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DESIGN AND ANALYSIS OF OPTICAL PARITY GENERATOR AND CHECKER USING MACH-ZEHNDER MODULATORS

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Abstract:
All optical devices can support high data rate in a communication system This paper contains discussion of electro-optic effect based MZI structure and its efficient application to construct parity generator and checker with sequence detector that detects the 3 bit sequence from the main bit stream. Titanium in-diffused lithium niobate profile of MZI through computer simulation has been used for this purpose and also to improve the performance of the switch on its crosstalk, power imbalance, extinction ratio and transition losses. The operations of the proposed device are analysed and verified using OptiBPM software.

Index Terms: Electro-optic devices, Optical logic devices, Lithium niobite, Waveguides, Modulators.

I. INTRODUCTION

Today the demand for high bandwidth has rapidly increased to obtain the speed limit of electronic devices. The general purpose of all-optical signal processing is still on the horizon. to develop the performances of basic and complex digital devices. Optical logic device is a better alternative to process the information with high speed as, it is a timely interest of many to realize various logic gates optically, in particularly XOR and XNOR. Because, these two optical logic devices provide way for realization of number of other functions such as equality detectors, parity generators and code converters also. The ultrafast all-optical XOR gate using two types of semiconductor optical amplifier-based mech-zehnder interferometer configuration (SOA-MZI) was analyzed and key parameters were optimized through mathematical simulations by Zhang et al. [1]. The electro-optic effect based optical switching phenomena in MZI was efficiently considered and it was broadly investigated to implement the optical full adder and full subtractor by Ajay Kumar et al. [2]. In digital communication, parity generator and checker had been used to retrieve the lost information. But, realizing them optically was not possible for many years. Now, the optical communication era also tends to focus towards secured communication of information without any loss. Electro optic effect is a change in refractive index of a material for a variation of intensity of applied electric field. This effect has speed less than 1ns [3]. Mach Zehnder modulator (MZM) plays major role in fiber optic network and it had been designed with various materials like LiNbO3 [4], semiconductors [5], and polymers [6] etc. With the help of this design, Boolean function generators [2], switches [7], logical gates [8], encoders [9], and routers [10], had been realized by computer simulation. Compared to its digital counterpart, optical parity devices provide less cross talk, efficient transmission of larger data over longer distance and wide wavelength range. In this paper, we have implemented optical parity device with the help of MZI through Beam propagation method (BPM) by computer simulation. In figure 1 the different classification of optical logical gate.

