Reconfigurable Multi-logic Gates Based on SOA Nonlinear Polarization Rotation Effect

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***Abstract*-- We demonstrate a reconfigurable all-optical logic gate based on predominant nonlinear polarization rotation effect in a single semiconductor optical amplifier. The principle of operation is explained in detail. Five reconfigurable logic functions, including NOT, OR, NOR, AND, and NAND, were realized using 10-Gb/s on-off keying signals with flexible wavelength tenability. The logic operations were achieved by adjusting polarization controllers and the input data power.**

I. INTRODUCTION

Optical logic gates are key elements for realizing all-optical functions such as header recognition, label swapping and parity checking for future optical packet switching (OPS) networks. Recently, multi logic operations in a same logic device, namely, reconfigurable logic gates, have attracted much interest of the research communities due to its flexibility and potential low cost. Previously reported techniques for achieving the all-optical reconfigurable logic functions mainly utilized nonlinear effects in highly nonlinear fibers [1-2] and semiconductor optical amplifiers (SOAs) [3-5]. Among them, the logic gates based on semiconductor devices feature the advantages of compactness, monolithic integration and low power consumption. Logic functions including XOR, NOR, OR and NAND were realized based on cross-phase modulation (XPM) in a complex SOA-based Mach-Zehnder interferometer (SOA-MZI) structure [3]. A single SOA was used to realize multi logic operations utilizing simultaneous cross-gain modulation (XGM) and four-wave mixing (FWM) effects [4], or FWM accompanied with polarization encoding of signals [5]. However, the different logic functions must be operated at different output wavelengths and different output ports [4], while in [5] the input signals had to be encoded in polarization, which could limit the applications of the logic devices.

In this paper, we demonstrate a reconfigurable logic gate based on predominant nonlinear polarization rotation (NPR) effect in a single SOA. Multi-logic operations including NOT, OR, NOR, AND and NAND are successfully realized with 10-Gb/s non return-to-zero on-off keying (NRZ-OOK) signals. All the logic operations are obtained at a same output of the device by adjusting polarization controllers and the data power in the setup, and the operating wavelength of the logic functions can be flexibly tuned by changing the wavelength of a probe light. Such operations may be desired in practical reconfigurable logic gates.

Table 1: The basic logic operations

D1	D2	NOT (D1)	OR	NOR	AND	NAND	XOR	XNOR
0	0	1	0	1	0	1	0	1
0	1	1	1	0	0	1	1	0
1	0	0	1	0	0	1	1	0
1	1	0	1	0	1	0	0	1

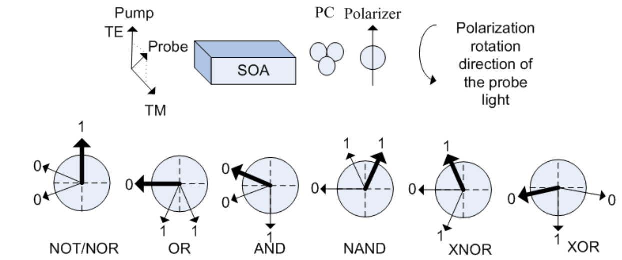

Fig.1 Schematics of the logic operations based on NPR in an SOA. In the six operations, the arrows represent the polarization states of the probe light existing from the PC, where the bold arrow is the original polarization state without the pump, corresponding to the input state of '00'. The numbers on the arrows represent the operation results.

II. PRINCIPLE OF OPERATION

Tab. 1 shows seven basic logic operations (NOT, OR, NOT, AND, NAND, XOR, and XNOR). Other more sophisticated logic operations can be realized based on their combinations. Except for the NOT operation, the '01' and '10' inputs of D1D2 lead to the same output value, therefore the four input states (00, 01, 10, 11) of D1D2 result in three different optical power states, namely 0, 1 and 2, if D1 and D2 have the same polarization states. In the following explanation, we use different power states ($0\rightarrow1\rightarrow2$) of a continue-wave (CW) light to replace the four input states of D1D2. The power difference from 0 to 1 corresponds to the extinction ratio (ER) of the data, and the one from 1 to 2 is about a 3-dB change.

