All-Optical XOR Based on Integrated MZI-SOA with Co and Counter-Propagation Scheme

C. Reis, R. P. Dionísio*, *Student Member, IEEE*, B. Neto, A. Teixeira and P. André**, *Member, IEEE***
Instituto de Telecomunicações, Campus de Santiago, 3810-193 Aveiro; Portugal.
** Escola Superior de Tecnologia, Instituto Politécnico de Castelo Branco, 6000-767 Castelo Branco, Portugal*
*** Departamento de Física da Universidade de Aveiro, Campus de Santiago, 3810-193 Aveiro, Portugal.*
Tel: (+351) 234377900, Fax: (+351) 234377901, e-mail: pandre@av.it.pt

ABSTRACT
In this work we present a review of all-optical XOR gates based on Mach-Zehnder Interferometer with Semiconductor Optical Amplifiers (MZI-SOA), using NRZ modulated signals driven at 10 Gbit/s.
The performance of two alternative schemes for logical XOR gates implementation is demonstrated through numerical simulations and experimentally. The extinction ratio shows high operation performance with low degradation.
Keywords: SOA based devices, all-optical signal processing, all-optical logical gates.

1. INTRODUCTION

In transparent optical networks, there is a need to perform all-optical signal processing that allows treating data information only in the optical domain, avoiding the optical-electrical-optical conversion and reducing the latency of the communications link [1].

High speed all-optical logic gates are crucial devices in optical networks because they execute essential signal processing functions such as switching, regeneration and header recognition processing in photonic switching nodes.

One of the main building blocks to implement several all-optical devices such as comparators, adders and counters is the optical XOR gate [2].

Many approaches have been reported to achieve all-optical XOR operation, and are mostly based on the nonlinear effects in semiconductor optical amplifier (SOA) such as cross-phase modulation (XPM), cross-gain modulation (XGM) and four-wave mixing (FWM) [3]-[5].

In this paper, we have implemented an optical logic XOR gate based on a hybrid integrated MZI-SOA, using cross-phase modulation (XPM). The SOA-MZI is an element that performs a variety of optical logic functions and provides high extinction ratio (ER), requires low switching energies to operate and have regenerative capability and compactness.

Two schemes for all-optical logical XOR operation will be compared and the results obtained experimentally and from simulation will be discussed.

2. SYSTEM DESCRIPTION

The two experimental setups are depicted in Fig. 1 and consist of an external cavity laser peaking at 1549.32 nm, followed by a polarization controller and a Mach-Zehnder external modulator driven at 10 Gbit/s. The NRZ optical signal is then amplified in an Erbium Doped Fiber Amplifier (IPG-EAD-500-C3-W) and split into two equal parts using a 3 dB coupler. At this point both data signals are launched into the MZI-SOA (CIP 40G-2R2-ORP) port A and port D through an optical delay line, a variable optical attenuator and a polarization controller to adjust and synchronize the signals. Different data patterns are obtained by delaying signals at port A and port D.

For the co-propagation scheme, the control signal, a continuous wave (CW) lasing at 1546.12 nm and with 0 dBm mean power, is launched into port B and the XOR signal is recovered at port I, using a filter with a 25 GHz bandwidth (X-tract Net Test) and centered at the control signal wavelength.

The counter-propagation scheme uses the same control signal and it is launched into port I. The output is now at port B. For this setup, an isolator is placed between the EDFA and the 3 dB coupler.

As receivers, a PIN (HP-11982A) and an (Agilent Infinium 86100A) oscilloscope were used.

The work reported in this paper was supported by the PANORAMA project, the European Union EURO-FOS and BONE projects, COST MP0702 action and by a FCT grant (SFRH/BD/28904/2006).

