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Implementation of All-Optical Even Parity Checker using the Micro-Ring Resonator Structures

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Abstract: All-optical 4-bit even parity checker in the optical domain is proposed using micro-ring resonator for the optical communication. It incorporates multiple micro-ring resonators where no optoelectronics conversion is required it help in avoiding undesirable latencies and speed limitation imposed by optical to electrical and electrical to optical conversion. All-optical circuits can work at high frequency. It also includes some considerable advantages of optical communication, e.g., compact size, immunity to electromagnetic interference, low attenuation, higher bandwidth and cheap computing. The proposed study explores the concept of switching activity of micro-ring resonator. Further, the switching activity of micro-ring resonator are efficiently applied to implement the proposed device. The study describes the mathematical aspects of the proposed device along with appropriate layout diagram. The match between the analytical and MATLAB simulated result confirms accuracy of the proposed device.

Key words: All-optical, logic gates, micro-ring resonator, parity checker, compact size, MATLAB

INTRODUCTION

Next generation communication system demands the design of compact devices. All-optical signal processing has the advantage of large bandwidth and ultra-fast processing speed. Integrated photonics technology is used to fabricate the all-optical devices where the optical devices are controlled by photons and does not require any optoelectronics conversion. However, due to the smaller dimension, we need the high level of accuracy in designing the device. Ring resonators plays an important role in the silicon photonics (Bogaerts *et al*., 2012). Micro ring resonator is a promising building block for the large scale integrated optics. A vertically coupled GaInAsP-aInP micro ring resonator is proposed (Grover *et al*., 2001).A silicon micro ring resonator of the dimension of 1.5 μm is proposed (Xu *et al*., 2008). Silicon on insulator micro ring resonator give the high Q factor (Pei-Li *et al*., 2006). A array of micro ring resonators can also be used in the designing of ultra-high VLSI photonics (Little *et al*., 2000). Several research work has been reported using the switching phenomena of the micro-ring resonator, micro ring resonator based tunable laser (Matsuo and Segawa, 2009), optical decoder (Chen *et al*., 2014), all-optical XOR and XNOR gate (Sethi and Roy, 2014), 4×1 multiplexer (Rakshit and Roy, 2014), optical adder and subtractor (Rakshit *et al*., 2013), signal selectivity in the form of N×N optical switch (Li *et al*., 2018). Sequential logic circuits are also reported using the micro-ring resonator all-optical D flip-flop is proposed using the micro ring resonator (Rakshit *et al*., 2014), shift register (Rakshit and Roy, 2016). A monotithic optical wavelength routing switch is proposed (Segawa *et al*., 2009). All-optical devices also find application in the optical wireless communication. The proposed device is composed of all-optical devices and can generate data in the range of Gbps. The design has an advantages of small size, low cross talk and large extinction ratio.

MATERIALS AND METHODS

Micro-ring resonator structures: Micro-Ring Resonator (MRR) is an optical device which is associated with the coupling phenomena between the ring resonator and the input and output waveguide. MRR consists of an optical ring of radius r. Some fraction of the incoming input signal is transferred to the ring as shown in Fig. 1. Coupling coefficient between the input waveguide and ring is represented as k_1, coupling co-efficient between ring and output waveguide is k_2. Constructive interference will take place if the path length of the round trip is a multiple of wavelength. The constructive interference in MRR is

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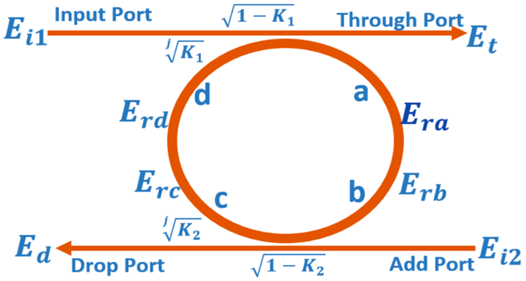


Fig. 1: The single micro-ring resonator

termed as "on resonance". As a result, periodic fringes at the output port is observed, hence, drop port shows the maximum transmission. Minimum resonance is observed at the through port.

Resonance phenomena depends upon the applied pump signal. If the pump signal is applied to the MRR is vertically it is known as Vertically Coupled Micro-Ring Resonator (VCMRR) and if it is applied latterly it is known as Laterally Coupled Micro-Ring Resonator (LCMRR). The effective index of the resonator changes on application of optical pump signal and there is generation of high-density carriers.

