All Optical Logic Full Adder Based On XPM Effect In SOA-MZI

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Abstract: *With the development of all optical networks, Requires that all optical system including logic gate is consistent with the new format. We proposed and demonstrated a novel structure of ultrafast all optical full adder based on the Cross-phase modulation (XPM) that is principle nonlinear effect in a semiconductor optical amplifier (SOA) assisted mach zehnder interferometer (MZI). In this architecture quantum logic gates including: Feynman, Toffoli and Peres gates are used to implement all optical full adder. By using the presented structure, we obtain low power penalty for designed full adder and error-free performance at 10Gb/s and the receiver sensitivity for a bit-error rate of 10-9 is below -10dbm. In additional, the results show this structure will enhance the future optical signal processing application for ultrafast operation.*

Keywords: Semiconductor Optical Amplifier, Cross Phase Modulation, All Optical Signal Processing, quantum logic gate, Mach Zehnder Interferomer.

1. Introduction

Nowdays, in transmission systems, the rate of data has been approaching the speed limitation of electronics [1], [2], so far all optical systems are highly desirably to support the all optical signal processing. All optical full adder is one of the key element for ultrafast all optical signal processing such as ultrafast encryption and decryption [3], arithmetic operations and complicated processing circuits (e.g., multiplier, shift registers, counter, serial/parallel data converter and central processing unit). [4]-[14], and digital comparison [15],[16]. All optical full adder using logic gates which works on nonlinear effect of medium, so far two method using the nonlinear effect of optical fiber and semiconductor optical amplifier (SOA) [17],[18]. In the different methods, integrated mach zehnder interferometer (MZI) based on SOA have been developed as a practical due to their compact size [19],[20], thermal stability and low power. All optical full adder implemented with various nonlinearities in SOA including cross gain modulation (XGM), cross phase modulation (XPM) and four wave mixing (FWM) which enable switching light to another wavelength [21]-[23]. In this article for he first time, we proposed and demonstrated an all optical full adder based on XPM in SOA assisted MZI. Moreover, our work differs in working principle and implementation structure as will be seen. The remainder of the paper is organized as follows. In section 2. We describe how we can achieve the full adder and principle of operation and structure, and we derive, analyze, and interpret results on the performance of the all optical full adder gate. Finally, in Section 4. we summarize the main findings of our work and simulation results.

2. Principle Of Operation

We proposed and demonstrated logic operation based on MZI-SOA for implement all optical full adder that shown in Fig. 1. A structure of mach zehnder interferometer (MZI) is created of two 3db-couplers (50:50 coupler) connected by arms of equal optical length. Also two semiconductor optical amplifier (SOA) are placed into the upper and lower arms of MZI. mach zehnder interferometer (MZI) has two input ports, two output ports and input signal is split in the two arms of the input 3db-coupler. Finally signal splited, are recombined in the output combiner. In both arms, SOA used for amplification and attenuation of an optical signal. With XPM effect, changing the refractive index of one of the arms, so the phase difference at the input of the 3db-combiner changed and signal switches from one output port to the other. In MZI-SOA, if one signal presented attenuated in one arm and amplified in the other arm. The working principle of the MZI-SOA can be explained as follows. In the demonstrated structure, the $\lambda 2$ signal is propagates simultaneously in the two arms of MZI. If input signal at the wavelength $\lambda 1$ is split at