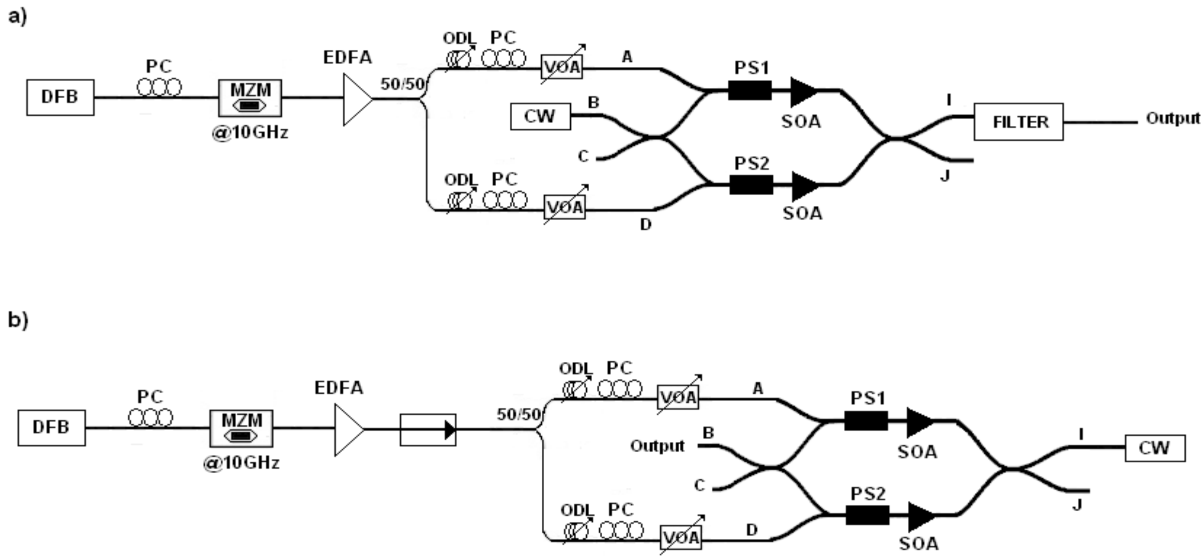

Figure 1.Experimental setup a) co-propagation scheme b) counter-propagation scheme. DFB: distributed-feedback laser; PC: polarization controller; MZM: Mach-Zehnder modulator; EDFA: erbium doped fiber amplifier; ODL: optical delay line; VOA: variable optical attenuator; CW: continuous wave; SOA: semiconductor optical amplifier; PS: phase shifter.

Simulation of both systems depicted in Fig. 1 has been done using the Virtual Photonics Inc. Software. SOA parameters were based on the parameters used by Sun et al [6] and they are illustrated in Table 1.

Table 1. Parameters used in simulation for the MZI-SOA XOR gate.

Parameter	Value	Unit
InjectionCurrent	0.2	A
Length	4.25×10^{-4}	M
Width	1.5×10^{-6}	m
Height	1×10^{-7}	m
OptConfinement	0.2	
InternalLosses	2×10^{-9}	m^{-1}
DifferentialGain	1.5×10^{-20}	m^2
CarrierDensityTransp	1.5×10^{-12}	m^{-3}
IndexToGainCoupl	5	
LinearRecombination	5×10^{7}	s^{-1}
BimolecularRecombination	1×10^{-16}	m^3s^{-1}
AugerRecombination	7.5×10^{-41}	m^6s^{-1}
InitCarrierDens	1×10^{-12}	m^{-3}

3. TEST RESULTS AND DISCUSSION

3.1 XOR Operation

The truth table for the logical operation exclusive disjunction is shown in Table 2. As it can be seen, the logical XOR gate output presents the value 0 if both of the operands have the same value.

Table 2. Truth table for the XOR function.

A	B	XOR
0	0	0
0	1	1
1	0	1
1	1	0

Figure 2 illustrates the data input signals injected into the arms A and D of the MZI-SOA, each with 2 dBm mean power, and the corresponding XOR gate output, at 10 Gbit/s. The results obtained experimentally are in agreement with the principle of operation of an XOR gate.

.

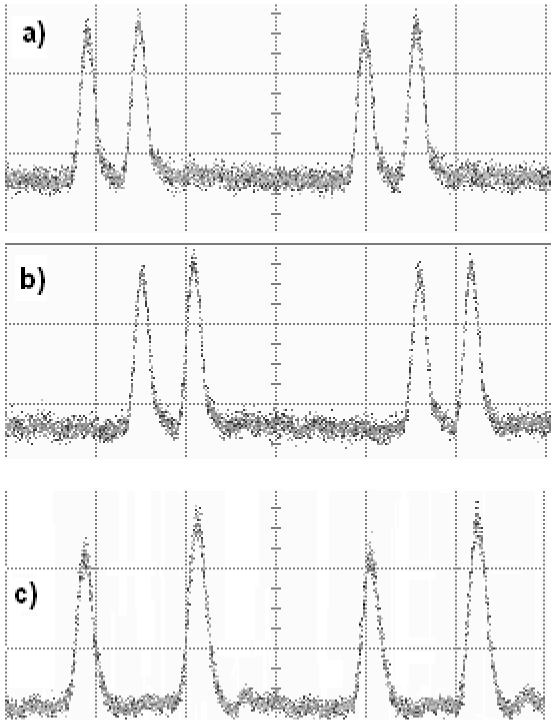

Figure 2.a) and b) Data sequences c) XOR output.Vertical scale is arbitrary and horizontal scale is 500 ps/div.

