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An Asymmetrical Directional Coupler Switch with Switching Operation-Induced SOI Platform, Insertion Loss and Extinction Ratio-Enhanced Sections

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Abstract: *A novel design of slab structured asymmetrical optical directional coupler switch with S-bend waveguides on silicon-on-insulator (SOI) platform has been designed by using R-Soft CAD tool. Beam propagation method is used for light propagation analysis. The simulation results of asymmetrical optical directional coupler switches are reported. We found that the asymmetrical directional coupler switch has lower insertion losses and higher extinction ratios with waveguide parameters such as, wavelength, waveguide gap, and index differences. Simulation results designate that the switching efficiency for TE and TM modes can reached both TE and TM modes, with extinction ratio about 3dB when the waveguide gap is 3.5μm for both the polarization modes and insertion loss is 13dB with same waveguide gap in TE mode and 16dB in TM mode at 1550nm wavelength.*

Keywords: *Beam propagation method, Insertion loss, Photonic integrated circuits, extinction ratio, optical switch, optical directional coupler, silicon-on-insulator (SOI).*

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I. Introduction

An optical switch is one of the key components in optical networks for optical switch phenomenon for routing, switching, protections switching, cross connection, add-drop multiplexing, optical modulator, and ring resonator [1]. SOI based waveguides on silicon play a key role due to superior performance such as low propagation loss, high extinction ratio, better scalability, and low waveguide coupling loss [2-3]. Directional couplers have been usefully employed in the design of all optical integrated circuits including optical switches/modulators [4].

In this paper, we have shown how the asymmetrical directional coupler switch extinction ratios and propagation losses could improve the polarization dependent modes such as TE and TM polarization modes with coupling parameters such as wavelength, waveguide gap, and index difference between the core and cladding of the device, which consists of one input and eight outputs. In this article, we propose a new design of asymmetrical directional coupler switch on SOI platform by using an R-Soft CAD tool and simulated using beam propagation method at 1550nm wavelength.

II. Design of optical switch

The schematic diagram of the proposed design of asymmetrical optical directional coupler switch is shown in Fig.1. It consists of two waveguides that are straight and S-bend waveguides on silicon on insulator (SOI) substrate with slab structure. And also it contains 7 asymmetrical optical directional couplers (ASODCs). ASODC-1 has 1160μm, ASODC-2, 3 has 1120μm, and remaining all ASODC-4, 5, 6, 7 has the same 1120μm length with total length of designed optical switch is 3.4mm. The input power is 1μW, width is 5μm, height of the device is 5μm, with step index profile, offset S-bend waveguides, free space wavelength is 1.55μm, and waveguide separation is 3.5μm, under TE and TM polarization modes, which are basic parameters of the asymmetrical optical directional coupler switch.

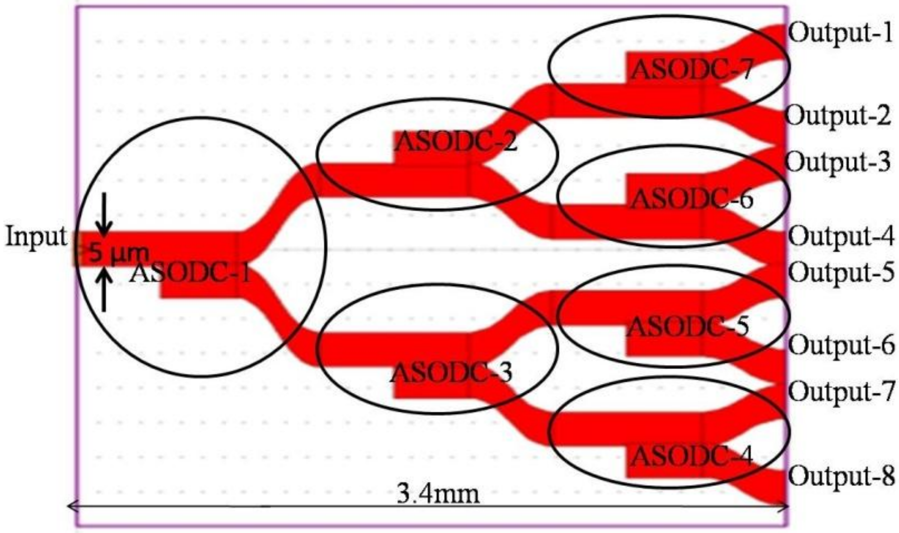

Fig.1. Schematic diagram of optical switch by asymmetrical optical directional coupler (ASODC) with 8-outputs