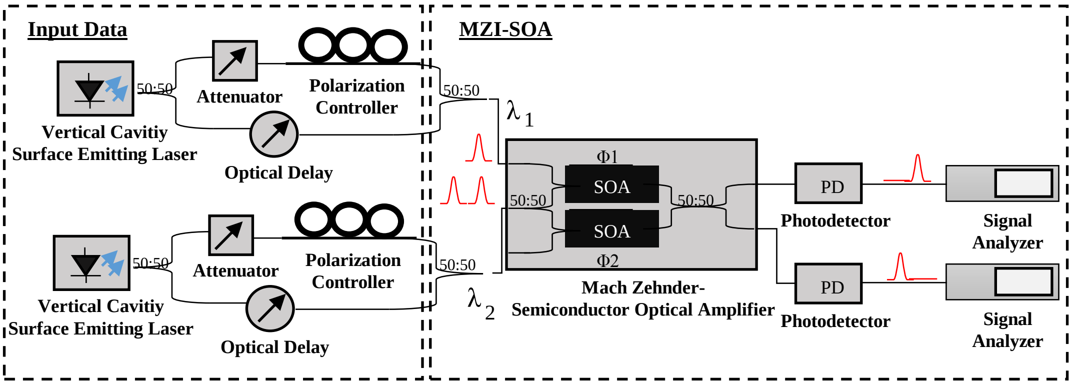

Fig. 1. Mach Zender Interferometer assisted semiconductor optical amplifier, this structure is comprised of two discrete subsystems including: Input Data and MZI-SOA . In input data two VCSEL laser, LD_1 (1550nm) and LD_2 (1554nm) to provide optical pulse.

the upper coupler, more power pass through upper arm. With XPM effect in SOA, gain saturation induced and carrier density reduced, as a result, an additional π phase can be introduced on the λ1 because of the XPM. Now its clear with no signal λ1 , the λ2 signal pass through two arms and nothing exits from upper output port. The nonlinear switching component used was a 1mm bulk InGaAsP/InP ridge waveguide SOA, when driven with 300mA. In this structure optical filter is placed in front of the output ports for blocking the amplified spontaneous emission (ASE) noise and Bit synchronization in structure was achieved using optical delay [24]-[26].

For implement all optical full adder, we used quantum logic gates based on MZI-SOA. In this section we explain the working principle and circuit operation of quantum logic gates. The structure of proposed full adder is comprised of the three quantum logic gates including: Feynman, Toffoli and Peres gates. A 2×2 feynman gate (FG), also know as controlled-not for implementation the logic functions. A Feynman gate is a 2input and 2output having the mapping (A,B) to (P=A,Q=A xor B). The demonstrated structure of FG is shown in Fig. 2.

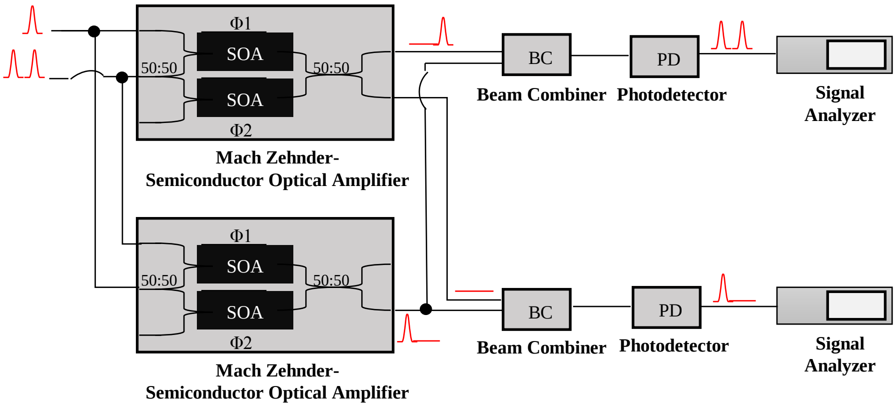

Fig. 2. Strucrue of Feynman gate based on MZI-SOA

The proposed Feynman gate using two MZI-SOA and two beam combiner (BC) based all optical logic gate. BC is to simply combine the optical signal while the beam splitter, splits the beams into two optical signal. A 3×3 Toffoli gate (TG) has three input: 2 control input, that are copied to the first two outputs. one of the input that is complemented if two control inputs are one, and that is directly copied to the last output otherwise. On the other hand, in this gate having the mapping (A,B,C) to (P=A,Q=B,R=A.B xor C). The demonstrated structure of TG is shown in Fig. 3.

