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Research Article

Performance Analysis of SOA-MZI based All-Optical AND & XOR Gate

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Abstract

Presently, semiconductor optical amplifiers (SOA) are the key components of all-optical networks. By proposing the SOA-MZI configuration, all optical AND & XOR gate are designed for ultrahigh speed operation. SOA-MZI plays a significant role in the field of ultrafast all optical signals processing, here the non-linear properties of the SOA are properly utilized. In this paper, the performance analysis of SOA-MZI based all optical AND & XOR gate is demonstrated. The performance of these two gates are analysed through their quality factor and bit error rate (BER), recorded with different wavelength and the length of SOA.

Keywords: *Mach-Zehnder interferometer (MZI); Semiconductor optical amplifiers (SOA); Travelling-wave SOA; Cross phase modulation (XPM); Cross gain modulation*

1. Introduction

In today's world, huge amount of data is being generated, transmitted and processed. Optical fibre is the medium used for transmission of data at high rate. For electronic data processing, opto-electronic conversion of data takes place at the receiving end. High data rate signal processing result in increased consumption of power and heat generation in electronic integrated circuit.

The optical signal processing is increasingly important in future ultrahigh capacity telecommunication network. The development of all optical logic technology is important for a wide range of application in all optical networks including high speed all optical packet routing. For high speed optical network, it is required to develop the all optical gates to avoid power consumption in opto-electronics conversion.

These interferometric SOA-based configurations are compact. Mach-Zehnder interferometers (MZI) have been widely used to implement optical logic gates. The non- linear behaviour of the SOA makes it a good choice for all optical digital devices.

1.1 Semiconductor optical amplifiers

SOA are used as transmission amplifiers, especially in 1300nm window which is used in cable TV transmission. In addition, it been used as a switches, filter, modulator, wavelength converter and tapping devices. The main advantages of SOA is its ability to operate at 1300nm as well as 1550nm simultaneously. It has wide bandwidth up to 100nm (much larger than EDFA). SOA can readily be integrated along with other semiconductor and photonic devices into one monolithic chip of opto-electronic integrated circuit.

1.2 Travelling wave SOA

TWA is essentially an active medium without reflective facets so that an input signal is amplified by a single passage through the active region and the reflectance of the facets are kept zero.

1.3 Non-Linearities of SOA

SOAs due to its non-linear behaviour finds applications which are very useful as optical networks devices. One such effort is its use as logic gates where in the parameters of SOA are varied to achieve the various operations. XPM & XGM are the two non-linear phenomenon being utilized for the operation of SOAs as gates.

1.4 XPM (Cross-phase modulation)

XPM appears in WDM system. In this case, the name is derived from the fact that the non-linearity of the material brings in variation in optical phase fluctuation in a particular adjacent wavelength channel. Phase fluctuation in another propagating channel and in addition therefore the refractive index seen by a

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particular wavelength is influenced by both the optical intensity of that wave itself and also by the optical power fluctuation in the neighbouring wavelength. Self-phase modulation is always present when the XPM occurs.

1.5 XGM (Cross-gain modulation)

The variation of SOA gain depends on the input power which is characterized as XGM effect. Depletion of carrier density due to increase in the power of input signal results in the reduction of amplification. The dynamic process that take place in the carrier density of the SOA are very fast, of the order of picosecond so it is possible to use this variation on the gain with bit to bit fluctuation of the input power.

2. Principle of Operation

2.1 AND gate based on SOA-MZI

We know about the functionality of AND gate. This logic gate gives logic 1 only when the two input signals are same as logic 1. Otherwise the output is logic 0. SOA-MZI based AND gate shown in the fig.1. The principle of operation for the AND gate is basically the same than that for the XOR logic function.

An optical pulse will be obtained at the output only in the case that both signals are logic 1, otherwise gives 0. In this case (P=1, Q=1) the pulse of data Q enables the operation. The operation of AND gate can be seen as performing the XOR comparison between data P and a zero level signal. When Q=0 there is no output produce by gate, means it has no data at port#2. In last condition in which Q=1 and P=0 the comparison is enabled but the signal is zero at both port#1 and port#2 there is no power obtained at the output of the device.

