Design and Simulation of All-Optical logic Gates Using SOA-MZI

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ABSTRACT

Ultra-fast telecommunication system requires eliminating OE and EO conversion in applications such as addressing, header recognition, signal regeneration, data encoding, optical computing etc. This can be achieved only with the use of All-optical logic gates. IN this Paper mechanism of co-propagating SOA-MZI configuration along with non-linear property of Cross Phase Modulation (XPM) is opted to design OR, NOT gates using Optisystem software.

Keywords: Semiconductor Optical Amplifier (SOA), Mach-Zehnder Interferometer (MZI), Cross-Phase Modulation (XPM), All-optical gates.

1 INTRODUCTION

In today's world, a number of users of the internet increase the demand for larger bandwidth in multimedia applications with high speed in communication industries. The speed of the electronic processor increases every 18 months but with increased chip power consumption and dissipation during optoelectronic (OE) conversion. To overcome the demerits electronic processing, all-optical processing is preferred due to its larger bandwidth with low power consumption [1] and high data rate without the need for OE conversion. The basic key element of all-optical processing is all-optical logic gates which are used for header recognition, signal regeneration, addressing, data encoding [2]. All-optical gates can be classified based on fiber-based gates [3] and Semiconductor Optical Amplifier (SOA) based gates [4]. The fiber-based gate can be easily affected by external vibrations and it does not have photonic integration capability. All-optical gates are classified as with SOA and without SOA [5]. SOA based gates have been preferred to design all-optical gates due to its capability of integrating photonic components. According to the interferometric configurations, all-optical gates with SOA have been classified as Ultra Non-linear Interferometer (UNI) gates, Sagnac Interferometer gates [6], Michelson Interferometer (MI) gates [7], Mach-Zehnder Interferometer (MZI) gates and Delay Interferometer (DI) gates.

In this paper, SOA and its non-linearity, MZI, design, principle of operation, simulation steps and results of OR, NOT gate based on SOA-MZI have been discussed and a Boolean expression is also verified using OR, NOT gates.

1.1 Semiconductor Optical Amplifier:

SOA is an optical amplifier. Based on the semiconductor gain medium, the input optical signals are amplified. SOA is compact, fair amplification, good wavelength conversion, insensitive to polarization and has high non-linear property. This property of SOA is a suitable choice to design all-optical gates. The non-linearities of SOA are Self Phase Modulation (SPM), Cross-Gain Modulation (XGM), Cross-Phase Modulation (XPM), Four Wave Mixing (FWM), Cross Polarization Modulation (XPolM).When the power of the input signal changes then the gain of the SOA is also varied. This is known as SGM.When injection current is applied to SOA, electrons from the lower energy level moves to the upper energy and it is stimulated by optical signal. Then the electrons reach the lower energy level. The stimulated emission continues until the input signal travels out of SOA as amplified signals. Due to this, there is reduction in carrier density which in turn reduces the gain of SOA. This is known as XGM [8].When the probe and pump signal propagates through SOA at a time, refractive index is changed due to carrier density reduction which in turn changes the phase of the probe signal. This is known as XPM.

The SOA active region refractive index can be altered by varying the carrier density with pump signal [9] and the rate of change of carrier density in SOA is given as [10],

$$\frac{dN}{dt} = \frac{J}{ed} - R(N) - v_g \cdot g(N)N_{ph} \quad (1)$$

where, N is the carrier density, N_{ph} is the photon density, J is the density of the injection current, v_g is the group velocity of light, R (N) is the recombination rate, E is the charge of the electron, d is the thickness of the active layer, g (N) is the material gain coefficient which depends on the light intensity and specific band structure of the semiconductor used.

The gain coefficient of SOA is given as,

$$g(N) = \frac{\Gamma \cdot \sigma_g}{V}(N - N_0) \quad (2)$$

$$g(N) = \frac{g_0}{1+\frac{I}{I_{sat}}} \quad (3)$$

where, g_0 is the small signal gain, I is the intensity of light, I_{sat} is the saturated light intensity, Γ is the confinement factor, σ_g is the differential gain, V is the volume of the active region.

$$g_0 = \frac{\Gamma \cdot \sigma_g}{V}(\frac{J}{ed} \cdot \tau - N_0) \quad (4)$$

The saturated light intensity is given as,

$$I_{sat} = \frac{hv \cdot L \cdot w}{\Gamma^2 \cdot \sigma_g \cdot \tau_s} \quad (5)$$

where, $N_0$is the carrier density for transparency, h is the Planck's constant, v is the frequency, L is the length of the amplifier, w is the width of the amplifier, τ is the carrier life time.

The total gain g per unit length for SOA is shown as [11],

$$g = \Gamma \cdot g(N) - \alpha \quad (6)$$

where, α is the overall loss coefficient per unit length.