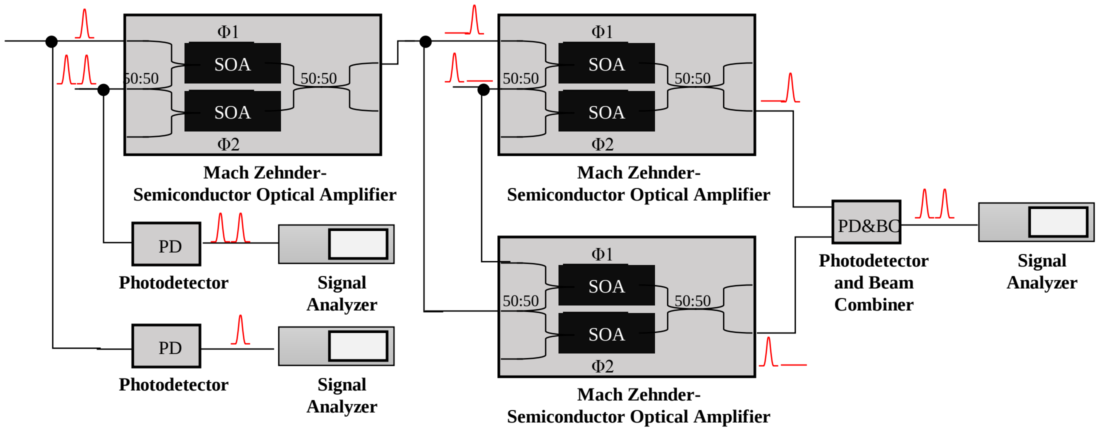

Fig. 3. Strucrue of Toffoli gate based on MZI-SOA

The proposed Toffoli gate using three MZI-SOA and a beam combiner based all optical logic gate. A 3×3 Peres gate (PG), is equivalent to the transformation produced by a Toffoli gate followed by a Feynman gate. In this gate having the mapping (A,B,C) to (P=A,Q=A xor B,R=A.B xor C). The logical operation of PG shown in Fig .6 and demonstrated structure of PG is shown in Fig. 4. The proposed Peres gate using four MZI-SOA and two beam combiner based all optical logic gate.

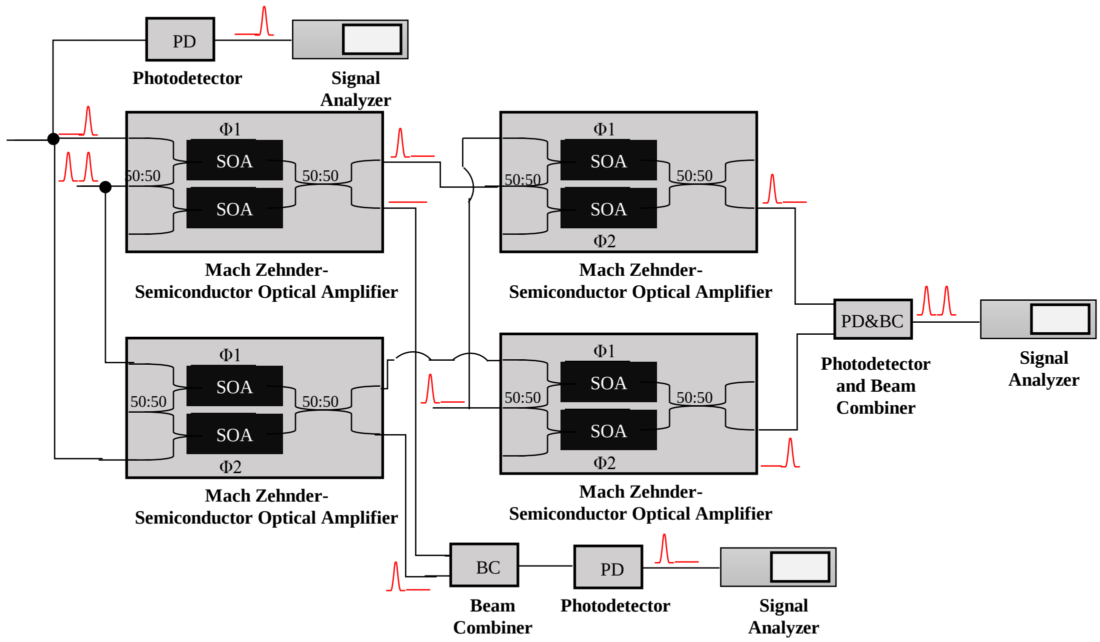

Fig. 4. Strucrue of Peres gate based on MZI-SOA

In Fig .5 we shown the gate level conceptual scheme of all optical full adder using conventional quantum gate symbols. In fact, full adder is fundamental binary arithmetic units. In this structure having the mapping (A,B,C) to two binary outputs of SUM(S=A xor B xor C) and CARRY(C=AB xor C(A xor B)). The output sum is logical "1" when one or three of inputs (A,B,C) are logical "1" and "0" otherwise. The output carry is logical "1" when both or three of inputs are logical "1". We have experimentally demonstrated a new all optical full adder at 10Gbit/s using three inputs without any additional input signal such as continuous wave (CW). In this structure we obtain low power penalty for designed full adder and error-free performance at 10Gb/s and the receiver sensitivity for a bit-error rate of 10-9 is below -10dbm.