III. BPM simulation results

The beam propagation method (BPM) is the most powerful method to investigate linear and nonlinear lightwave propagation phenomena in axially varying waveguides. Recently, beam propagation method (BPM) is the most widely used propagation technique for modeling integrated and fiber optic photonic devices. The BPM is essentially a particular approach for approximating the exact wave equation for monochromatic waves, and solving the resulting equations numerically. The basic approach is illustrated by formulating the problem under the restrictions of a scalar field (i.e. neglecting polarization effects) and paraxiality (i.e. propagation restricted to a narrow range of angles). The scalar field assumption allows the wave equation to be written in the form of the well-known Helmholtz equation for monochromatic waves.

$$\frac{\partial^2\Phi}{\partial x^2}+\frac{\partial^2\Phi}{\partial y^2}+\frac{\partial^2\Phi}{\partial z^2}+k(x,y,z)^2\Phi = 0 \qquad (1)$$

Here the scalar electric field has been written as $E(x,y,z,t) = \Phi(x,y,z)e^{-iwt}$ and the notation $k(x,y,z,t) = k_{\circ} n(x,y,z)$ has been introduced for the spatially dependent wave number, with $k_{\circ} = {}^{2\pi}/_{\lambda}$ being the wave number in free space. The geometry of the problem is defined entirely by the refractive index distribution n (x, y, z). Assuming that axis is predominantly along the z-direction, it is beneficial to factor the rapid phase variation out of the problem by introducing a so-called slowly varying field u along the direction z

$$\Phi(x,y,z) = u(x,y,z)e^{i\bar{k}z} \qquad (2)$$

$\bar{k}$ is a constant number to be chosen to represent the average phase variation of the field Φ. Then, introducing the expression into the Helmholtz equation yields the following equation for the slowly varying field

$$\frac{\partial^2 u}{\partial z^2}+2i\bar{k}\frac{\partial u}{\partial z}+\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\left(k^2-\bar{k}^2\right)u = 0 \qquad (3)$$

$$\frac{\partial u}{\partial z} = \frac{i}{2\bar{k}}\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\left(k^2-\bar{k}^2\right)u\right) \qquad (4)$$

This is the basic BPM equation in three dimensions (3D), simplification to two dimensions (2D) is obtained by omitting any dependence on y [5-6].

Simulation has been carried out by BPM tool by considering the propagation of an optical signal of fundamental TE and TM modes through the asymmetrical optical directional coupler switch. Here we depicted some of the simulation profiles, in Fig. 2 shows the launching field of the asymmetrical optical directional coupler switch with contour approach with various waveguide gaps. Fig. 3 shows the light propagation direction of the asymmetrical optical directional coupler switch with various index differences. Fig.4 shows the propagation of amplitude view throughout the asymmetrical optical directional coupler switch, from this profile we can confirm the light propagation through all eight ports. Fig. 5 shows the 3D view of simulation of asymmetrical optical directional coupler switch with 5μm width, 1550nm wavelength, 3.4mm length.

Simulation results enable the extinction ratio (ER) and coupling ratio (R) which is used to calculate these values by using the following formulae.

$$ER_{TM} = 10\log_{10}\frac{P_{TM}}{P_{TE}}\ dB \qquad (5)$$

$$ER_{TE} = 10\log_{10}\frac{P_{TE}}{P_{TM}}\ dB \qquad (6)$$

$$R = \frac{P_2}{P_1} = \frac{\text{Output Power at coupled waveguide}}{\text{Input Power}} \qquad (7)$$

Where ER is the Extinction ratio (dB) of an asymmetrical optical directional coupler switch, is defined as the ratio between the transmitted powers of two polarizations at the same output port. P_{TM} is the transmitted power at TM-mode, P_{TE} is the transmitted power at TE-mode [7].