The net gain of the entire length of the active region of SOA is given by,

$$G_s = e^{g \cdot L} = e(\Gamma \cdot \frac{g_0}{I} + \frac{I}{I_{sat}} - \alpha)L \quad (7)$$

1.2. Mach-Zehnder Interferometer (MZI):

The output of a logic function can be realized in MZI. MZI is opted to design all-optical gates. MZI introduces phase changes of the optical signal [12]. This phase change is obtained when SOA is placed at the arms of MZI. The interference pattern obtained may be constructive interference and destructive interference. When both the signals are in phase, they are added together and forms constructive interference. When both the signals are out of phase, they cancel each other and it is called as destructive interference. MZI is categorized as co-propagating MZI and counter-propagating MZI. In co-propagating MZI, probe and the pump signals travel in the same direction. So the filter is not required to separate the probe signal from pump signal. In counter-propagating MZI, no filter is required because both the probe and the pump signal travels in opposite direction [13]. MZI co-propagating method ensures very high efficiency and good extinction ratio.

1.3 SOA-MZI:

SOA-MZI method is proposed to design all-optical gates because phase modulation to intensity modulation is possible only with MZI scheme and finding optimum bias point is easy. The non-linearity used in this proposed system is XPM. The typical physical features of SOA used in this simulation are shown in Table 1.1.

Table 1.1 Parameters of SOA

SI.NO	PARAMETERS	VALUE
1	Input power of the pump signal	OR-0.3mW NOT-0.5mW
2	Input power of the probe signal	0.25mW
3	Frequency of the pump signal	OR-1552.52nm NOT-1550nm
4	Frequency of the probe signal	OR-1558nm NOT-1540nm
5	Injection current	0.15A
6	Length	0.5mm
7	Width	3μm
8	Optical confinement factor	0.3
9	Line width enhancement factor	5

II PROPOSED DESIGN

2.1 OR gate based on SOA-MZI:

The truth table for OR gate is shown in Table.2.1. When both the inputs are zero, the result of OR gate is logic “0”. When any one of the input is one, then the result of OR gate is logic “1”.

Table 2.1 Truth table of OR gate

INPUTS		OUTPUT
A	B	Y
0	0	0
0	1	1
1	0	1
1	1	1

The block diagram of OR gate base on SOA-MZI is shown in Fig. 2.1

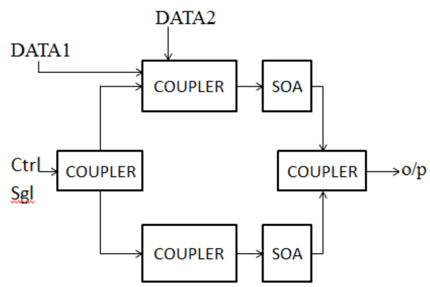

Fig. 2.1 Block diagram of OR gate

2.1.1 Principle of Operation:

In OR gate, when both the inputs are zero, there is no change in the gain of SOA placed in the upper arm of MZI when compared to SOA in lower arm. When both the outputs of SOA is coupled at the output port using coupler, they cancel each other due to destructive interference and the result of OR gate is logic “0”. When any one of the input is one, then the gain of SOA placed in the upper arm of MZI is varied and the clock signal undergoes a radical change in phase known as XPM. This differential phase shift may be adjusted to π radians which increases the output power and due to this effect there is presence of output signal i.e., logic “1”.

The simulation setup for OR gate is shown in Fig. 2.2.

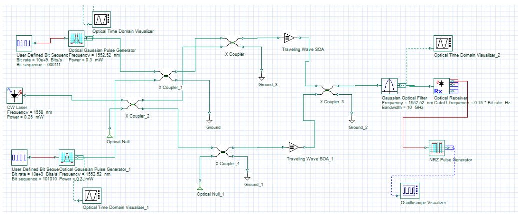

Fig. 2.2 Simulation setup of OR gate

2.1.2 Simulation Results:

Two input data signals are generated at a wavelength of 1552.52nm as in Fig. 2.3 a) and b) using optical pulse generator and OR operation is performed using SOA-MZI scheme and the output of OR function appears at the output port is shown in Fig. 2.3 c)

