All-Optical Logic and Arithmetic Operations Designed by Modified Add-drop Filter

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***Abstract*— A small scale optical device system based on microring resonator system is designed for optical logic applications, which is used the optical logic and arithmetic operations based on optical tree architecture (OTA). In this paper, we study the effected of the system, which is comprised with modified add/drop filter, which is injected by the nonlinear pulses input for generated optical logic. The input and control of the circuit can be forms by nonlinear pluses. The obtained simulation results have shown that the nonlinear pulse generated by nonlinear ring resonator can be control the intensity output. In applications, the output consistency is importance, when the interconnection between each output part is required. The advantages of modified add/drop filter ring resonator are low power, ultra-fast switching and tunable output, which is suitable for small scale device and system requirements.**

Keywords*— All-optical logic; All-optical arithmetic; Photonic circuits; Digital optics

I. INTRODUCTION

Communication and information processing toward the limitation of electrical copper wire to all-optical technology are the key success for next generation of ultrafast data transmission, in which the speed of optical processing is the ultimately limited by the speed of electronic input and output [1]. The ring resonator has been used in various circuits and applications for an electronic circuit replacement. The advantages of ring resonator are small, low power, low loss, high Q, ultra-fast switching. Many researchers have proposes various architectures, techniques and designs for all-optical logic and all-optical processing, for instance, semiconductor optical amplifier (SOA) [2-5], a quantum dot [6,7], a terahertz optical asymmetric de-multiplex (TOAD) [8,9], cascaded micro ring resonators [10,11], an all-optical arithmetic unit [12,13] , an all-optical binary counter [14], an all-optical adder [15, 16]. Therefore, the search of new materials and techniques has become the challenge especial nonlinear material device. The nonlinear ring resonator and nonlinear signal system behaviors will produce a new generation components. It is recommended and great of interest because the ring resonator, in which the advantages for photonic integrated circuit and nonlinear pulses are better for the information carriers to transmit the digital signal at high bit rates over long distances [17].

In this paper, we study the effected of the system, which is comprised with modified add/drop filter, which is injected by the nonlinear pulses for generated optical logic and arithmetic operation based on tree architecture, which can be used for an electronic logic replacement and improvement performance and control intensity output threshold. In this concept, the simultaneous logic operation of binary based on nonlinear pulse control behaviors can be performed. The proposed scheme is based on a 1 bit binary, which logic '0' and '1' used the dark and bright nonlinear pulses, respectively.

II. OPERATING PRINCIPLE

The modified add/drop filter is as shown in Figure 1. The coupling region is defined by the coupling factor κ. The equations describe the coupled electric fields are given by references [19, 20, 21, 28].

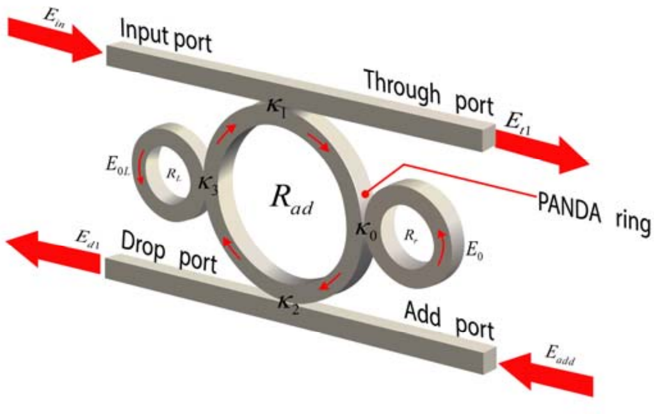


FIG.1 THE MODIFIED ADD/DROP RING RESONATOR

The input and control fields at the input and add ports are formed by the dark and bright optical nonlinear pulses, which are given by reference [18] as shown in Eqs. (1) – (2).

$$E_{in}(t) = A_0 \tanh\left[\frac{T}{T_0}\right]\exp\left[\left(\frac{z}{2L_D}\right) - i\omega_0 t\right] \qquad (1)$$

$$E_{in}(t) = A_0 \operatorname{sech}\left[\frac{T}{T_0}\right]\exp\left[\left(\frac{z}{2L_D}\right) - i\omega_0 t\right] \qquad (2)$$

When light propagates within the nonlinear material (medium), the refractive index (n) of light within the medium is given by Eq. (3), which is given by references [22, 23, 24].

$$n = n_0 + n_2 I = n_0 + \frac{n_2}{A_{eff}} P \qquad (3)$$

An optical tree architecture is the multiplying system of a single straight path into several distributed branches and sub branch paths is as shown in Figure 2 [25], where light beam emits from point, which will break into two parts BC and BD, two beams will be split again into four parts, i.e. BC to CE, CF and BD to DG and DH. In this way more optical output channels could be obtained from the single input light beam. An all-optical logic and arithmetic operations in this paper is based on the optical tree architecture, which can be formed by beam splitter and beam combiner to generated logic operation at each output port.

