ALL OPTICAL XOR GATE USING SINGLE SOA AT 100 GB/S

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Abstract- The authors have demonstrated SOA-based all-optical XOR at 100 Gbps through simulation. The performance of the proposed all-optical XOR is also analyzed. The proposed design is simpler in structure and provides the user with an option to give two different data input signals simultaneously, eliminating the need of optical delay lines. Also, it allows scope for photonic integration which is imperative to realize higher level components like half-adder, full-adder etc. In comparison to fiber based gates, SOA based gates offer wide bandwidth and are simpler in structure. Most of the published designs of all -optical gates work up to 10 Gbps. However, the proposed design of XOR gate can be operated up to 100 Gbps.

Keywords- Cross gain modulation, cross phase modulation, Semiconductor optical amplifier, XOR gate, high bit rate, fiber based gates, All -optical processing, optical gates

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Introduction

Electronic circuits are expected to face the speed as a restraining barrier in the coming future. This is accounted to the fact that need for higher bit rates is imminent All-optical processing is being seen as a apposite answer to the need of higher bit-rate performance [1].

The all-optical processing is especially appealing in high-capacity core optical networks where we want to avoid inefficient optoelectronic conversion. All optical gates form an essential component of all-optical processing system. Optical gates are key devices for realization of many functionalities in optical networks and optical computing All-optical logic devices required in optical add-drop multiplexers (OADMs) and optical cross connects (OXCs) perform networking functions, such as addressing and header recognition, data encoding and encryption, pattern matching, etc. [2].

All-optical logic device can be classified into two broad categories such as the nonlinearity based on fibers, nonlinearity based on a semiconductor optical amplifier. All optical logic gates based on semiconductor optical amplifiers are promising because of their power efficiency and their potential for photonic integration [3]. SOAs not only provide the gating operation but they can be used for fair amplification and efficient wavelength conversion [4].

The wide applicability of SOAs is because of its non-linear behavior such as Four wave mixing (FWM) [5], Cross gain modulation (XGM) [6-9], Cross phase modulation (XPM) [10] Cross polariza-

tion modulation (XPolM) [11]. All-optical processing utilizes any of these nonlinear properties or their suitable combinations.

The XGM characteristics are easier to implement and good results have been achieved at higher bit rates. All-optical gates utilizing XGM reveal high conversion efficiency and polarization independence to input signals [12-13].

To realize all-optical gates (fundamental unit of optical processors), various configurations have been projected. These include gates using fiber nonlinearity for eg. nonlinear optical loop mirror configuration (NOLM), Terahertz optical asymmetric demultiplexer configuration (TOAD), optical Kerr gate, solitons dragging logic gate and gates using SOA such as delayed interferometric structures, Mach Zender interferometric structures, co-propagating SOA structures, Ultrafast nonlinear interferometer structures, Four wave mixing in SOA, Single structure SOA based gates.

In this paper, the authors have exploited the XGM characteristics of SOA at 100 Gbps to realize XOR gate. This design can still be operated at rates upto 200 Gbps with fair performance. Using the same setup other logic functions can be obtained such as NAND as in [14], AND, OR as in [15]. All optical XOR gate is of key importance for decision and comparator circuits as well as data encryption.

Principle of Operation

Cross Gain Modulation (XGM) is a non linear effect that takes place inside an SOA cavity, when both a high power signal (Pump)

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and a low power signal (Probe) are shot together into the SOA simultaneously. Most of the carriers in the active region are used to amplify the pump, while the probe sustains the absorption due to XGM. Because of XGM, the trailing edge of the probe is shifted by the SOA towards the longer wavelength (red-shift), whilst the leading edge is shifted towards the shorter wavelength (blue-shift)[3]. Hence, the probe spectrum is widened, as has been indicated in [Fig-1].

The carrier density changes in the active region of an SOA affect all the input signals. It is possible that signal at one wavelength delivers an impact on the signal at another wavelength [1].
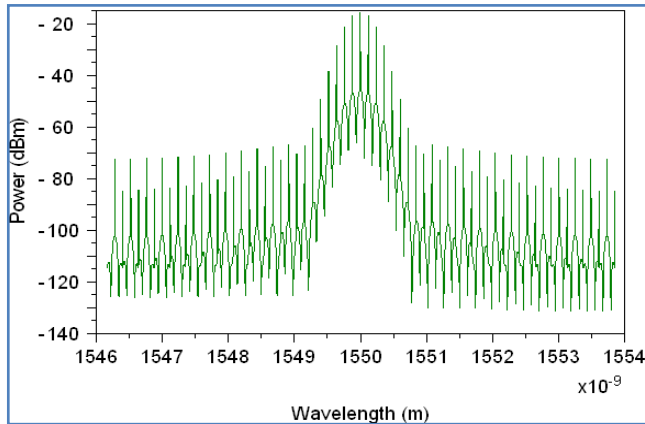