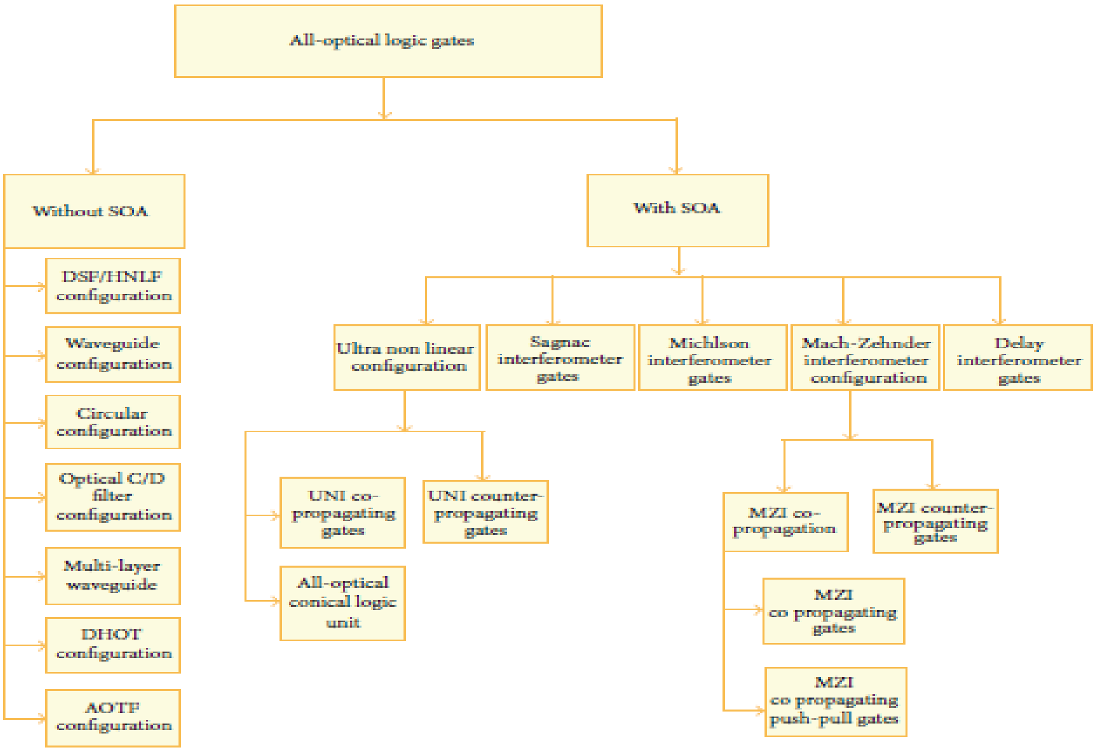

Fig.1.Different classification of optical logical gate.

II. DESIGN

MZI switch is made on a z-cut wafer of LiNbO3 and is surrounded by air cladding. MZI switch is designed with 33 mm length of LiNbO3 wafer with 10 µm of thickness and 0.1mm of width. As-designed single bit parity device is shown in Fig.2. Introducing electrode to this MZI forms a MZM. This MZM is a combination of 3dB coupler (Splitter and Combiner), delay lines and electrodes.

In order to achieve optic switching, Titanium indiffusion with LiNbO3 serves the principle of perfect electro-optic behavior. The indiffusion process is done by insertion of a Ti-strip of fixed thickness and width on LiNbO3 substrate followed by heating. After this process, the titanium ions penetrate into the host substrate and form a graded index waveguide. The above concepts of Ti-indiffusion process within LiNbO3 substrate are mainly taken from Technical Background and Tutorial [11]. The bell-shaped refractive index can be characterized by diffusion lengths or, as an alternative, by diffusion constants, diffusion temperature and a diffusion temperature coefficient for their distributions of graded waveguide in lateral and in-depth directions. Ti-LiNbO3 MZI better performances compared to other doping materials into LiNbO3 and the effective operating optimum voltage of the electrode is chosen as 6.75 V [12]. The central electrode is energized to achieve the required switching function and realize the parity bit generation. The initial device parameters such as wafer properties, electrode specification and Ti-LiNbO3 channel profile specification.

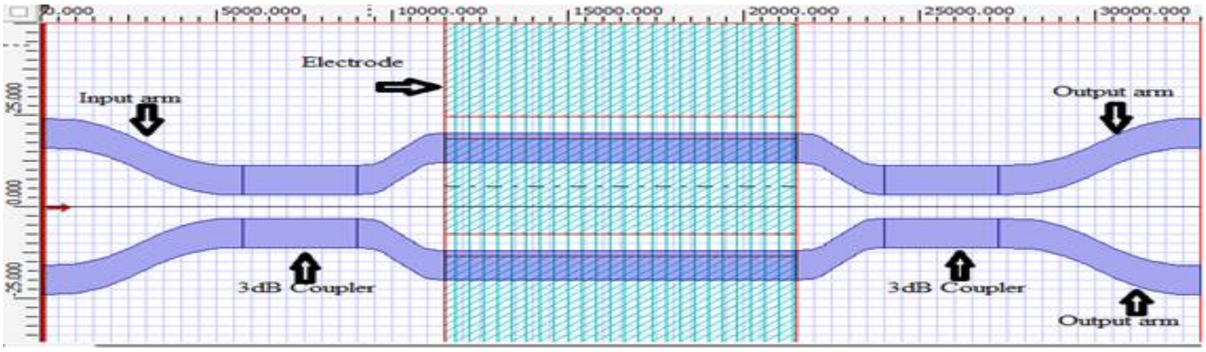

Fig.2.Parity generator waveguide structure for 1-bit sequence

The number of MZIs in the parity generator depends upon the number of bits. The MZIs are concatenated and the last MZM in this connection generates the required output parity bit. In figure 2 shown that the parity generator waveguide structure for 1-bit sequence The bit sequence (Odd (or) Even) decides the generated parity bit of lower arm and upper arm of the MZM. That is, for an even sequence, the last MZM output of lower arm is even parity generator. Likewise, for an odd sequence, the last MZM lower arm output is odd parity generator. A three-bit parity generator is obtained by a cascade connection of three MZIs in Figure 3 shown parity generator waveguide structure for 3-bit sequence and the electrodes have been placed at the middle of the longer linear waveguides to control the output signal. In this design, right end of the lower arm is output of odd parity generator and the upper arm is output of an even parity generator. In addition to this realization of parity generator with three MZIs parity checker function by adding one more stage of MZI to the parity generator and the figure 4 shown that Parity Checker waveguide structure for 3 bit sequence .