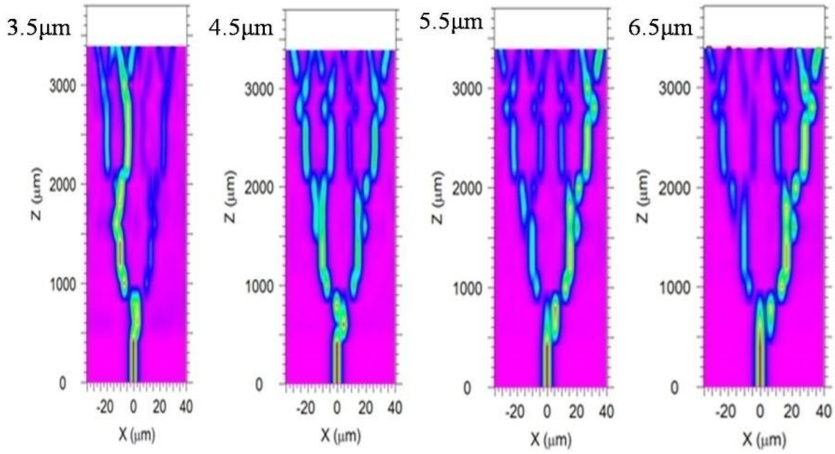

Fig.2. the propagation of light with various waveguide gaps

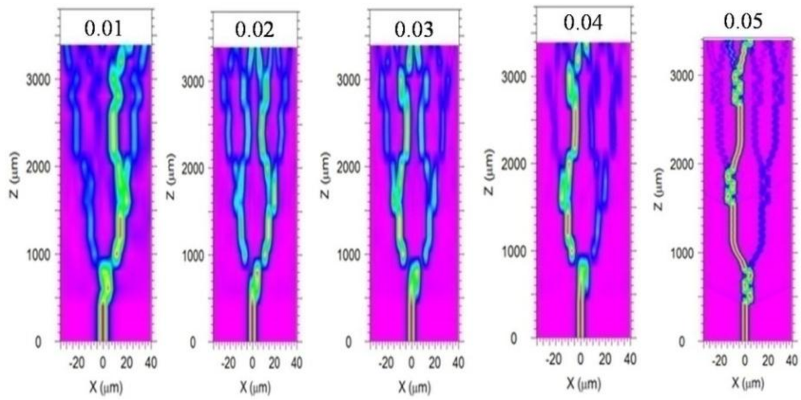

Fig.3. the propagation of light with various index differences

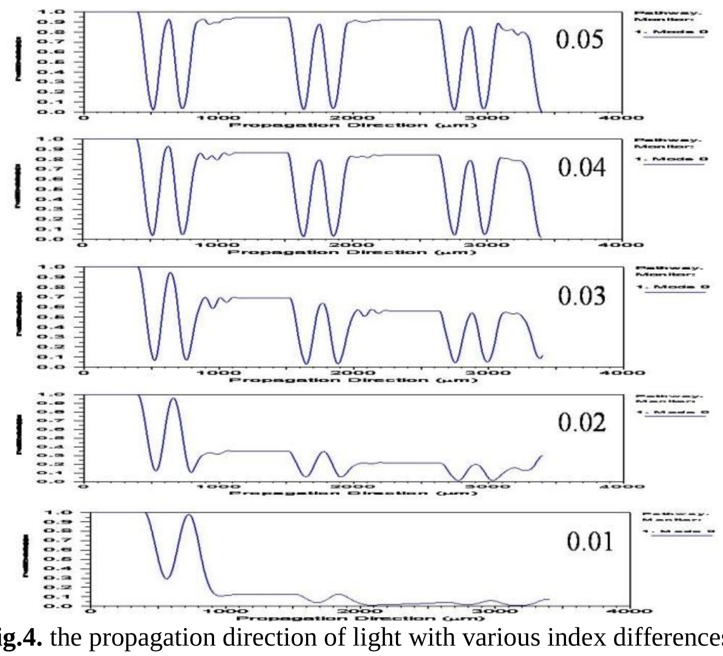

Fig.4. the propagation direction of light with various index differences

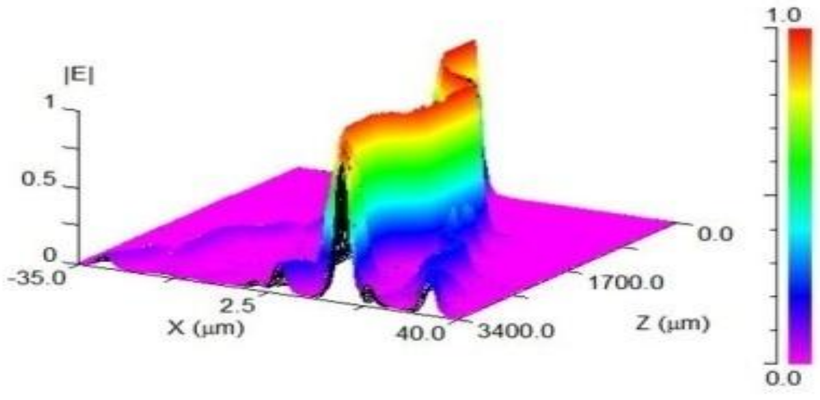

Fig.5. view of 3D simulation optical switch profile

IV. Results and Discussion

Figure. 6 shows the refractive index differences between the core and cladding of the optical switch with insertion loss in TE mode. it clearly reveals that the change in index difference enables the phase change leads to the interference of constructive and destructive based on paths of the light. Change in polarization light travels through the waveguide interacting with the medium and is proportional to the intensity of the field. We observed