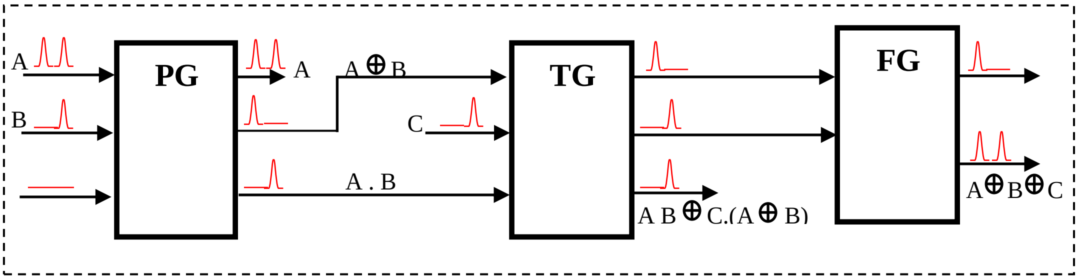

Fig. 5. Proposed Strucrue of all optical full adder based on MZI-SOA

3. Conclusion

In this paper, the fundamental all optical quantum logic gate including Feynman, Toffoli and Peres gates by using the SOA assisted MZI are demonstrated for implement the all optical full adder. By adjusting the injection times of the input signal, various data pattern were used to test the performance of the full adder shown in Fig .6. The full adder structure operated successfully for various different input patterns. In the following simultaneous, three synchronized independent input signal A,B and C are assumbed to be 10Gbit/s.

The wavelength of input signal A,B and C as shown in Fig 6(a)-(c) are set at 1550,1554 and 1559nm, respectively. The sum and carry outputs as shown in Fig .6(d)-(e). Finally, it is key to note that the structure requires only the data signals as input signal and no additional input. The performance of this full adder is extremely fast and with future improvement, more advanced all optical digital processor are expected, such as multiplier, divider, advanced encryption/decryption central processing unit.