The change in refractive index will lead to change in resonance wavelength which is further used to switch the signal on or off. If we consider the circumference of the ring as L, k_1 is coupling co-efficient between the input and the ring, k_2 is coupling co-efficient between ring and the output, α is intensity attenuation co-efficient of the ring, the intensity insertion loss co-efficient is γ and k_n is wave propagation constant where, $k_n = 2\pi/\lambda n_{eff}$, λ is resonant wavelength of the ring. $n_{eff} = n_0+n_2.I = n_0+n_2/A_{eff}\,P$ where, n_0 and n_2 are linear and nonlinear refractive index, respectively. I and P are the intensity and power of optical pump signal. The intensity of optical signal are E_{i1} and E_{i2} at the input and add port respectively. The field at the points a-d of the ring are assumed as E_{ra}-E_{rc}:

$$E_{ra} = (1\text{-}\gamma)^{1/2}\left[j\sqrt{k_1}E_{i1}+\sqrt{(1\text{-}k_1)}E_{rd}\right] \tag{1}$$

$$E_{rb} = E_{ra}\exp\left(-\alpha {}^{L}\!/\!_{4}\right)\exp\left(j^{k_nL}\!/\!_{2}\right) \tag{2}$$

$$E_{rc} = (1\text{-}\gamma)^{1/2}\left[j\sqrt{k_2}E_{i2}+\sqrt{(1\text{-}k_2)}E_{rb}\right] \tag{3}$$

$$E_{rd} = E_{rc}\exp\left(-\alpha {}^{L}\!/\!_{4}\right)\exp\left(j^{k_nL}\!/\!_{2}\right) \tag{4}$$

The field at the through port is given by:

$$E_t = (1\text{-}\gamma)^{1/2}\left[\sqrt{(1\text{-}k_1)}E_{i1}+j\sqrt{k_1}E_{rd}\right] \tag{5}$$

The field at the drop port is given by:

$$E_d = (1\text{-}\gamma)^{1/2}\left[\sqrt{(1\text{-}k_2)}E_{i2}+j\sqrt{k_2}E_{rb}\right] \tag{6}$$

For the simplification let us consider:

$$D = (1\text{-}\gamma)^{1/2},\ x = D\exp\left(-\alpha\frac{L}{4}\right)$$

and $\phi = k_nL/2$. Solving Eq. 1-6, we get the Through Port (TP) and the Drop Port (DP) field as:

$$E_t = \frac{D\sqrt{1\text{-}k_1}\,\text{-}D\sqrt{1\text{-}k_2}\,x^2\exp^2(j\phi)}{1\text{-}\sqrt{1\text{-}k_1}\sqrt{1\text{-}k_2}\,x^2\exp^2(j\phi)}E_{i1}+\frac{\text{-}D\sqrt{k_1k_2}\,x\exp(j\phi)}{1\text{-}\sqrt{1\text{-}k_1}\sqrt{1\text{-}k_2}\,x^2\exp^2(j\phi)}E_{i2} \tag{7}$$

$$E_d = \frac{\text{-}D\sqrt{k_1k_2}\,x\exp(j\phi)}{1\text{-}\sqrt{1\text{-}k_1}\sqrt{1\text{-}k_2}\,x^2\exp^2(j\phi)}E_{i1}+\frac{D\sqrt{1\text{-}k_1}\,\text{-}D\sqrt{1\text{-}k_2}\,x^2\exp^2(j\phi)}{1\text{-}\sqrt{1\text{-}k_1}\sqrt{1\text{-}k_2}\,x^2\exp^2(j\phi)}E_{i2} \tag{8}$$