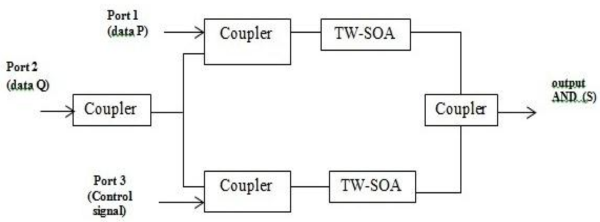


Fig.1 Block schematic of SOA-MZI based AND gate

By using the same simulation tool SOA-MZI based AND is performed. The simulation setup of SOA-MZI based AND gate is shown in Fig.2 operation for the AND gate is basically the same than that for the XOR logic function. Similarly pulse will generated at output end when both data signals are 1.

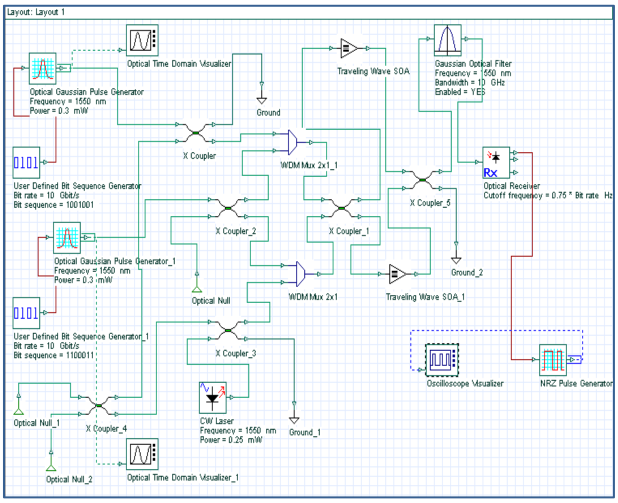
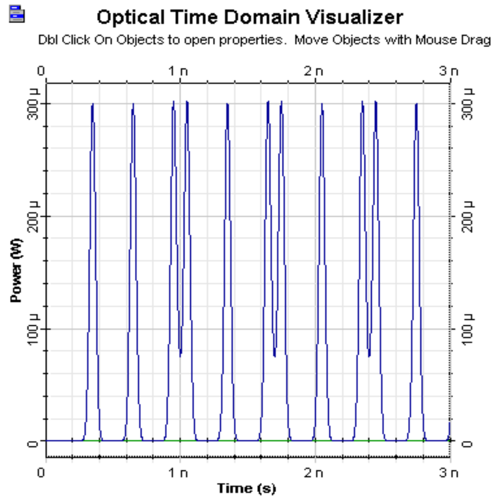


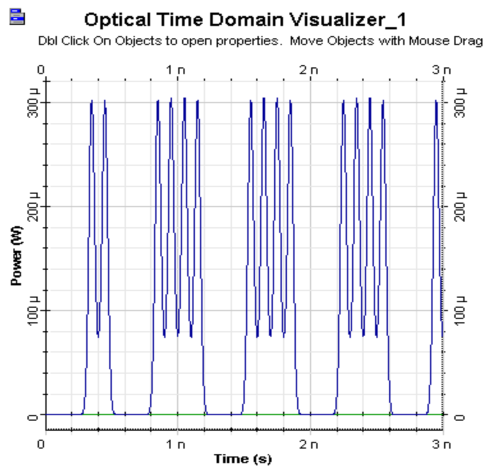
Fig.2 Simulation setup of SOA based AND gate

Fig.3 shows the simulation result are obtained by oscilloscope by simulation of SOA based optical AND gate. We are able to obtain the logical expression for AND gate:

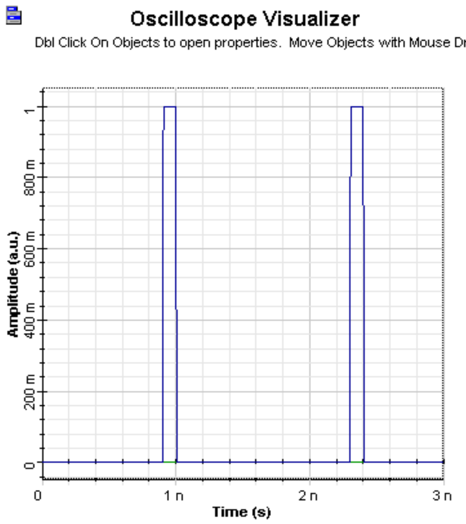
$$S=PQ \quad (1)$$



Data P(1001001)



Data Q(1100011)



Output S (1000001)

Fig.3 Simulation result of SOA based AND gate

2.2 XOR gate based on SOA-MZI

This Boolean function gives a logic 1, if the two inputs are different (combination is P=1, Q=0 & P=0, Q=1). On the other hand, if the inputs are same (combination is P=0=Q & P=1=Q) the output will zero. Logic 1 represents the presence of the optical and logic 0 represents the absence of the optical pulse. Fig.4 shows the block schematic of SOA-MZI.