Fig. 1- Broadened pulse spectrum of probe at wavelength 1550 nm

This is what happens with all-optical gates. In accordance with the changes in data inputs (pump signals), the probe signal is modulated and we get the desired logic operation. When carrier modulation takes place in accordance with the changes in data signals, both the gain and phase of the probe signals are modified giving rise to XGM and XPM [13].

The electrical pumping of the active region of the SOA leads to the excitation of charge carriers to higher energy levels. These excited carriers cause stimulated emission when input pump signal is propagating through the SOA until the photons emanate out as an amplified signal. This amplification eats up a lot of charge carriers which causes reduction of amplifier gain. This process is termed as gain saturation [5].

Simulation Setup

All-optical XOR logic is treated as one of the fundamental logic gates in signal processing, which plays a significant role in applications such as bit pattern recognition, pseudorandom bit sequence (PRBS) generation, parity checking and optical computing. A high-speed all-optical XOR gate possesses future applications for on-the-fly digital serial processing of optical signals, such as all-optical packet header recognition, error detection and coding/decoding. In this section, all-optical XOR gate has been presented at 100 Gbps.

The simulation for XOR gate as shown in [Fig-2] was performed using a simulation tool Rsoft's OptSim 5.2. The simulation based tool for designing advanced optical communication systems.

The two data streams Data1 (λ =1557.75nm) and Data2 (λ =1563.15 nm) are generated at 100 Gbps using the mode-locked lasers MLLaser1 and MLLaser2 respectively. The output of the

lasers is modulated according to the data provided by the user in the custom files of the respective PRBS (pseudo random binary sequence) generators PRBS1 and PRBS2.

The two data streams Data1 and Data2 are then combined to generate a single stream using an optical multiplexer OptMux1. This combined data stream is then amplified using an EDFA amplifier (Erbium doped fiber amplifier) EdfaBB1. The probe signal of wavelength 1548.3 nm is generated using another mode-locked laser MLLaser3 at 100 Gbps. PRBS3 for probe signal generation is fed with alternating '1' and '0' pulses at 100 Gbps.

The combined data stream along with the probe signal is introduced into the Semiconductor optical amplifier SOAT1 through an optical multiplexer OptMux5. Inside the Semiconductor optical amplifier SOAT1, cross gain modulation (XGM) takes place and gain of the amplifier gets modulated. The moderate saturation regime for obtaining the XOR operation is selected by using an optical band pass filter OptFilt1 tuned at wavelength 1554.5 nm and bandwidth 0.1nm. The resultant XOR operation was observed and verified using the signal analyzer Result_XOR.

The input power levels of both the data signals 1 & 2 and probe signal for XOR gate is summarized in [Table-1].

Table 1- Input power levels of data and the probe.

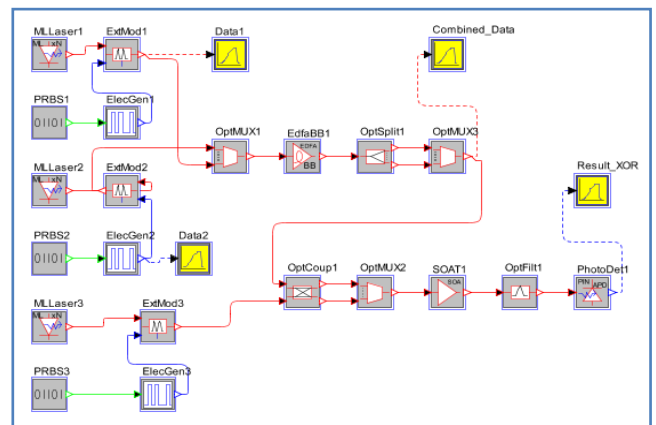| S. No	Signal	Power Level
1	Data1	0.786 mW
2	Data 2	0.965 mW
3	Probe signal	0.55 mW

Fig. 2- Simulation setup of all-optical XOR gate

The various SOA parameters that need to be adjusted for optimum SOA performance are listed in [Table- 2]

Results and Discussion

As in the XOR logic, we have logic high only and only when only one of the input signals are high. When both the signals are high, the output is low. In the simulation results it was observed that logic high pulses are obtained but when one of the data signals are high and low is obtained when both signals are high or low [Table-3].