insertion loss with index difference from 0.01 to 0.05 between the core and cladding of the optical switch. The port-5 (coupled) has minimum insertion loss 0.90dB in TE mode at 0.05 index difference. The port-5 (coupled) has maximum insertion loss of 16dB for TE-mode therefore at 0.05 index difference switching phenomenon was observed. In TM mode, the port-5 (coupled) has minimum insertion loss 0.45dB at 0.05 index differences and maximum insertion loss 13dB at the same index differences switching phenomenon was observed which is shown in Fig.3 simulation profile. The extinction ratio was observed 6dB in TE and TM modes at 0.05 index differences with port-6, which is shown in Figure.7.

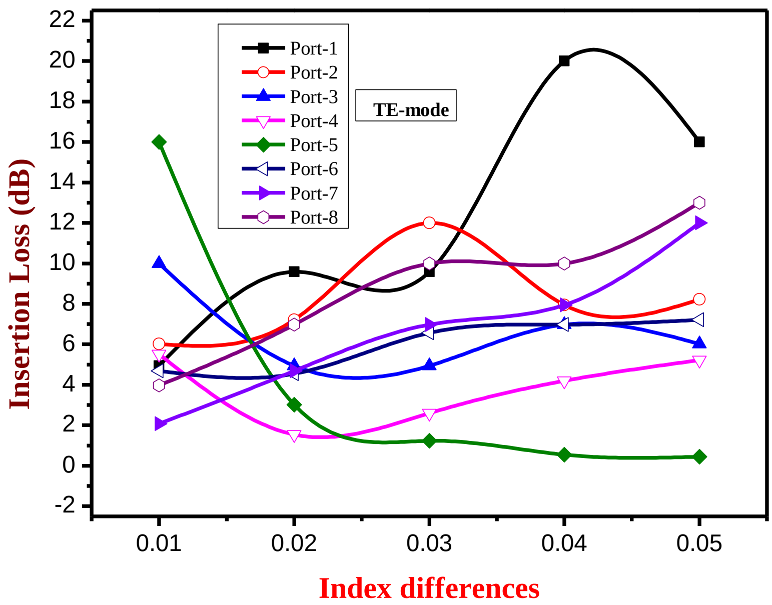

Fig.6 Insertion loss with index differences (TE-mode)

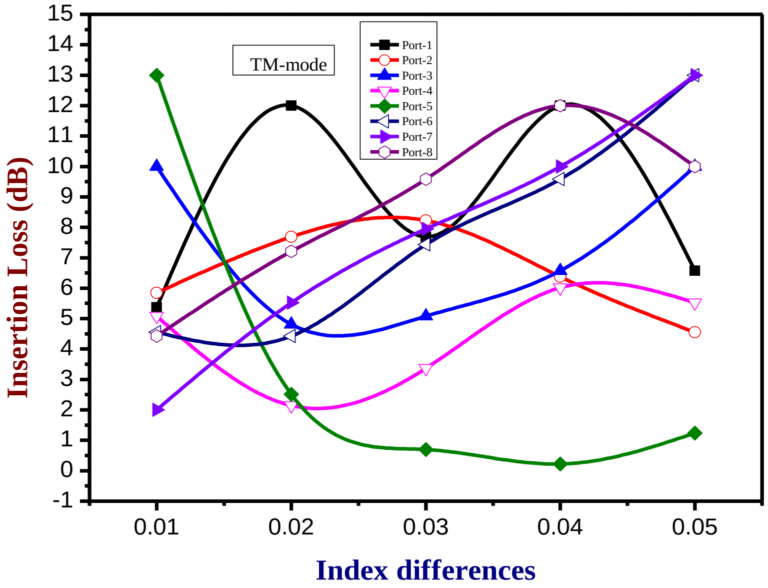

Fig. 7 Insertion loss with index differences (TM-mode)