The mathematical model of through port and drop port of MRR2 can be expressed as:

$$E_d{}' = \frac{\text{-}D\sqrt{k_1k_2}\,x\exp(j\phi)}{1\text{-}\sqrt{1\text{-}k_1}\sqrt{1\text{-}k_2}\,x^2\exp^2(j\phi)}E_d+\frac{D\sqrt{1\text{-}k_1}\,\text{-}D\sqrt{1\text{-}k_2}\,x^2\exp^2(j\phi)}{1\text{-}\sqrt{1\text{-}k_1}\sqrt{1\text{-}k_2}\,x^2\exp^2(j\phi)}E_t \tag{9}$$

$$E_{t'} = \frac{D\sqrt{1\text{-}k_1}\,\text{-}D\sqrt{1\text{-}k_2}\,x^2\exp^2(j\phi)}{1\text{-}\sqrt{1\text{-}k_1}\sqrt{1\text{-}k_2}\,x^2\exp^2(j\phi)}E_d+\frac{\text{-}D\sqrt{k_1k_2}\,x\exp(j\phi)}{1\text{-}\sqrt{1\text{-}k_1}\sqrt{1\text{-}k_2}\,x^2\exp^2(j\phi)}E_t \tag{10}$$

Similarly, mathematical model of all the MRR structure can be derived. Using the above mathematical equation the switching phenomena of micro-ring resonator can be explained.

The simulation for the cascaded GaAs-AlGaAs micro-ring resonator is done with the assumption that there is no optical input signal at the add port and a continuous optical signal of wavelength λ is applied to the input of the ring resonator. Coupling co-efficient is assumed as $K_s = 0.25$, attenuation coefficient $(\alpha) = 0.0005$ μm^{-1}, effective cross-sectional area = 0.25 μm^2 and resonator wavelength $\lambda = 1.55$ μm.

RESULTS AND DISCUSSION

Design of all-optical parity checker using the micro-ring resonator structure: To detect an error occurred during the transmission of any binary information an extra bit is added known as parity bit. It research on the principal of number of 1's in any binary symbol is even or odd.

At the transmitter, the parity bits are generated and the circuit associated with it is parity generator and at the receiver end it is parity checker. The truth table of the 4-bit even parity checker is shown in Table 1. Based on the truth table of even parity checkers, an error will occur if the number of 1's is odd in the received binary message. Hence, Table 1 can be used for the K-map analysis as shown in Fig.2 and the appropriate digital circuit can be represented using Fig. 3.

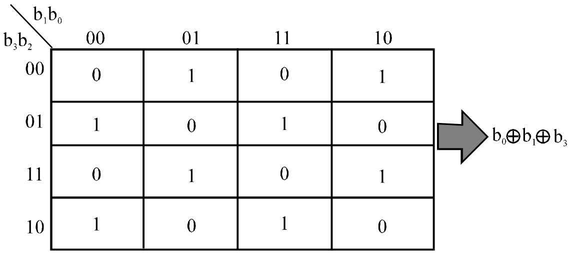
The layout diagram for the implementation of 4-bit even parity checker is shown in Fig. 4. The layout diagram consists of six identical micro-ring resonators. Continuous optical signal of wavelength $\lambda = 1.55$ µm is applied to the input port of the MRR1, MRR3 and MRR5. The specified the arrangement of MRR1 and MRR2 generates the XOR equivalent at the drop port of MRR2 where MRR1 and MRR2 are modulated through the optical control pump signal b_0 and b_1, respectively. Hence, MRR1 and MRR2 provide the optical equivalent of b_0 XOR b_1, it can be termed as g_0. Similarly, optical control pump signal b_2 and b_3 are applied to the specific arrangement of MRR3 and MRR4, respectively. Hence, we can generate the b_2 XOR b_3 optically at the drop port of MRR4 which can be termed as g_1 (Fig. 5-7).

Table 1: Truth table of 4-bit even parity checker

P (even parity checker truth table)	b_3	b_2	b_1	b_0
0	0	0	0	0
1	0	0	0	1
1	0	0	1	0
0	0	0	1	1
1	0	1	0	0
0	0	1	0	1
0	0	1	1	0
1	0	1	1	1
1	1	0	0	0
0	1	0	0	1
0	1	0	1	0
1	1	0	1	1
0	1	0	0	0
1	1	1	0	1
1	1	1	1	0
0	1	1	1	1

Finally, optical pulse g_0 and g_1 are applied as the input control pulse for MRR5 and 6, respectively. The specific configuration of MRR5 and MRR6 generates the optical pulse equivalent of g_0 XOR g_1 which can be treated as optical even parity checker bit. The proposed devices are simulated using the MATLAB Software. Using Eq. 7 and 8, the MATLAB simulation result of the proposed logic design is shown in Fig. 5-7.