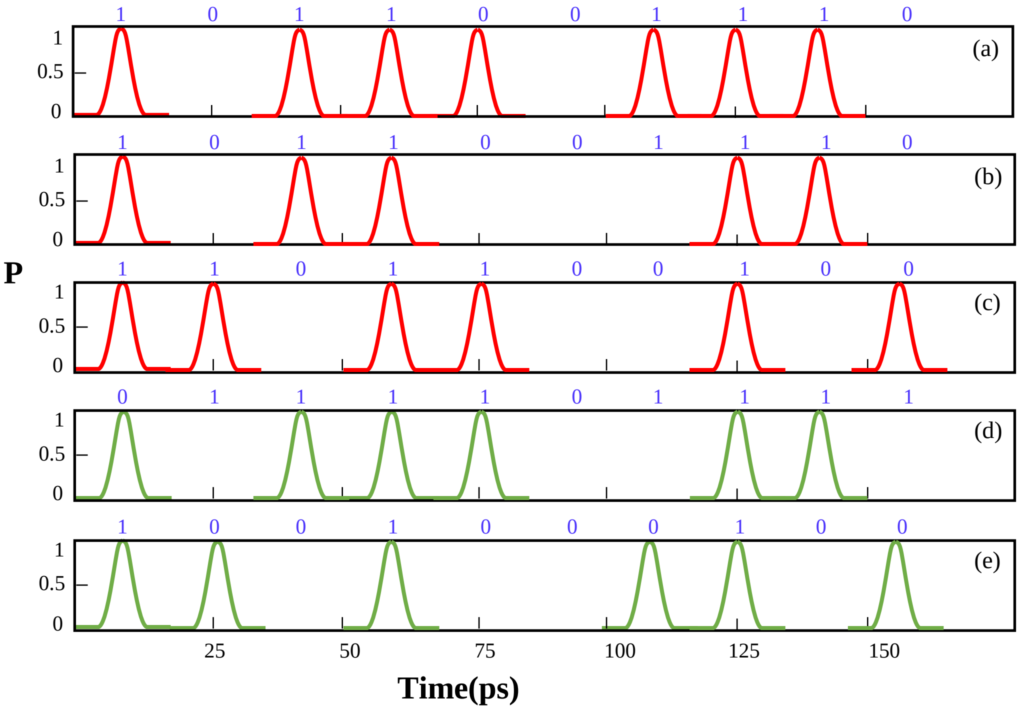

Fig. 6. Experimental results: the various input pattern: (a)-(c) the sum and carry output result: (d),(e).