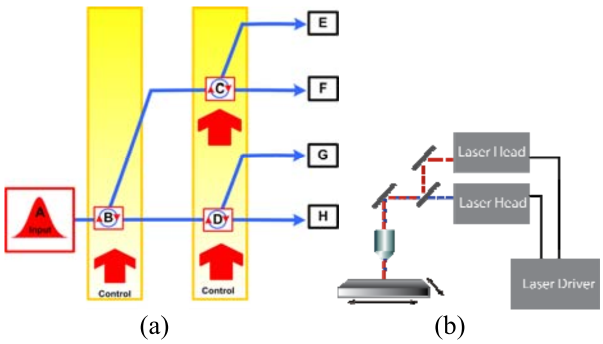


FIG.2 (a) OPTICAL TREE ARCHITECTURE (b) PUMP SIGNAL

III. ALL OPTICAL LOGIC AND ARITHMETIC OPERATION

A modified add/drop ring resonator for all-optical logic and arithmetic operations by a nonlinear pulse can be successful operated with optical tree architecture as shown in Fig. 3. In this scheme, where 3 ring resonators (MRR1, MRR2, MRR3) are used and set at B, C and D, in which an optical filter is applied at all output ports to reduce the power nonlinear formation and the switching threshold output, which is shown in Fig. 3, where the input and control field which is generated by dark-bright nonlinear pulse. By using dark-bright nonlinear for power ripple control and switching signal output, the CW bright nonlinear and dark nonlinear pulse input ('0') used wavelength λ_1, and bright nonlinear pulse λ_2 is used for input pulse ('1'). In this scheme, the dark nonlinear pulse is used to represent logic '0' and the bright nonlinear pulse represents the logic '1'. The all-optical switch by applied optical pumping on top . The pumping energy near material bandgap energy and almost fully absorbed in the ring resonator [27]. The cross-phase modulation (XPM) is applied to the dark-bright nonlinear light pulse circumference into the nonlinear ring resonator, which can be used to increase or decrease (forward and reverse bias) refractive index simultaneously, which is shown in Fig. 4 (a)-(b). The optical signal output at through and drop ports can be controlled, which can make the optical signal at the through and drop ports out of phase of π [26]. Regarding to the nonlinear effect phenomena, the optical logic switching at the output port of ring resonator (throughput port and drop port) can be formed and represented the NOT gate, as shown in Fig. 4 (a)-(b), the data can be concluded by the logic operation in Table.1. Results of the configuration by exciting on top of ring resonator using dark-bright nonlinear are obtained simultaneously and seen at the drop and through ports by T2, D2, T3 and D3 for optical logic operation as shown in Fig. 5.