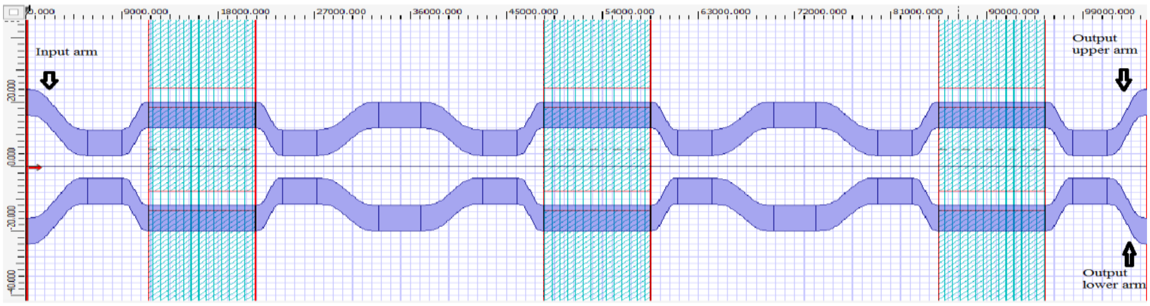

Fig. 3. parity generator waveguide structure for 3-bit sequence

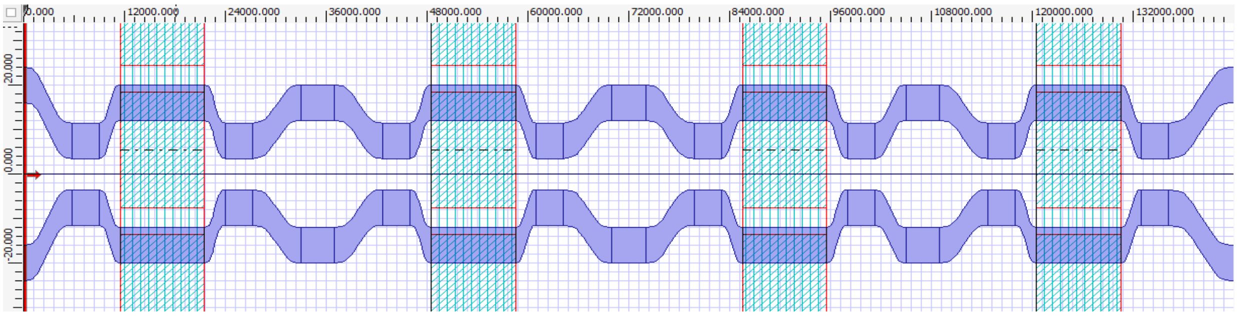

Fig. 4. Parity Checker waveguide structure for 3 bit sequence

III. SIMULATION USING OPTISYSTEM

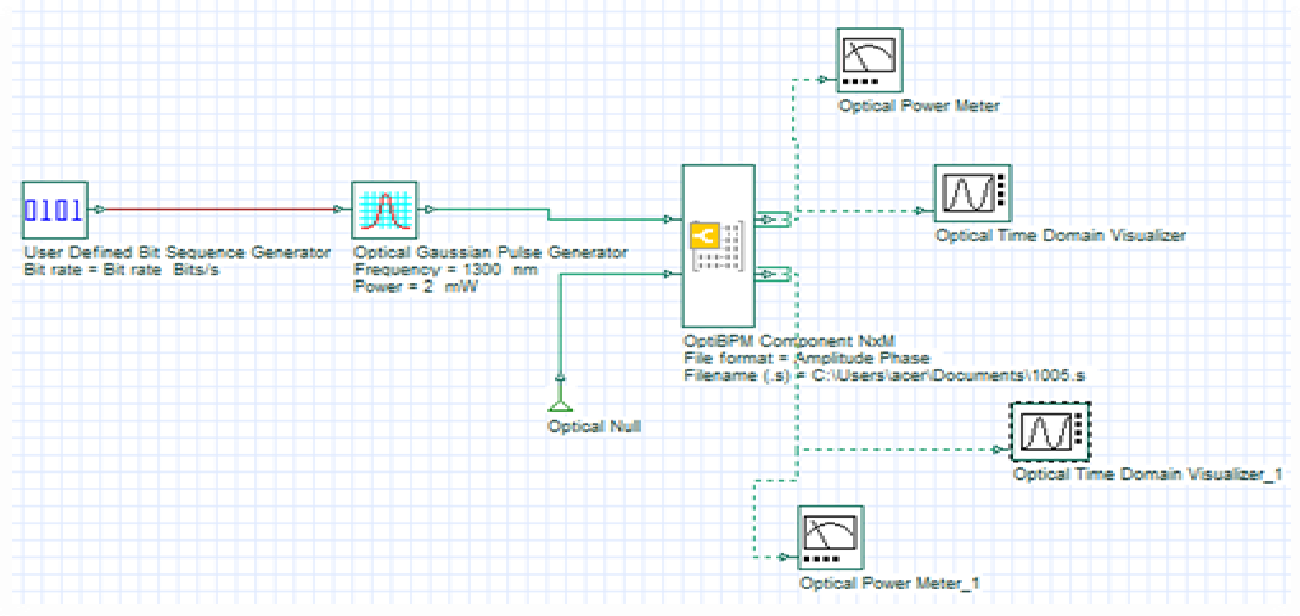

Fig.5: Parity generator system layout in optisystem

The proposed model of Parity generator in OptiBPM simulation software is tested for its genuine operation in the optical networks using OptiSystem simulation software. The system setup for the parity generator with OptiSystem is as shown in Fig.5. Here, optical gaussian pulse was given as input for the parity. The given input sequence of X, Y, and Z is 0, 0, and 1 respectively. The output 1 was received at the upper arm of the parity device (Pe) and at the lower arm of the parity device (Po) it was 0.

OptiBPM simulation software is used to analyze and demonstrate the proposed structure. OptiBPM essentially works on the principle of Finite Difference Beam Propagation method (FD-BPM) and provides the whole information of the optical waveguide depending upon its refractive index profile, structure, and material used for the construction of the optical waveguide. An optical signal can be followed at any point as it propagates along a guiding structure of designed integrated optics. BPM allows computer-simulated scrutiny of the light field distribution where the radiation and the guided field can be examined concurrently. The MZIs based parity device is analyzed by paraxial BPM solver with finite difference engine scheme parameter of 0.5 and using transparent boundary condition method. The global data is introduced as refractive index MODAL and TM polarized test signals from wavelength 1.3 µm to 1.65 µm is analyzed.