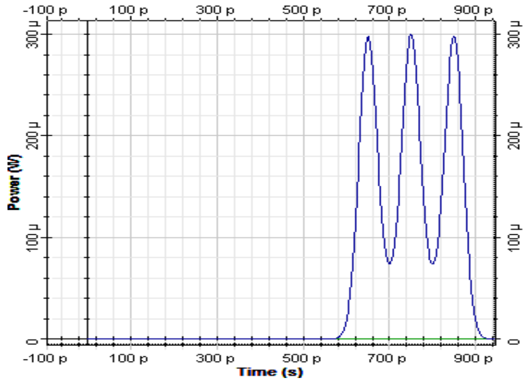

Fig. 2.3 a) Data A: 000111

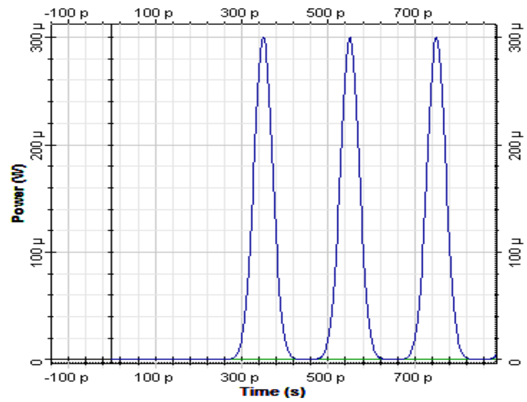

Fig. 2.3 b) Data B: 101010

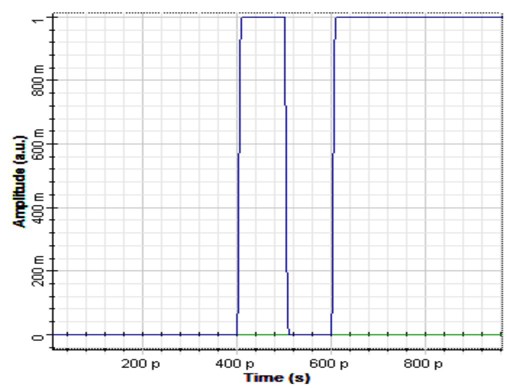

Fig. 2.3 c) Output: 101111

Fig. 2.3 Simulation results of OR gate

2.2 NOT gate based on SOA-MZI:

The truth table for NOT gate is shown in Table 2.2. For NOT gate, when the input is one, the output will be logic “0”. When the input is zero, then the output will be logic “1”.

Table 2.2 Truth Table of NOT gate

INPUT	**OUTPUT**
A	**Y**
0	1
1	0

The block diagram for SOA-MZI based NOT gate is shown in Fig. 2.4.

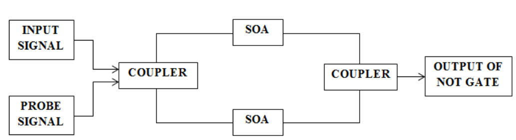

Fig. 2.4 Block diagram of NOT gate

2.2.1 Principle of Operation:

For NOT gate, when the input is one, the gain of the SOA is changed when in turn changes the phase of the probe signal and the output is logic “0”. When the input is zero, the same operation is performed and the output is logic “1”. The simulation setup for NOT gate is shown in Fig. 2.5.

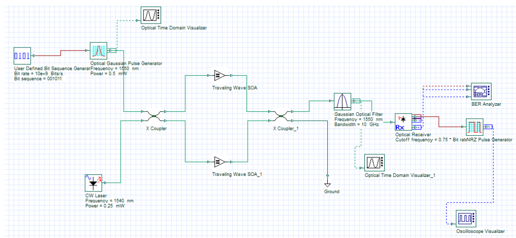

Fig. 2.5 Simulation setup of NOT gate

2.2.2 Simulation Results:

The input signal is generated at wavelength of 1550nm as shown in Fig. 2.6 a) using optical pulse generator. NOT gate operation is performed using SOA-MZI scheme and the output of NOT function appears at the output port as shown in Fig. 2.8 b).

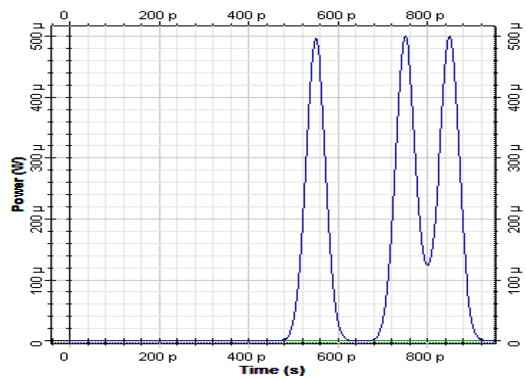

Fig. 2.6 a) Data A: 001011

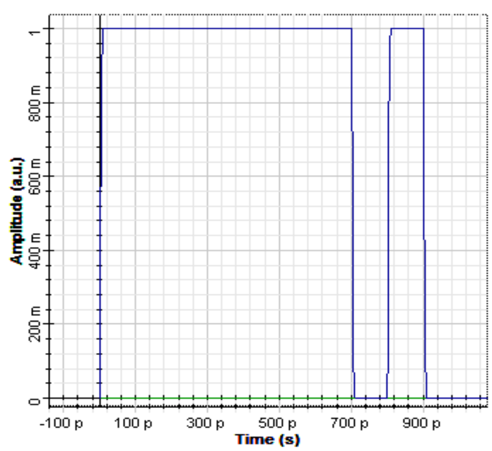

Fig. 2.6 b) Output: 110100

Fig. 2.6 Simulation results of NOT gate

III CONCLUSION

SOA-MZI based All-optical logic gates OR, NOT gates have been simulated at 10GBits/s using co-propagating SOA-MZI structure. The Obtained results ensure good performance of the proposed design.

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