Fig.1 depicts the principle of the logic operations based on NPR in an SOA. The CW pump light represents D1 and D2 having the same polarization orientation in parallel with one of the principal axes of the SOA (TE or TM mode). The polarization state of a CW probe light is adjusted by 45^o with respect to the principle axes of the SOA to achieve the best operating performance. The projections of the probe light at TM and TM modes experience different gains and refractive index variations because of the different total optical powers in the two modes, thus the phase variations experienced by the two projections are also different. The variation of the phase difference in the two axes leads to the polarization rotation of the probe light, and the rotation radian increases with the pump power.

Multi-logic operations could be obtained by tuning the polarization state of the probe light exiting from the SOA using a polarization controller (PC) and a polarizer. If the original polarization state (without the pump) of the output probe light is aligned with the polarizer, the output power is the maximum, corresponding to the operation result of “1”. With the pump power increases (0→1→2), the transmitted power firstly decreases to the minimum and then increases due to the polarization rotation of the probe light. We can set two equal powers close to the minimum as the operation results of ‘0’, therefore the corresponding power variation of the probe light is 1→0→0, which achieves NOR operation. In the similar process, OR, AND, NAND, XNOR and XOR operations can be realize by tuning the original polarization states of the output probe light, respectively.

III. Experiment Results and discussion

We modulate the signal data with a fixed pattern at 10-Gb/s at the bit sequences “110110000011011000” and “000110110000011011” of D1 and D2, respectively. Fig. 2 shows the observed multi-logic operations. All operations with the inputs of 00, 01, 10 and 11 are achieved. By carefully tuning the PCs and the total power of D1 and D2, best performance can be achieved.

In practice, one can firstly record the optimum working state of each logic operation by employing the digitally controllable PC and the power-controlled optical amplifier of the input data, and then choose the corresponding state based on the requirement to realize the switching of different logic operations. It can be seen that NOR, OR, AND, NAND, and NOT are implemented correctly. No obvious pattern effects are observed even thought the SOA is deeply saturated, as the SOA has fast recovery time. The power fluctuations in the high and low levels and the different pulse-width for some logic operations are mainly due to the non-ideal tuning of the data power and the time mismatch of D1D2. We obtained multi-logic operations at the same output port of the logic device by tuning the PCs and the data power. The operating wavelength could also be flexibly tuned by varying the wavelength of the probe light, which is different with the FWM-based reconfigurable logic gates [4-5], where the wavelength of logic operations is limited by the signal wavelengths, and D1 and D2 must be operated in different wavelengths to realize FWM.

In principle, XNOR and XOR operations can also be obtained, however the small polarization rotation radian in as-used SOA and the simultaneous XGM effect make them difficult to realize in this experiment. For NOT, NOR, OR, AND, and NAND operations, with the increasing of the data power, the XGM effect will also affect the power variation of the transmitted probe light, and show different impacts on the output power and ER in different logic operations.

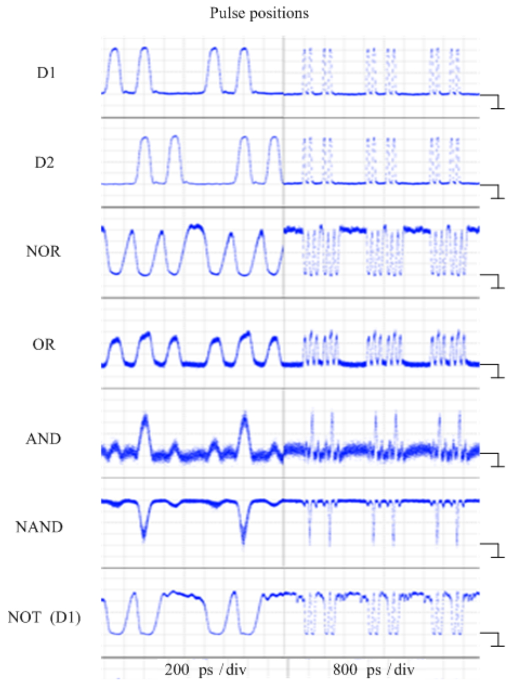

Fig.2 The results of the logic operations.

IV. Conclusions

A compact, flexible and reconfigurable all-optical logic gate has been demonstrated based on predominant NPR effects in a single SOA. NOT, OR, NOR, AND, NAND operations at 10-Gb/s bit rate was successfully realized. All the logic operations are obtained from the same port of the logic gate and the operating wavelength can be tuned according to the practical requirements. Such a reconfigurable multi-logic gate would be a potential candidate in the future all-optical network.

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