Sequence number	Electrode Voltage	Upper arm (Even parity)	Lower arm (Odd parity)	Transmitted Sequence (Even parity)	Transmitted Sequence (Odd parity)
1	0	0	1	00	01
2	1	1	0	11	10

Table 1. Transmitted Sequence for Single bit input

sequence	Voltage in 3 bit	Even parity	Odd parity	Transmitted bit in even parity	Transmitted bit in odd parity
1	000	0	1	0000	0001
2	001	1	0	0011	0010
3	010	1	0	0101	0100
4	011	0	1	0110	0111
5	100	1	0	1001	1000
6	101	0	1	1010	1011
7	110	0	1	1100	1101
8	111	1	0	1111	1110

Table 2. Transmitted Sequence for 3-bit input

In this design we consider the electrode voltage as the input bits and it controls the optical signal which passes through the waveguide structure to the receiving end. The control signals X, Y and Z are the voltage applied at the middle electrode of first, second and third MZIs respectively. When an optical signal is applied at the input of MZI, as per the working principle of the MZI the light output is obtained at the lower arm of the output of MZI when no electric field is applied across the electrodes. But, when an electric field is applied across the electrodes, then the Ti-LiNbO3 channel experiences a change in its refractive index in one of the arms which makes the output signal to get shifted to the upper arm. The continuous wave optical signal is applied at the input port of MZI-1. Here, no signal is provided at the second input terminal of MZI-1 and finally output of MZI-3 is nothing but generated parity bit of given sequence. Here we use odd parity bit sequence and hence the lower arm of the last waveguide generates the odd parity and upper arm of the waveguide generates even parity. The optical field intensity distribution of Parity Generator and checker for the two different input sequences. The output transmitted sequence (along with parity bit P) for the single and three-bit input sequence are tabulated in table 1 and 2 respectively.