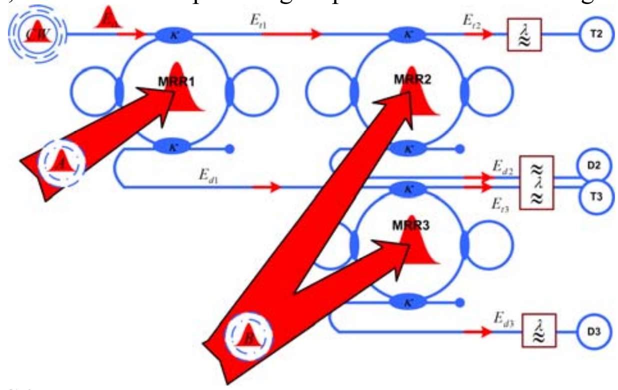


FIG.3 RING RESONATOR CIRCUITS FOR ALL-OPTICAL LOGIC AND ARITHMETIC OPERATIONS OPTICAL BASE TREE ARCHITECTURE

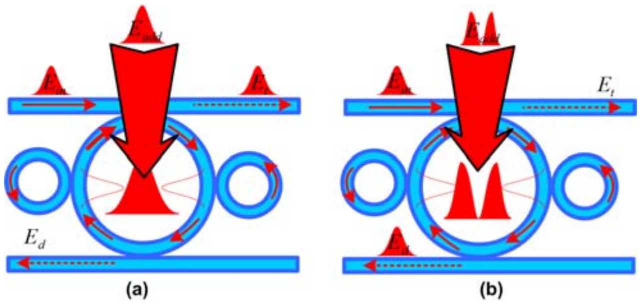


FIG.4 DARK-BRIGHT NONLINEAR CONTROL SWITCH

E_{in}	E_{pump}	E_{th}	E_{drop}
0	0	0	0
0	1	0	0
1	0	1	0
1	1	0	1

TABLE I. DARK-BRIGHT NONLINEAR CONTROL SWITCH

IV. SIMULATION

In the simulation, for optical logic and arithmetic operation, the parameters of modified add/drop ring resonator are fixed to be κ_0 = 0.5, κ_1 = 0.25, κ_2 = 0.25 and κ_3 = 0.5, respectively. The ring radii R_{ad}= 5 µm, R_r= 1.5 µm, R_L= 1.5 µm. In order to make the system associating with the practical device [28], the selected parameters of the system are fixed to n_0 = 3.34 (**InGaAsP/InP**), A_{eff} = 0.50 µm^2 and 0.25 µm^2 for a add/drop ring resonator, respectively, α = 0.5 dBmm^{-1}, γ = 0.1. The nonlinear refractive index of the microring used is n_2=2.2 x 10^{-17} m^2/W. In this case, the attenuation of light propagates within the system (i.e. wave guided) used is 0.5dBmm^{-1}. From Fig.4, the dark-bright nonlinear pulse with wavelength (λ_1) at 1.55 µm for input and control signal, respectively. The bright nonlinear input pulse with wavelength (λ_2) at 1.25 µm, pulse width of $50\,fs$, peak power at 1 mW. The simulation result signal output as shown in Fig. 5 (a-d), the simultaneous output optical logic gate is seen, which can be configured as following details.

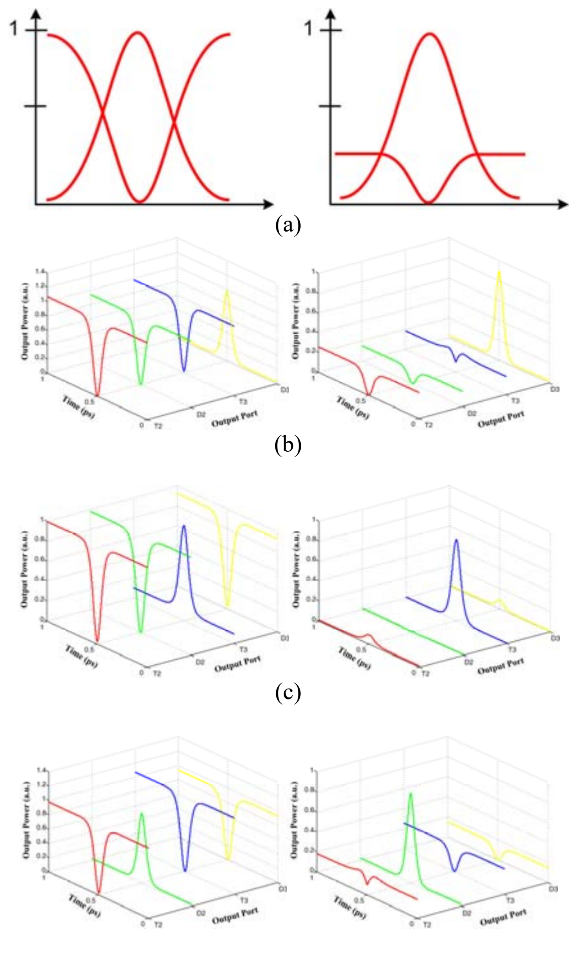
State 1: When the optical pump input data logic **"00"** is added (*A*=0 and *B*=0) , the obtained optical logic output appear at port D3 is formed optical logic output is "**0001**"(see Fig.5 (b)).

State 2: When the optical pump input data logic "**01**" is added (*A=0 and B=1),* the optical logic output "**0010**" is formed (see Fig. 5(c)).

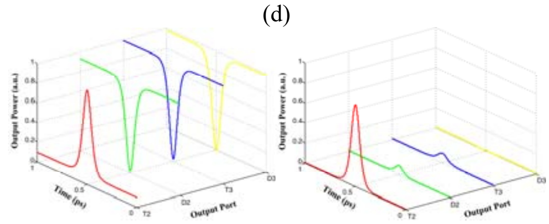
State 3: When the optical pump input data logic "**10**" is added (*A*=1 and *B*=0), the optical logic output "**0100**" is formed (see Fig. 5(d)).

State 4: When the optical pump input data logic "**11**" is added (*A*=1 and *B*=1) is added, the optical logic output "**1000**" is obtained (see Fig 5(e)).