Figure 5-7 represents the simulated result of the proposed device. The first four sub figure represents different combinations of input optical bit sequence $b_3b_2b_1b_0$ ranges from 0000-1111. The 5th column



b_3b_2 \ b_1b_0	00	01	11	10
00	0	1	0	1
01	1	0	1	0
11	0	1	0	1
10	1	0	1	0

Fig. 2: K-map of 4-bit even parity checker

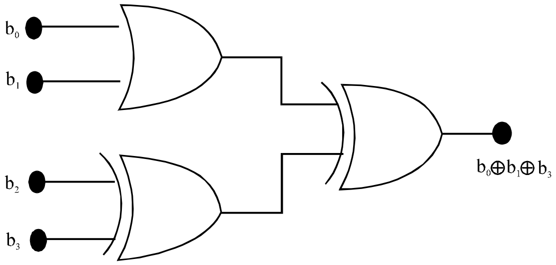


Fig. 3: Circuit diagram of 4-bit even parity checker

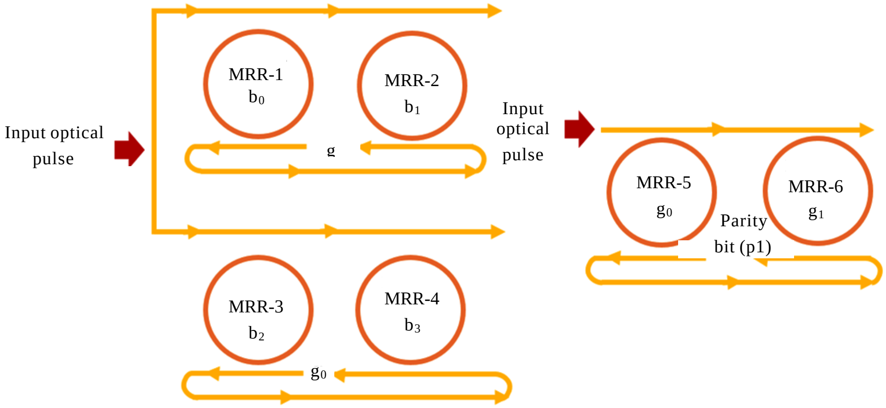


Fig. 4: The layout diagram of all-optical 4-bit even parity checker using the MRR structures

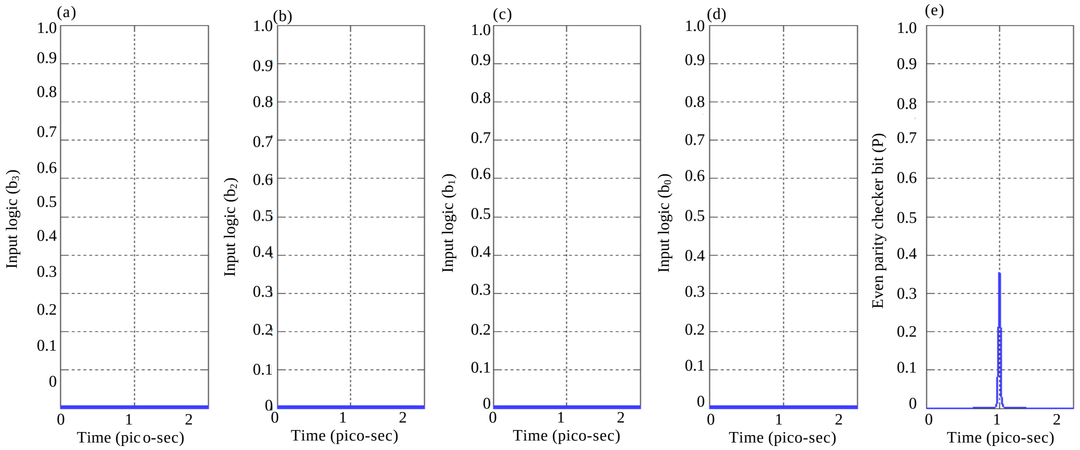


Fig. 5: a-e) The input bit sequence $b_3b_2b_1b_0$→0000 which shows the corresponding even parity checker bit as ‘0’