Figure 8 shows the insertion loss as function of the telecommunication wavelength region. We found that the wavelength 1550nm gave less insertion loss 1.87dB and high extinction ratio 2.63dB at port-4 in TE mode. The port-5 (coupled) has maximum insertion loss of 16dB in both polarization modes. The switching phenomenon was observed at port-5 because of the coupling of the waveguide at 1700nm wavelength, which is shown in Figure.9.

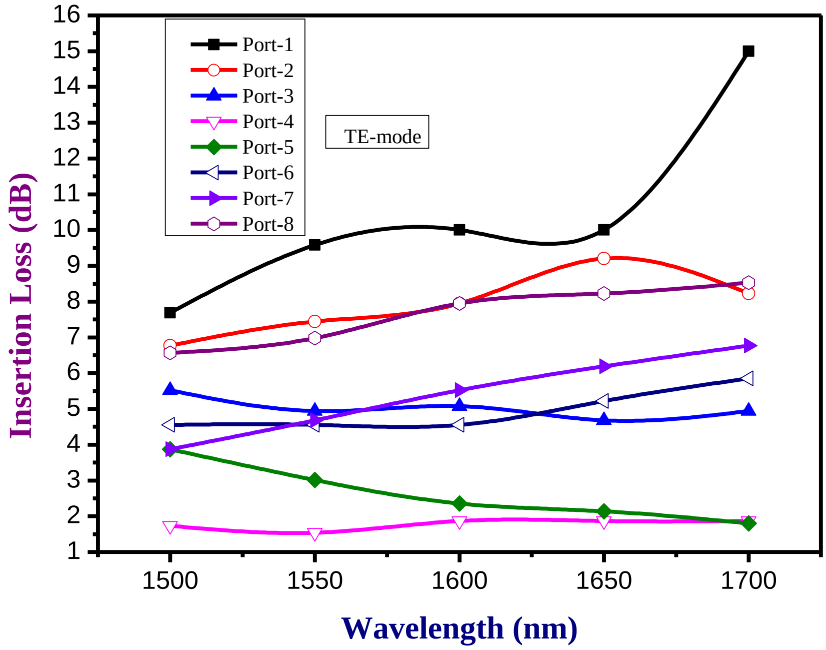

Fig. 8 Insertion loss with wavelengths (TE-mode)

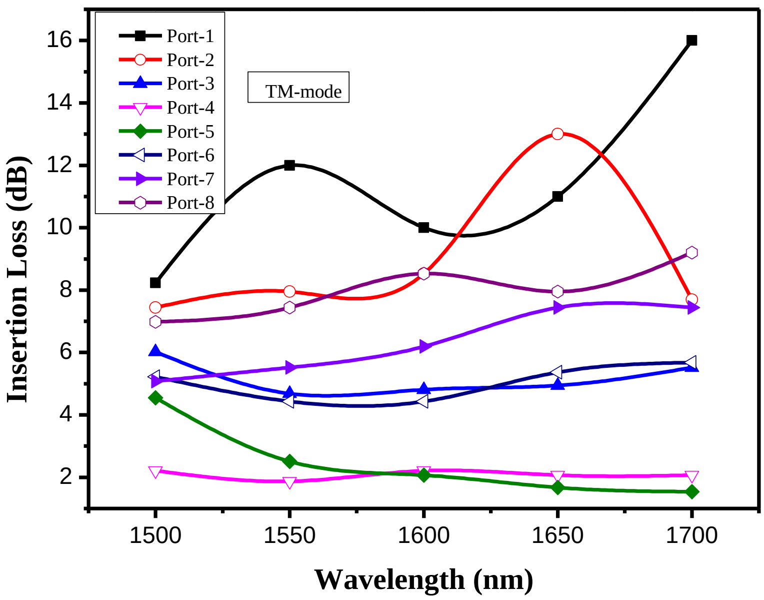

Fig. 9 Insertion loss with wavelengths (TM-mode)

Figure 10 shows the insertion loss as function of the waveguide gap in TE mode. We found that the waveguide gap 3.5µm, 1550nm wavelength gave maximum insertion loss 13dB and high extinction ratio 3dB at port-8 in TE mode. The switching phenomena occurred at 4.5µm waveguide gap with port-4 because of the effective index of the different ports. Insertion loss is the amount of power loss in the signal in coupling to the output port is special criteria for estimating the switching phenomena.