3.1 PARITY GENERATOR

When X = logic 0, Y = logic 0 and Z= logic 0, where all the electrode voltages (X, Y, Z) are in the OFF state, the optical signal applied to the input of MZI. In selection of output port decides the transmitted bit sequence and the type of parity generator. In figure. 6 shows that the of Parity Generator and checker for the two different input sequences

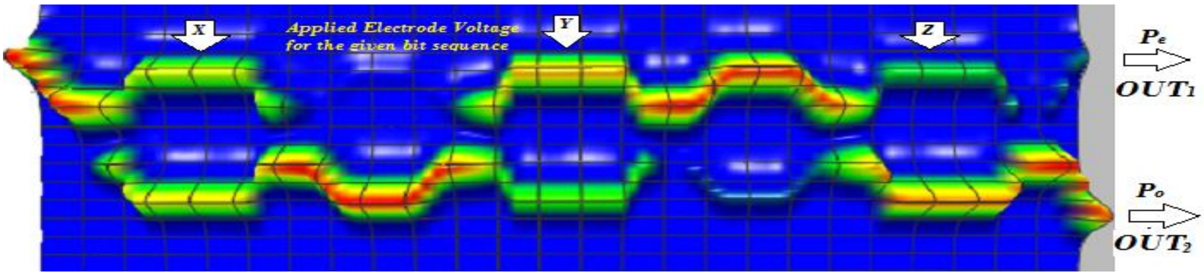

Fig.6: Optical parity generator output for the sequence (000)

3.2 PARITY CHECKER

In Parity checker function.in figure.7 If the transmitted sequence is X = logic 1, Y = logic 0, Z = logic 0 and P= logic 1 the electrode voltages for X and Y are in the OFF state, and the electrode voltages for Z and P and the Checker output is enabled at even parity.

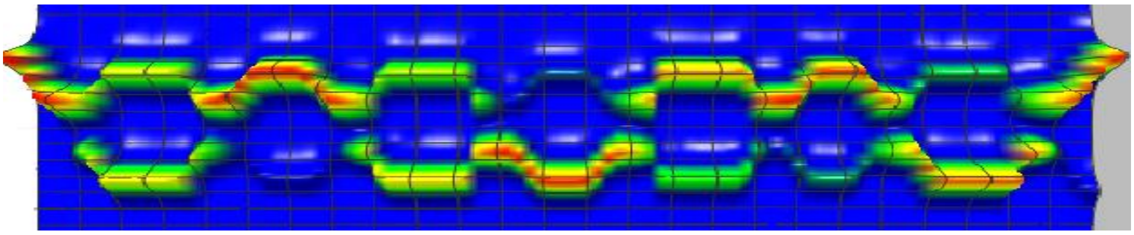

Fig. 7.Optical parity checker field intensity for the sequence (100)

iv. ANALYSIS OF SOME IMPORTANT FACTORS INFLUENCING THE PERFORMANCES

Optical power imbalance (PI) is defined as the ratio of power in cross state output waveguide, relative to the power in the bar state output waveguide. The power imbalance should be very low in order to maintain very low crosstalk in optical waveguides. The power imbalance at the output splitter of MZI can be obtained using the equation

$$PI = 10\log\frac{X}{Y}$$

- Where, X is maximum output power at splitter and Y is minimum output power at splitter.

Extinction ratio

$$\mathbf{ER} = \frac{(\mathrm{OUT}_1 + \mathrm{OUT}_2)^2}{(\mathrm{OUT}_1 - \mathrm{OUT}_2)^2}$$

CALCULATION OF CROSS TALK

$$CT = 10\log\frac{\left(\frac{1}{P_2} - \frac{1}{Q_2}\right)^2}{\left(\frac{1}{P_2} + \frac{1}{Q_2}\right)^2}$$

Where,

$$P = \frac{1}{2\left(10PI^{10} - 1\right)}$$

$$Q = 2\left(1 - \frac{P}{2}\right)$$

The power and distance are inversely proportional The normalized output power of parity generator with respect to distance is plotted in Figure.8. If the number of input bit sequence is increased, then it will increase the number of MZIs and the respective distance of optical signal propagation. This increase in distance will limit the normalized power at the optical output. At each MZI some amount of transmission loss has occurred.

