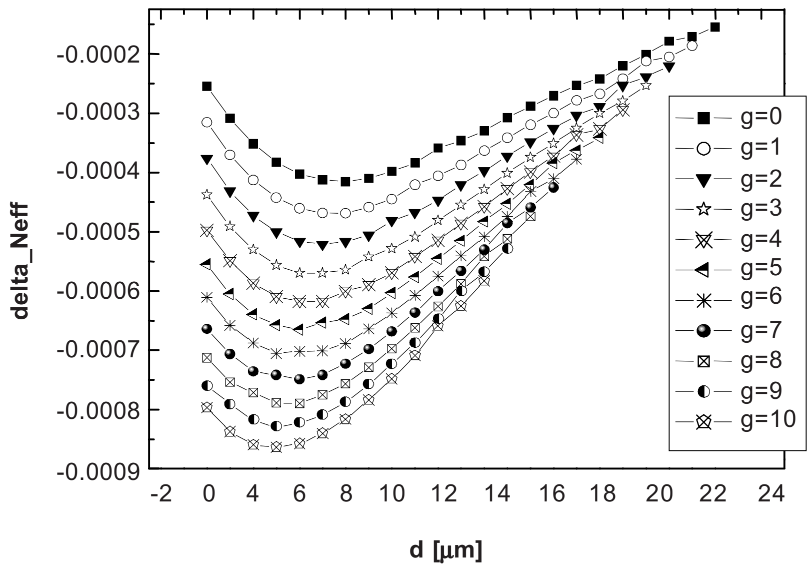

Figure 3 Difference in effective indices between branches for various waveguide gap, g

5.0 COUPLING LENGTH, LC

Figure 4 shows a schematic diagram of the directional coupler. The plane structure consists of two symmetric waveguides that are close together but separated by waveguide spacing of g. The bend waveguides with curvature of radius, R_c, connected to both the input and output port to form the directional coupler.

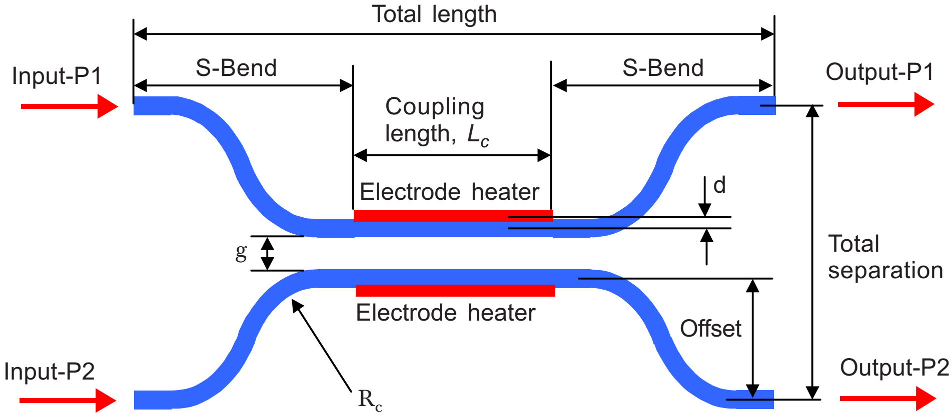

Figure 4 A schematic diagram of the directional coupler switch

Near the end of the two symmetric waveguides, where all the switching have occurred, the transferred power has to be prevented from coupling back to the other output channel. We therefore, investigate the coupling length of two identical parallel waveguide branches in the absence of a thermal field. Under these conditions, the two channels have identical propagation constants and 100% of power will transfer from one channel to the other. This will occur at a distance which equals to an integer times the coupling length, given by [8].

$$L_c = \frac{\lambda}{2\left(N_{sym} - N_{asym}\right)} \tag{3}$$

where N_{sym} and N_{asym} are the effective indices of the two lowest order system modes referred as symmetric and asymmetric modes respectively, and λ is the optical wavelength in free space.

The switch may have so many variations in the device fabrication process. Those variations could be the waveguide dimension (w × t), waveguide spacing, g, and effective index of the waveguides, etc. These variations will affect the coupling length and the switching characteristics of the switch. Thus, the following calculations are needed to know how much tolerance the switch has. As the calculation results, we found out that the coupling length could change for 200 μm, as waveguide dimension (w × t), waveguide spacing, g, and the effective index change. Therefore, we conclude that for the fabrication process, the coupling length tolerance of 200 μm can be adopted.