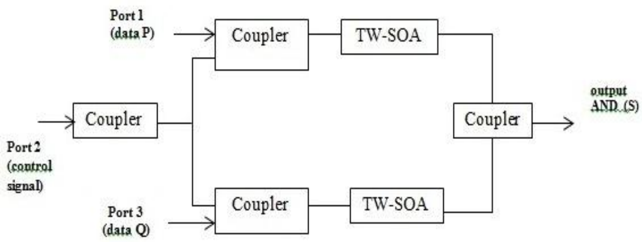


Fig.4 Block schematic of SOA-MZI based XOR gate

When bit sequences to be compared into the SOA, the refractive index at the carrier density changes will occur. This causes a phase shift over the control signal according to the intensity variation of the input pulse. By using the optisystem simulation tool SOA-MZI based XOR gate is performed. The simulation setup of SOA-MZI based XOR gate is shown in Fig.5.

When control pulse enters the SOA-MZI at port#2 in case in which P=0, Q=0 and then it splitted into two pulses, one reaching the lower SOA and the other one reaching the upper SOA. In this point coupler have phase shift, the phases of two splitted control pulse are shifted by π/2. SOAs are under the same state, no data pulse will be reached, so the phase shift is still π/2. Through both SOAs these two pulses are recombined at the output coupler but there again an additional π/2 phase shift occurs between them.

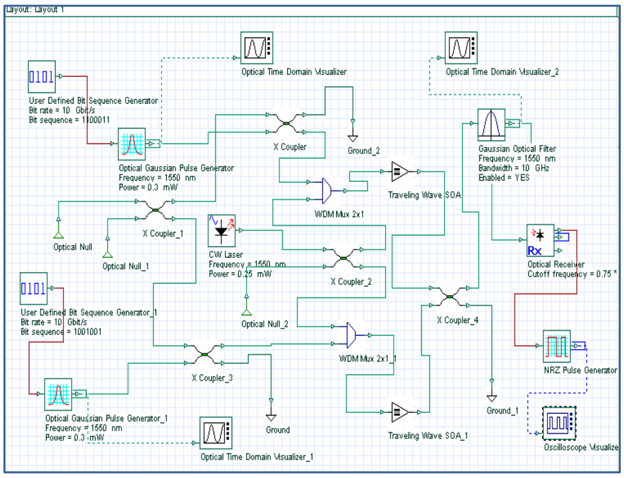


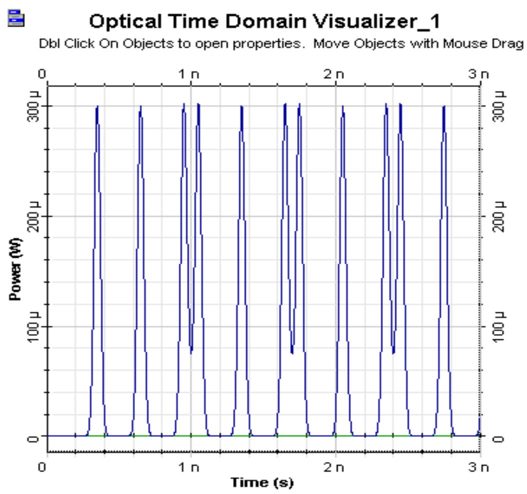
Fig.5 Simulation setup of SOA-MZI based XOR gate

So we get two pulses at the output end and with a total phase shift by π. There is no signal obtained due to destructive interference. This phenomenon is same for the other same input data signal (combination P=1=Q).