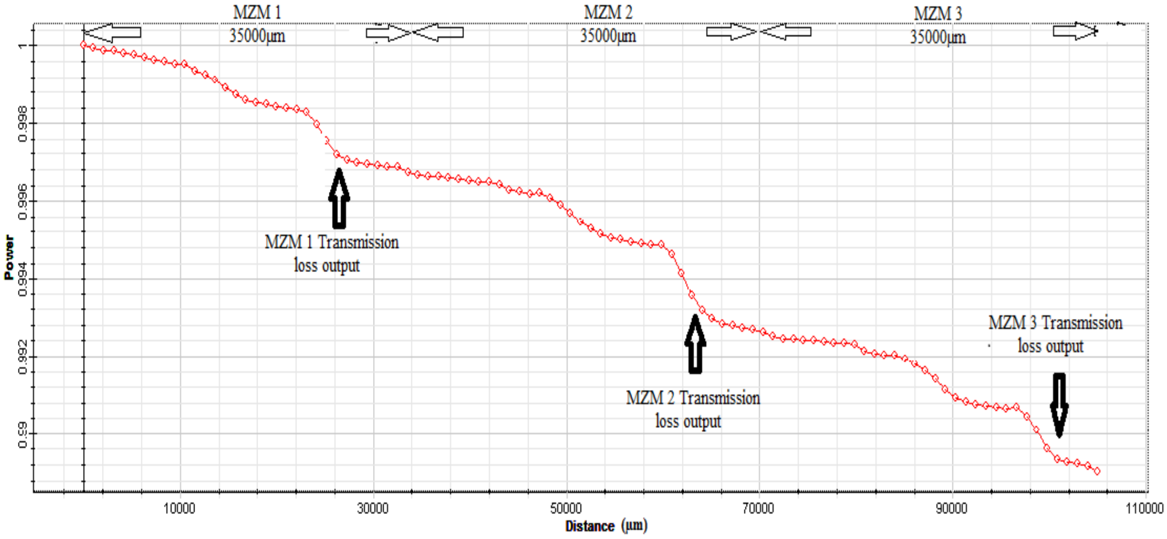

Fig.8. Distance vs. Power

In , P and Q are the power levels at the end of the MZI upper and lower arms respectively. Here, the crosstalk measurement is carried out at the MZI1 output of our proposed device Transmission loss is a metric that when light travels along a channel, its power decreases exponentially with distance. The Transmission loss versus the operational wavelength ranging from 1.3 µm to 1.65 µm. It reveals that the Transmission losses can be kept at low value by taking the value of Ti-stripe thicknesses at 0.09 µm over the wavelength range of 1.3-1.65 µm in Figure.9.

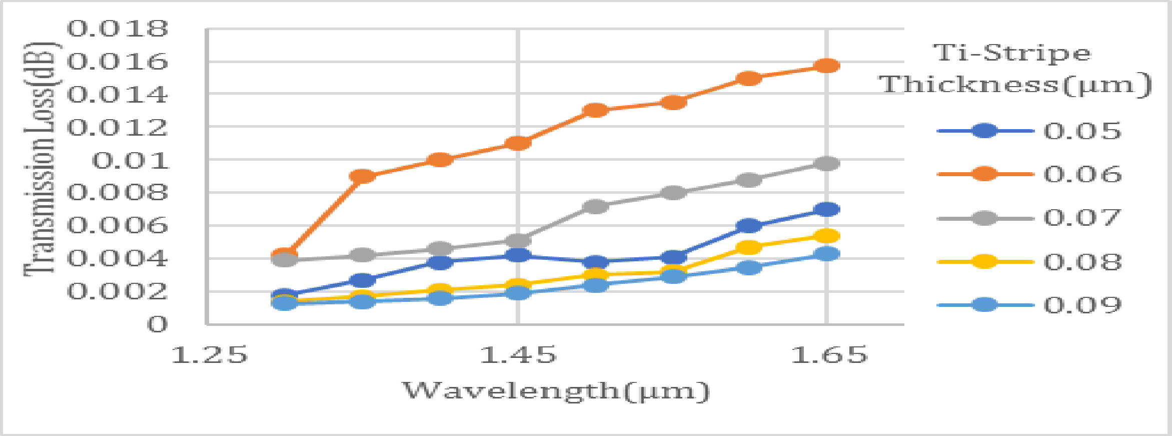

Fig. 9. Transmission loss (dB) vs. wavelength (µm) for various Ti-stripe thickness (µm)

V. CONCLUSION

We have analyzed the performance of The Mach–Zehnder interferometer based XOR gate through numerical simulations, and the optimal parameters are suitable operation condition. Several designed parameters, the optical XOR gate can be realized with high performance , and very low crosstalk of these key parameters

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