For the coupling length tolerance of 200 μm, the coupling length of the switch should be designed of about 50 μm spacing in a mask layout.

A) Coupling length variations as a function of waveguide dimension (w × t)

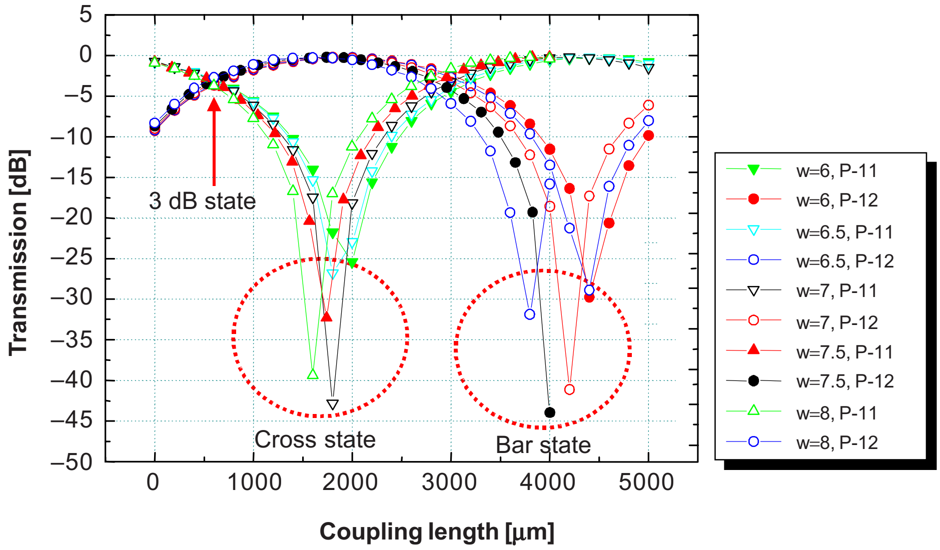

Figure 5 Coupling length as a function of various waveguide dimension

B) Coupling length variations as a function of waveguide gap, g, (with w × t = 7×7 μm^2)

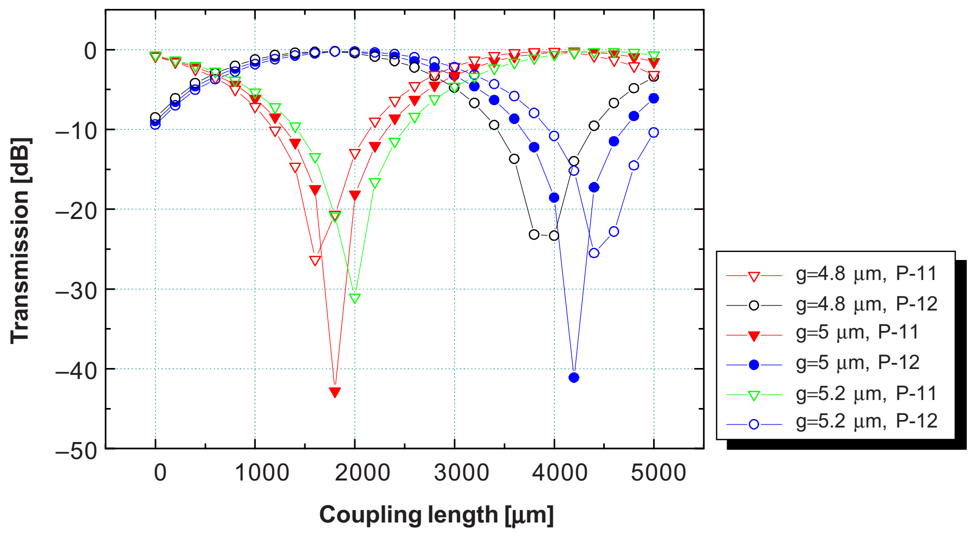

Figure 6 Coupling length as a function of various waveguide spacing, g

C) Coupling length variations as a function of effective index (with w × t = 7×7 μm^2)