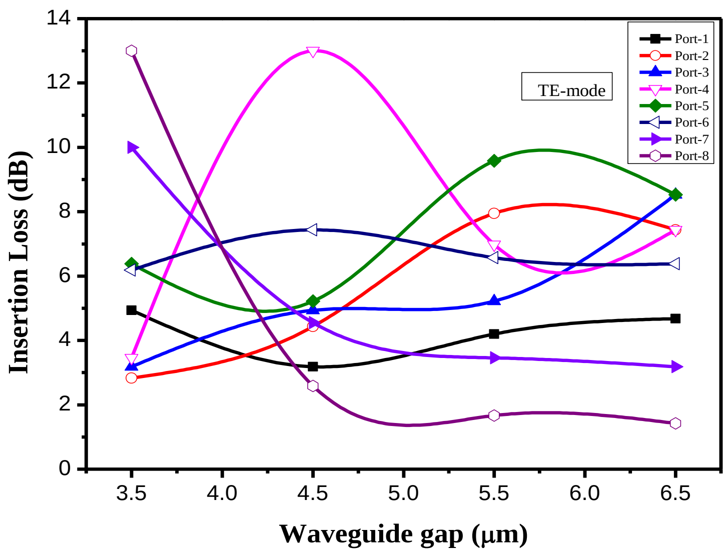

Fig. 10 Insertion loss with waveguide gaps (TE-mode)

Figure 11 shows the insertion loss as function of the waveguide gap in TM mode. We found that the waveguide gap 3.5µm, 1550nm wavelength gave maximum insertion loss 16dB and high extinction ratio 3dB at port-8 in TM mode.

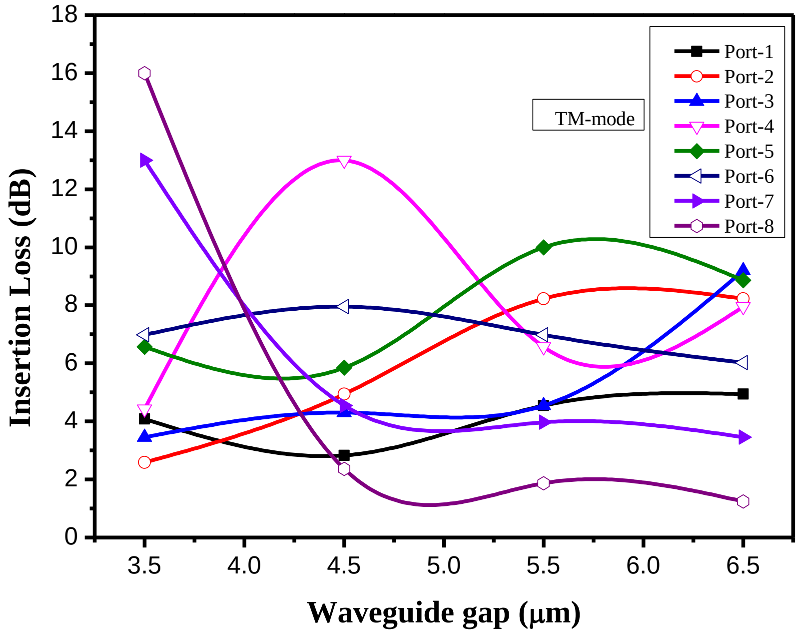

Fig. 11 Insertion loss with waveguide gaps (TM-mode)

V. Conclusions

In summary, we proposed an asymmetrical optical directional coupler switch exhibiting switching phenomena for changing waveguide gap between two waveguides of the coupler, wavelength, and index differences. We found from our BPM simulation results extinction ratio can be increased with waveguide parameter such as wavelength, C, L, U-band regions wavelength, waveguide gap, and index differences, insertion loss can be reduced with waveguide gap, wavelength, and index differences. These asymmetrical optical directional coupler switches can be developed as key components for integrated optical communication devices and useful for build up functional devices, optical clock distribution or arranged as I/O ports on SOI ULSI devices. This work supplies a capable solution for all optical directional couplers on a SOI chip.

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