

# *Design and Simulation of All Optical NOT logic gate using Micro-ring Resonator*

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## **Abstract**

*All optical computing phenomena are considered the most meticulous and inventive approach to meet the ever-expanding demand of immense speed and rapid switching communication networks. The micro-ring resonator can be used as an elemental apparatus for designing various all-optical computing phenomena. This piece describes the able switching ability of a micro-ring resonator architecture. Further, this also explains the suitable technique for implementing an all-optical NOT logic gate, along with the switching action of a micro-ring resonator architecture with MATLAB simulation result. Lastly, the outcome of the recommended device is authenticated using the MATLAB simulation result. Optical switching activity to obtain the NOT logical functionality includes some additional advantages in an optical communication network. e.g., immunisation from electromagnetic interference, security to the signals, parallel computation, compactness.*

**Keywords:** - *Optical logic gate, Micro-ring resonator, Optical NOT logic gate, Optical Switching.*

## **INTRODUCTION**

In the era of technical advancement, the doorway to high speed and immune communication is reached by employing all-optical logical functions. In contrast, the working of the logic gates depends upon some specific Boolean applications with one or multiple inputs. Boolean output depends upon some predefined expressions or functions. With the employment of these logical operations, some notable benefits are achieved in an optical network. Example: - more security to electromagnetic interference, increase in compactness of the system, lesser loss during transmission, eventually increased Bandwidth and uncomplicated, cheaper cost computing. However, there are numerous methods employed to perform the combinational optical logic functionalities. Following Photonic Crystal fibre, blueprints for XOR XNOR OR and NAND gate have been interpreted in-depth [1]. Multimode interference waveguide concepts are used as the building blocks of logic gates. We can notice the depth illustration of arithmetical and theoretical phases of the accomplishment of  $1 \times 4$  optical signal [1], XOR/XNOR and AND logic gates [2], optical full adder/subtractor [3] optical Gray Code Converters,

Even Parity Checkers [4] and universal optical logic gates [5]. Recently various experimenters have validated the accomplishments of differing optical logic functionality with the help of many schemes like quantum dot [6-7], terahertz optical asymmetric demultiplexer (TOAD) based interferometer devices [8-9]. A lot of research work is going on to showcase the capabilities of Micro-Ring Resonator architecture as elemental apparatus to enforce Optical functionality. The Micro-Ring Resonator (MRR) structures help design certain noted combinational and sequential optical-digital circuits [10]. In a similar fashion, the all-optical High-Speed Gray Code Converter [11] and all-optical NAND and Half Adder [12] is successfully designed with the help of MRR based structure. Innumerable exertions are being shown towards the evolution of elemental all-optical logical functions (i.e. Adder/Subtractor) by applying diverse styles like SOA-MZI dependent circuits [13-14], optoelectronic devices grounded on the optical nonlinear MRR [15-16] that firmly hold back electrons and photons casting the base for the coming generation compressed size, low powered and increased speed photonic circuits. In ditto fashion, varied forces are applicative to

different schemes to enforce the Optical Sequential circuits.

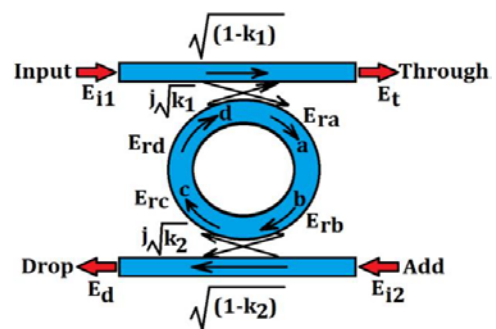
The notion of linear electro-optic effect rested upon Mach-Zehnder interferometer structures are creatively implemented to design optically clocked D flip-flop, synchronous shift register and optical counters [17]. The design of a D flip flop based on an all-optical PRBS generator using serially interconnected discrete Terahertz Optical Asymmetric De-multiplexer (TOAD) is talked about in [18]. In a similar context, to develop a drastic-high speed optical time-division multiplexing network, the base of the building modules is served by the sequential circuits and all optical shift registers. The comprehensive investigation of implementing, Regenerative Storage performance with all-optical re-circulating shift registers, with an inverter at Ten Gb/s using SOA and the assistance of a Sagnac switch and a second SOA, is carried out in [19]. Hence, the proposed paper shows overwhelming labour to realise the all optical NOT logic gate. The first section of this paper deals with a detailed discussion of the research works carried out in optical communication by various researchers. The second section deals with the switching action of the micro-ring resonator architecture. The elemental operations of MRR architecture have been discussed with its layout diagram. This section includes the mathematical discussion and appropriate MATLAB simulation results depicting the switching action.