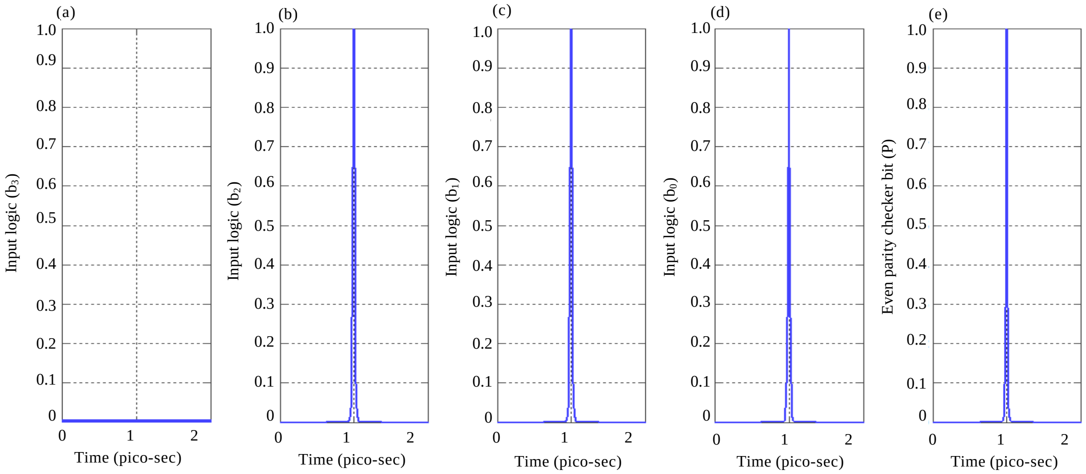


Fig. 6: a-e) The input bit sequence $b_3b_2b_1b_0$→0111 which shows the corresponding even parity checker bit as ‘1’

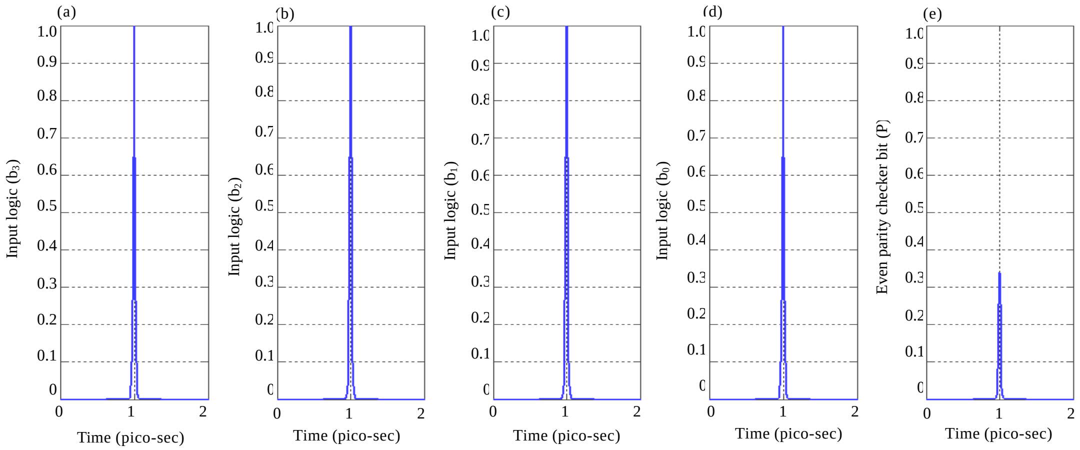


Fig. 7: a-e) The input bit sequence $b_3b_2b_1b_0$→1111 which shows the corresponding even parity checker bit as ‘0

equivalent of even parity checker. All pump signal applied to the structure should be in resonance for the proper functioning of the device.

CONCLUSION

The study describes the design of even parity checker using cascaded arrangement of micro-ring resonator. The micro ring resonator structure and the switching phenomena is discussed. The appropriate configuration of the optimum number of micro-ring resonator structure is used to design layout of the proposed devices. The simulation results are also discussed which prove the theoretical values. Design of all-optical devices can increase the operation speed to considerable amount and decrease the device dimension. Finally, the discussed scheme includes some considerable advantages of the optical communications, e.g., immunity to electromagnetic interference, signal security, larger bandwidth etc. Hence, the proposed scheme can be the stepping-stone in the field of high-speed communication system.

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