References

1. T. Houbavlis, K. E. Zoiros, M. Kalyvas, G. Theophilopoulos, C. Bintjas, K. Yiannopoulos, N. Pleros, K. Vlachos, H. Avramopoulos, L. Schares,L. Occhi, G. Guekos, J. R. Taylor, S. Hansmann, and W. Miller, “Alloptical signal processing and applications within the esprit project DO_ALL,” J. Lightw. Technol., vol. 23, no. 2, pp. 781–801, Feb. 2005.
2. S. Singh, Lovkesh, X. Ye, and R. S. Kaler, “Design of ultrafast encryption and decryption circuits for secured optical networks,” IEEE J. Quantum Electron., vol. 48, no. 12, pp. 1547–1553, Dec. 2012.
3. Y. Aikawa, S. Shimizu, and H. Uenohara, “Demonstration of all-optical divider circuit using SOA-MZI-type XOR gate and feedback loop for forward error detection,” J. Lightw. Technol., vol. 29, no. 15, pp. 2259–2266, Aug. 2011.
4. S. H. Kim, J. H. Kim, J. W. Choi, C. W. Son, Y. T. Byun, Y. M. Jhon, S. Lee, D. H. Woo, and S. H. Kim, “All-optical half adder using cross gain modulation in semiconductor optical amplifiers,” Opt. Exp., vol. 14, no. 22, pp. 10693–10698, Oct. 2006.
5. K. E. Stubkjaer, “Semiconductor optical amplifier-based all-optical gates for high-speed optical processing,” IEEE J.Sel. Topics Quantum Electron., vol. 6, no. 6, pp. 1428–1435, Nov./Dec. 2000.
6. J. Wang, J. Q. Sun, and Q. Z. Sun, “Single-PPLN-based simultaneous half-adder, half-subtracter, and OR logic gate: Proposed and simulation,” Opt. Exp., vol. 15, no. 4, pp. 1690–1699, Feb. 2007.
7. J. H. Kim, Y. T. Byun, Y. M. Jhon, S. Lee, D. H. Woo, and S. H. Kim, “All-optical half adder using semiconductor opticalamplifier based devices,” Opt. Commun., vol. 218, no. 4–6, pp. 345–349, Apr. 2003.
8. J. B. Dai, S. Shimizu, X. Wang, and N. Wada, “Simultaneous all-optical half-adder and half-subtracter based on two semiconductor optical amplifiers,” IEEE Photon. Technol. Lett., vol. 25, no. 1, pp. 91–93, Jan. 2013.
9. J. H. Kim, Y. M. Jhon, Y. T. Byun, S. Lee, D. H. Woo, and S. H. Kim, “All-optical XOR gate using semiconductor optical amplifier without additional input beam,” IEEE Photon. Technol. Lett., vol. 14, no. 10, pp. 1436–1438, Oct. 2002.
10. J. Wang, J. Q. Sun, Q. Z. Sun, D. L. Wang, X. L. Zhang, D. X. Huang, and M. M. Fejer, “PPLN-based flexible optical logic AND gate,” IEEE Photon. Technol. Lett., vol. 20, no. 3, pp. 211–213, Feb. 2008.
11. J. Wang, J. Q. Sun, X. L. Zhang, D. X. Huang, and M. M. Fejer, “Ultrafast all-optical three-input Boolean XOR operation for differential phase-shift keying signals using periodically poled lithium niobate,” Opt. Lett., vol. 33, no. 13, pp. 1419–1421, Jul. 2008.
12. L. Yin, J. Zhang, P. M. Fauchet, and G. P. Agrawal, “Optical switching using nonlinear polarization rotation inside silicon waveguides,” Opt. Lett., vol. 34, no. 4, pp. 476–478, Feb. 2009.
13. J. Y. Lee, L. Yin, G. P. Agrawal, and P. M. Fauchet, “Ultrafast optical switching based on nonlinear polarization rotation in silicon waveguides,” Opt. Exp., vol. 18, no. 11, pp. 11 514–11 523, May 2010.
14. Y. Wang, X. Zhang, J. Dong, and D. Huang, “Simultaneous demonstration on all-optical digital encoder and comparator at 40 Gb/s with semiconductor optical amplifiers,” Opt. Exp., vol. 15, no. 23, pp. 15080–15085, Nov. 2007.
15. M. Scaffardi, P. Ghelfi, E. Lazzeri, L. Poti, and A. Bogoni, “Photonic processing for digital comparison and full addition based on semiconductor optical amplifiers,” IEEE J. Sel. Topics Quantum Electron., vol. 14, no. 3, pp. 826–833, May/Jun. 2008.
16. Z. V. Rizou, K. E. Zoiros, A. Hatziefremidis, and M. J. Connelly, “Design analysis and performance optimization of a Lyot filter for semiconductor optical amplifier pattern effect suppression,” IEEE J. Sel. Topics Quantum Electron., vol. 19, no. 5, pp. 1–9, Sep./Oct. 2013.
17. J. Xu, X. Zhang, and J. Mark, “Investigation of patterning effects in ultrafast SOA-based optical switches,” IEEE J. Quantum Electron., vol. 46,no. 1, pp. 87–94, Jan. 2010.
18. T. Akiyama, M. Ekawa, M. Sugawara, K. Kawaguchi, H. Sudo, A. Kuramata, H. Ebe, and Y. Arakawa, “An ultrawide-band semiconductor optical amplifier having an extremely high penalty-free output power of 23 dBm achieved with quantum dots,” IEEE Photon. Technol. Lett., vol. 17, no. 8, pp. 1614–1616, Aug. 2005.
19. O. Qasaimeh, “Dynamics of optical pulse amplification and saturation in multiple state quantum dot semiconductor optical amplifiers,” Opt.Quantum Electron., vol. 41, no. 2, pp. 99–111, Jan. 2009.
20. G. P. Agrawal and N. A. Olsson, “Self-phase modulation and spectral broadening of optical pulses in semiconductor laser amplifiers,” IEEE J.Quantum Electron., vol. 25, no. 11, pp. 2297–2306, Nov. 1989.
21. Z. Li, Y. Liu, S. Zhang, H. Ju, H. de Waardt, G. D. Khoe, H. J. S. Dorren, and D. Lenstra, “All-optical logic gates using semiconductor optical amplifier assisted by optical filter,” Electron. Lett., vol. 41, no. 25, pp. 1397–1399, Dec. 2005.
22. A. Bogris, P. Velanas, and D. Syvridis, “Numerical investigation of a 160-Gb/s reconfigurable photonic logic gate based on cross-phase modulation in fibers,” IEEE Photon. Technol. Lett., vol. 19, no. 6, pp. 402–404, Mar. 2007.
23. T. K. Liang, L. R. Nunes, M. Tsuchiya, K. S. Abedin, T. Miyazaki, D. V. Thourhout, W. Bogaerts, P. Dumon, R. Baets, and H. K. Tsang, “High speed logic gate using two-photon absorption in silicon waveguides,” Opt. Commun., vol. 265, no. 1, pp. 171–174, Sep. 2006.
24. B. Dai, S. Shimizu, X. Wang, and N. Wada, “Simultaneous all-optical half-adder and half-subtracter based on two semiconductor optical amplifiers,” IEEE Photon. Technol. Lett., vol. 25, no. 1, pp. 91–93, Jan. 2013.
25. J. Wang, J. Q. Sun, Q. Z. Sun, X. L. Zhang, and D. X. Huang, “All-optical dual-direction half-subtracter based on sumfrequency generation,” Opt. Commun., vol. 281, no. 4, pp. 788–792, Feb. 2008.