The simultaneous all-optical output is concluded in Table 2, whereas the aforementioned assumption is provided. Here, the symbol represents the logic operation AND when the optical pulse trains A, B are fed into MRR2, MRR3 by the input and add ports, respectively, the optical pulse trains that appear at the through and drop ports have shown that the output logic in T2 gives the result of $A.B$ operation, whereas D2, T3 and D3 give the result of logic $A.\overline{B}$, $\overline{A}.B$, $\overline{A}.\overline{B}$ operations, respectively.



(d)



(e)

FIG.5 SIMULATION RESULTS OF THE OUTPUT LOGIC GATES WHEN THE INPUT LOGIC STATES ARE (B) 00 'DD', (C) 01 'DB', (D) 10 'BD' AND (E) 11 'BB'.

TABLE II. TRUTH TABLE OF THE DARK-BRIGHT NONLINEAR CONTROL SWITCH

CW	*INPUT*		*OUTPUT*			
	A	*B*	E_{th2}	E_{dr2}	E_{th3}	E_{dr3}
1	**0**	**0**	**0**	**0**	**0**	**1**
1	**0**	**1**	**0**	**0**	**1**	**0**
1	**1**	**0**	**0**	**1**	**0**	**0**
1	**1**	**1**	**1**	**0**	**0**	**0**
OPERATION			AB	$A\overline{B}$	$\overline{A}B$	$\overline{A}\overline{B}$

'0'= Dark nonlinear (D), '1'= Bright nonlinear (B).

V. SIMULTANEOUS ALL-OPTICAL LOGIC AND ARITHMETIC OPERATION

From the simulation results, we can form 16 logic operation form two input logic base tree architecture by using the beam combiner(BC) and beam splitters (BS), where the interconnection between each port output (T2,D2,T3,D3) can be concluded in Table 3. The plus (+) sign is used to represent the combine signal output form the expected port. In application to generated 2 bit comparator is as shown in Fig. 6. In order to generate the half adder/subtractor with 2 bit binary inputs, which can be done as shown in Fig.7.

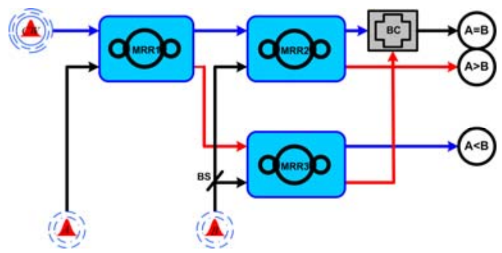


FIG. 6 ALL-OPTICAL DATA COMPARISON

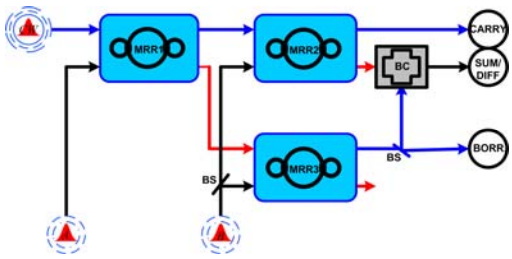


FIG. 7 ALL-OPTICAL HALF ADDER/SUBSTRACTOR

TABLE III. 16 LOGIC OPERATION FROM RING RESONATOR CIRCUIT BASE OPTICAL TREE ARCHITECTURE

Binary Operation	A	B	$\overline{A}$	$\overline{B}$	XOR	$\overline{XOR}$	$A+B$	$A+\overline{B}$	$\overline{A}+B$	$\overline{A}+\overline{B}$	AB	$\overline{A}B$	$A\overline{B}$	$\overline{A}\,\overline{B}$	$TRUE$	$FALSE$
All-Optical Tree Solution	T2 $\boxplus$ D2	T2 $\boxplus$ T3	T3 $\boxplus$ D3	D3 $\boxplus$ D2	D2 $\boxplus$ T3	T2 $\boxplus$ D3	T2 $\boxplus$ D2 $\boxplus$ T3	T2 $\boxplus$ D2 $\boxplus$ D3	T2 $\boxplus$ T3 $\boxplus$ D3	D2 $\boxplus$ T3 $\boxplus$ D3	T2	T3	D2	D3	T2 $\boxplus$ D2 $\boxplus$ T3 $\boxplus$ D3	No signal

VI. CONCLUSION

We have presented the use of simultaneous all-optical logic and arithmetic operation base on modified add/drop ring resonator by using the dark-bright nonlinear control simultaneous logic and arithmetic operation at the through and drop ports, respectively, where the advantages of device are switching speed, low power and each tunable channels can be operated independently. Therefore, the injected dark-bright nonlinear pulse for output logic control operation can be used for security logic operation, which is recognized as the simple and flexible system for performing the logic switching system. Moreover, such device can be extended and implemented for any higher number of input digits by a proper incorporation of dark-bright nonlinear control based optical switches, which can be available for more advanced applications

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