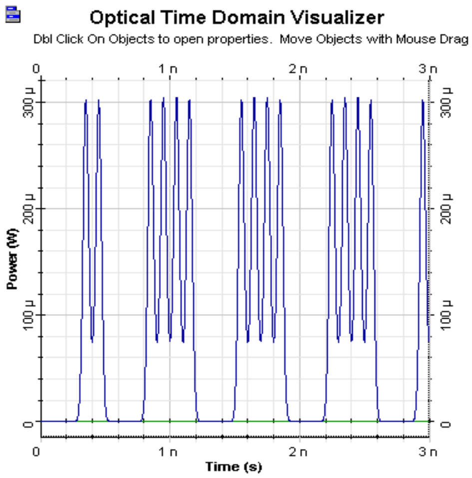
The optical pulse enters in SOA-MZI through port#1 in the case P=1,Q=0, and change the refractive index of the upper SOA but the lower one is unaffected. Thus, the two splitted control pulse travel through both SOAs. The phase difference between both splitted control pulse shifted by π (it is optimum phase shift). At the output end, parts of the control signals from the two SOAs are recombined again and an optical pulse is generated due to the constructive interference. So the total phase shift is by 2π because the optical coupler imposes an additional π phase shift between the input signals. This same phenomenon happens if the input combination are P=0, Q=1.

Fig.6 shows the simulation results are obtained by oscilloscope by simulation of SOA based optical XOR gate. We are able to obtain the logical expression for XOR gate.

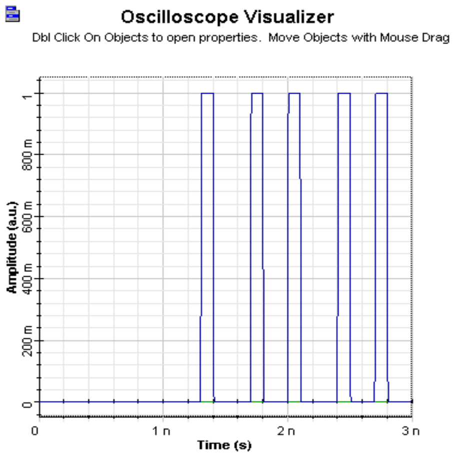
$$S=\overline{P}Q+P\overline{Q} \qquad (2)$$



Data P(1001001)



Data Q(1100011)



Output S(0101010)

Fig.6 Simulation result of SOA based XOR gate

3. Performance analysis

The analysis of the logic gates for the data rate of 10Gbps at two different wavelength (1550nm & 1555nm). A continuous wave (CW) signal with peak power of 25mW is modulated with MZI type modulator have insertion loss of 5dB and chirp factor of 0.5. Data sequences P & Q are generated by user define bit sequence (UDBS) generator. UDBS generator generates define binary data sequence data P & data Q depending upon the inputs given by the user. After generation of binary sequence of data P & data Q they are sent to their respective signal generators. Signal generator converts the binary signal into its electrical form. Here on-off (square-wave) pulse width modulation format of Non Return to Zero (NRZ) is the output of signal generator. NRZ pulse has a high amplitude for the entire bit period where as a low amplitude (or no optical signal) for entire bit represents a 0. Output will get from the oscilloscope visualizer. Table 1 shows the SOA parameters which is used in simulation tool for performance analysis between all-optical XOR & AND logic gates.

Table1 SOA parameters

S.No.	Parameters	Value	Unit
1.	Pump current	0.15	A
2.	Current injection efficiency	1	-
3.	Length of the active region	500-1000	µm
4.	Width of the active region	3	µm
5.	Height of the active region	0.08	µm
6.	Confinement factor	0.3	-
7.	Carrier density	3e24	m^{-3}
8.	Carrier density at transparency	1.4e24	m^{-3}

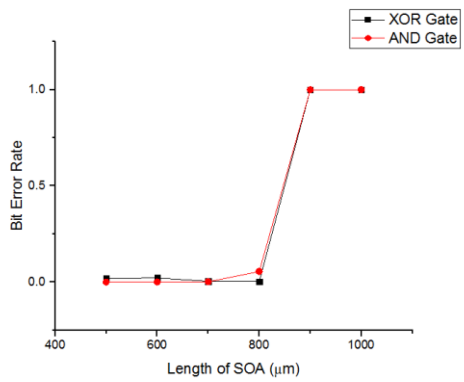
To evaluate the performance analysis of the AND & XOR logic gates the Bit Error Rate (BER) and the quality factor for various lengths of active region of SOA and confinement factor of SOA is fixed at 0.3. BER is the percentage of bits that have errors relative to the total number of bits received in a transmission, usually expressed as ten to a negative power. If E_i and B_i, is the number of errors and total number of bits sent respectively, then BER expressed as