The output of the photodetector i.e. the final output has been taken from signal analyzer (Result_XOR). The data signals Data1 and Data2, XOR output waveform, are shown in [Fig-3a], [Fig-3b] and [Fig-3c] respectively.

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Table 2- List of parameters for realizing XOR gate

Parameter	Value
Bit Rate	100 Gbps
Wavelength of Data1	1557.75 nm
Wavelength of Data2	1563.15 nm
Wavelength of probe	1548.3 nm
Modulation	Ideal
Drive type	On_off_ramp
Signal type	Voltage
Modulation type	NRZ
Gain of EDFA	30 dB
P_{sat} of EDFA	18 dBm
Bandwidth of EDFA	30 nm
Pump current of SOA	0.350 A
Spectral gain shape of SOA	Parabolic
Wavelength peak gain of SOA	1548.3 nm
Linewidth Enhancement factor of SOA	5
Confinement Factor of SOA	0.6
Internal loss of SOA	900 m^{-1}
Gain Slope of SOA	2.78 E-20 m^{-2}
Length of SOA	6000 µm
Width of SOA	1.5 µm
Thickness of SOA	0.15 µm
Central wavelength of OptFilt1	1554.5 nm
Bandwidth of OptFilt1	0.1 nm
Filter type of OptFilt1	Fabry Perot

Table 3- Truth table for XOR operation

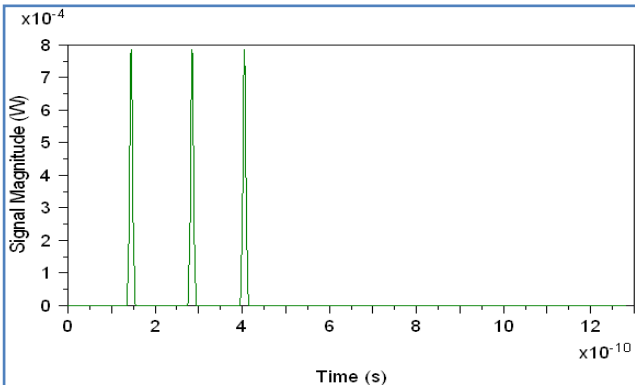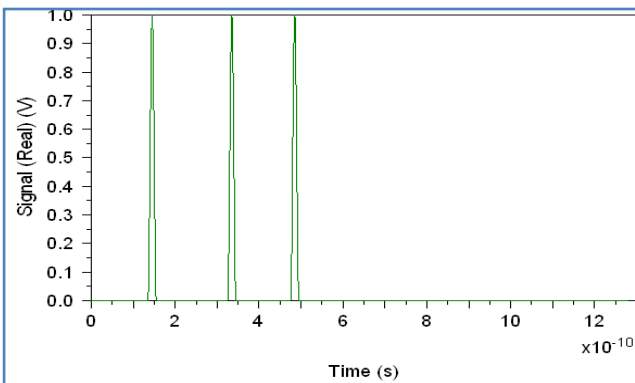| Data1	Data2	Output
0	0	0
0	1	1
1	0	1
1	1	0

Fig. 3a- Input signal Data 1
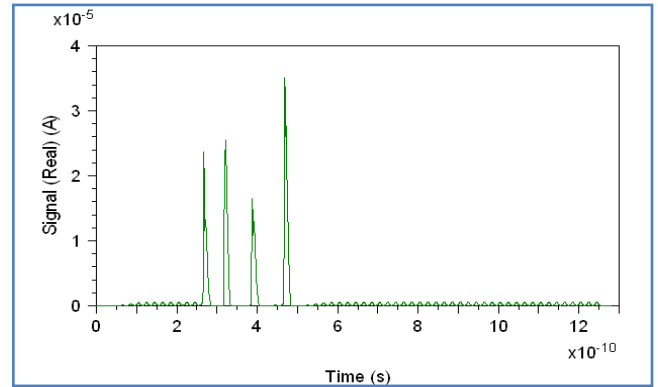

Fig. 3b- Input signal Data 2

Fig. 3c- XOR output waveform (Resultant signal)

Conclusion

The all-optical XOR gate has been investigated and verified successfully at 100 Gbps. The design is simple in structure and offers wide wavelength operability from 1540nm to 1570nm.

The all-optical XOR gate, will aid in design of other higher level all-optical components, thereby delivering an advantage of easy photonic integration.

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