3.2 Comparison of Extinction Ratio

Figure 3 presents the performance of all-optical XOR gates with the variation of the input power of the NRZ data signals from 0 to 4 dBm, maintaining at the same power the CW control signal (0 dBm). For both co and counter-propagation scheme, the performance of the XOR gate is almost independent of the input power, since the power variation of the two data signals involved in the comparison is the same. However, the counter-propagation scheme shows a better performance, with an improvement on the extinction ratio ranging from 0.72 dB to 1.64 dB.

Simulation results are in good agreement with the experimental measurements.

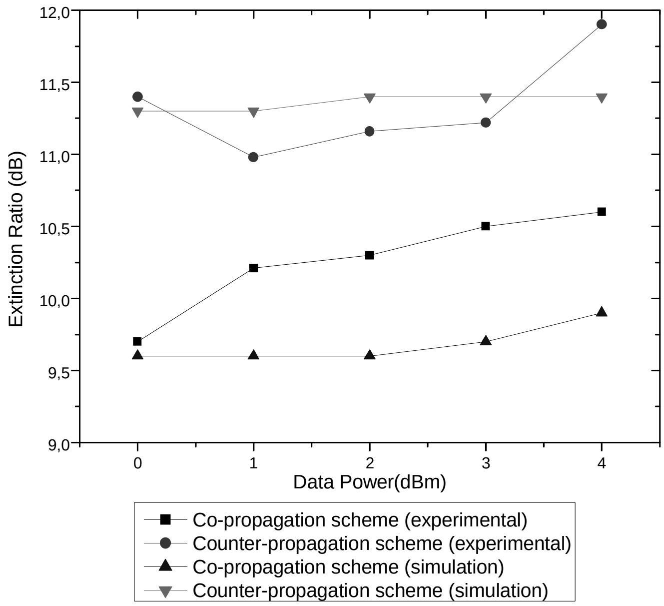

Figure 3 Performance of all-optical XOR gate Vs Input data signal.

4. CONCLUSIONS

We have shown experimentally and by means of simulation that MZI-SOA devices acting as logic XOR gates using a counter-propagation scheme have better performance than a co-propagation scheme, with extinction ratio values higher than 10 dB.

ACKNOWLEDGEMENTS

This work was supported by the European Union EURO-FOS and BONE projects and COST MP0702 action. C. Reis would also like to acknowledge PANORAMA project. B. Neto gratefully acknowledges her Ph. D. grants financed by FCT (SFRH/BD/28904/2006).

REFERENCES

[1] D. Tsiokos, *et al*: 10-Gb/s All-optical half-adder with interferometric SOA gates, *IEEE Photonics Technology Letters, Vol. 16, No. 1, 2004.*

[2] R. Vilar, *et al*: All-optical DGD monitor for packet-switched networks based on an integrated active Mach–Zehnder interferometer operating as logic XOR gate, *Optics Communications, Vol. 281, pp. 5330-5334, 2008.*

[3] A. Bogoni, *et al*: Regenerative and reconfigurable all-optical logic gates for ultra-fast applications, *Electronics Letters, Vol. 41, No. 7, 2005.*

[4] Li Pei-li, *et al:* Ultrahigh-speed all-optical half adder based on four-wave mixing in semiconductor optical amplifier, *Optics Express, Vol. 14, No. 24, November 2006.*

[5] D. M. Lai, *et al*: All-optical picoseconds logic gates based on a fiber optical parametric amplifier, *Optics Express, Vol. 16, 18362-18370, 2008.*

[6] J. Sun, G. Morthier, R. Baets, “Numerical and Theoretical Study of the Crosstalk in Gain Clamped Semiconductor Optical Amplifiers”, IEEE Journal of Selected Topics in Quantum Electronics, Vol. 3, Nº 5, October 1997.