$$BER = E_i / B_i \quad (3)$$

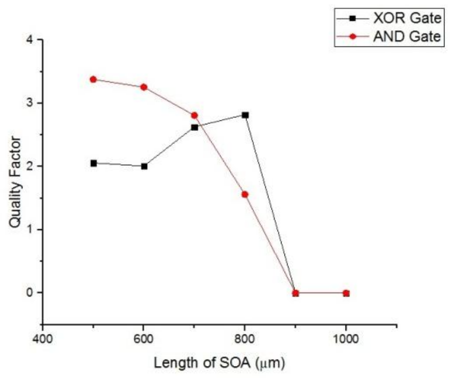
Another parameter through which the performance of the logic gates is analysed is Q factor of quality factor. It is defined as-

$$Q = \overline{P}_1 - \overline{P}_0 / \sigma_1 + \sigma_0 \quad (4)$$

Where $\overline{P}_1$ and $\overline{P}_0$ are the average power of output signal 1 and output signal 0 respectively. σ_1 and σ_2 are the standard deviation of all logic 1 and 0, it indicates the closeness of values with their mean value. By equation (4), Q is directly proportional to the difference of powers between bit 1 and bit 0. Therefore higher power difference ensures a good quality factor. If there are fluctuations occurs I powers indicating bit 1 & bit 0 it means that the value of $\sigma_1+\sigma_2$ would increase, which will degrade the system performance and the overall quality factor. Hence, higher value of quality factor indicates a good system performance.



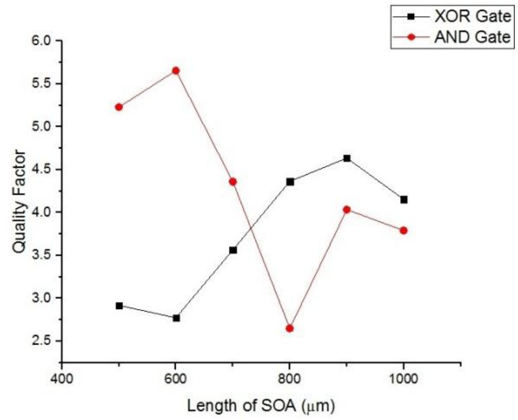
(a)



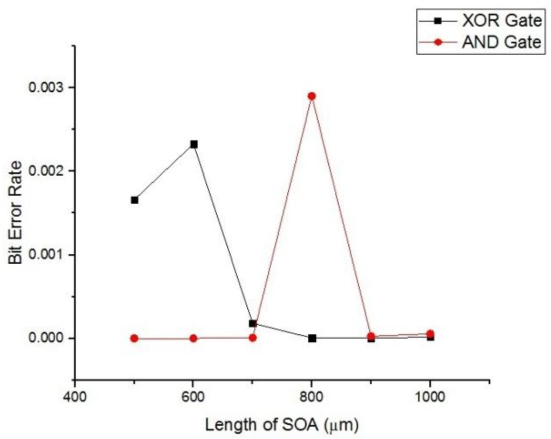
(b)

Fig.7 (a) Length v/s BER (b) Length v/s quality factor

Fig.7(a), (b) show the plots, length of SOA v/s BER and length of SOA v/s quality factor at wavelength of 1550nm for XOR & AND optical gates. Fig.8(a), (b) show the plots, length of SOA v/s quality factor and length of SOA v/s BER at wavelength of 1555nm for AND & XOR optical gates.



(a)



(b)

Fig.8 (a) Length v/s quality factor (b) Length v/s BER

It is clearly evident from the plots that as the length of the active region from 500-800μm, BER approximately lies to zero. After increase the length of SOA up to 800μm BER is also increase at 1550nm for AND & XOR gate. At wavelength of 1555nm when we increase the length of SOA BER remains same for AND gate but for XOR gate BER remains same after 600μm length of SOA. On the other hand, increasing of the length of SOA quality factor decrease rapidly to zero at 900μm and give approximately same value at 1550nm for both optical gates. Q factor is same after 900μm length of SOA. Increase the length of SOA quality factor is increase at1555nm for XOR gate & for AND gate its opposite.

Conclusion

Principle of operation of optical gates designed around SOAs are fully discussed in this manuscript. The performance of the XOR & AND optical gates is tested on the basis of BER and Q factor at two different wavelength. BER remained same for most of values. It has been found that on increasing the SOA length BER remains almost same.

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