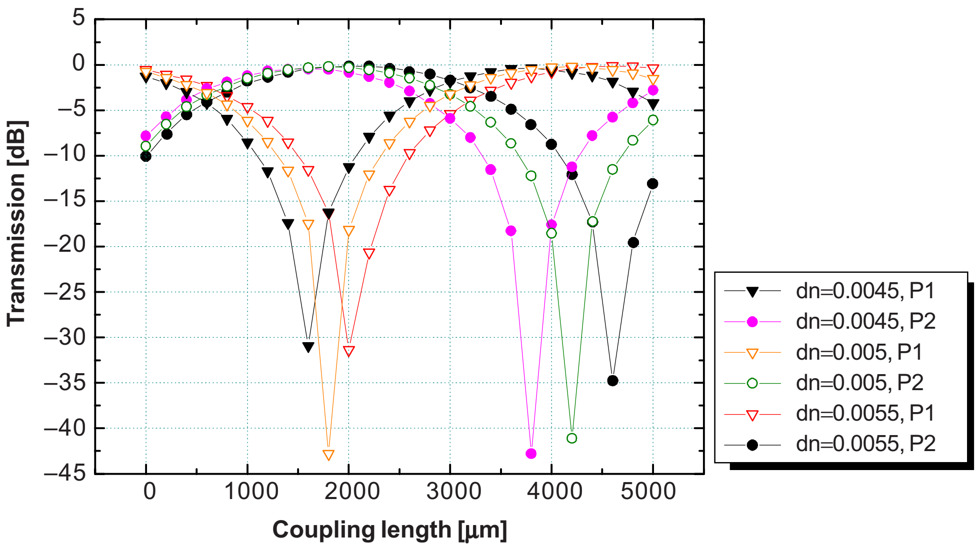

Figure 7 Coupling length as a function of various effective index contrast between the waveguides

6.0 SWITCHING CHARACTERISTICS

The crosstalks of the cross state and 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

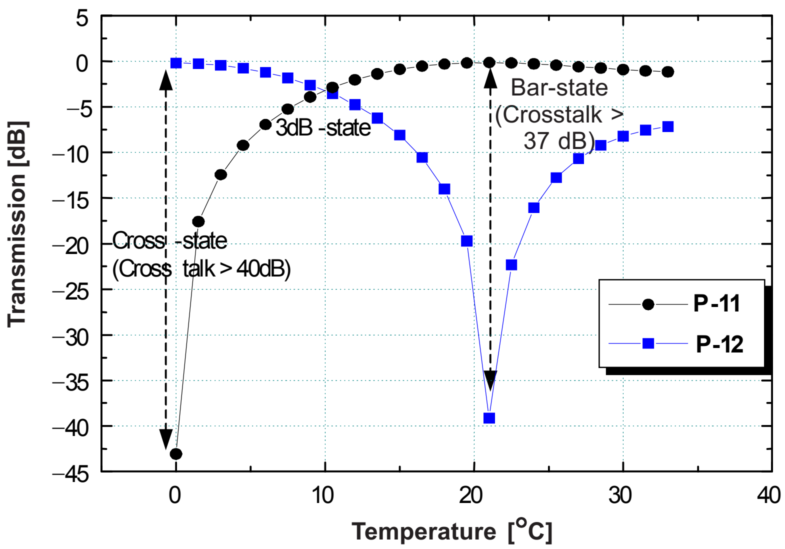

Figure 8 Switching characteristics as a function of temperature in °C

and bar state mean the light is coupled from input port P1 to output port P2, and from input port P1 to output port P1, respectively. With the optimization results obtained from the previous section, the switching characteristic is as shown in Figure 8.

7.0 CONCLUSIONS

The design of 2×2 polymer based directional coupler TO optical switch with buried square core waveguide structure of 7 μm × 7 μm had been demonstrated. Prometheus had been used to design and optimize a directional coupler based TO optical switch by varying a limited number of design parameters. An expected low power consumption switch, having a coupling length of approximately 1.85 mm and with the total length of 8.5 mm, resulted as the optimum design parameters of the device in this study. At a wavelength of 1550 nm with the index contrast of 0.005 between the wave guiding layer and the cladding layer, the crosstalk level of –40 dB and –37 dB for the cross state and the bar state of TO switch can be achieved respectively.

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