**STRUCTURE AND WORKING OF MICRO RING RESONATOR AS AN ALL-OPTICAL NOT GATE**

The Micro-ring resonator structure's basic working depends upon the coupling amongst the ring and input-output waveguide. The MRR structure comprises a ring waveguide as resonator cavity nearby coupled with either one or two straight waveguides [20]. Let  $k_1$  be the coupling coefficients between the input waveguide and the ring, along which the incoming field is transferred to the ring. In fig-1,  $r$  is the radius of the ring resonator. The constructive resonance phenomenon "On Resonance" is observed when the round trip of optical path length acquires the value multiple of the effective wavelength. As a result, periodic fringes at the output port is observed. When  $k_2$  (coupling coefficient between the ring and output waveguide) of the built-up wave inside the ring is coupled to this port, a resonance condition prevails that allows transmission at the drop, whereas through port finds the minimum at this resonance. The

involvement of materials of nonlinear nature, resulting in an optical device with high switching capability, is very interesting. Depending upon the hypothesis of the nonlinear effect, the intensity of the light can be utilised in changing the refractive index over the ring resonator. The signal is pumped from the top of the ring with the help of a Laser. The micro-ring waveguide entirely absorbs the pumped optical signal resulting in the generation of high-density carriers. The temporary blue shift of the micro-ring resonance wavelength is due to the effective lowering down of the refractive index of the micro ring waveguide caused by the generated carriers. The resonant wavelength can be changed using variations in the refractive index. The varied resonant wavelength can be used as a switch to on-off the optical signals or to turn the resonance using a particular wavelength.

Let  $L$  be the circumference of the ring ( $2\pi R$ , where the radius of the ring is  $R$ ),  $k_1$  be the field coupling coefficients between the input and the ring and  $k_2$  be the field coupling coefficients between the ring and the output bus,  $\alpha$  be the intensity attenuation coefficients of the ring,  $\gamma$  is the intensity insertion loss coefficient and the wave propagation constant is  $k_n$ , where  $k_n = 2\pi\lambda n_{eff}$ , the resonant wavelength of the ring is  $\lambda$ .  $n_{eff} = n_0 + n_2 I = n_0 + n_2 A_{eff} P$ , where  $n_0$  and  $n_2$  represents linear refractive index and nonlinear refractive index respectively.  $P$  and  $I$  are the power and intensity of the optical pump signal. We have assumed  $E_{i1}$  and  $E_{i2}$  as the input port and add port field respectively. We also assumed that the field at the points a,b,c and d are  $E_{ra}, E_{rb}, E_{rc}$  and  $E_{rd}$  respectively and can be written as [21],



**Fig. 1: Architecture of Micro ring resonator**

$$E_{ra} = (1-\gamma) \frac{1}{2} [j\sqrt{k_1} E_{i1} + \sqrt{(1-k_1)} E_{rd}] \quad (1)$$

$$E_{rb} = E_{ra} \exp(-\alpha L) \exp(jk_n L) \quad (2)$$

$$E_{rc} = (1-\gamma) \frac{1}{2} [j\sqrt{k_2} E_{i2} + \sqrt{(1-k_2)} E_{rb}] \quad (3)$$

$$E_{rd} = E_{rc} \exp(-\alpha L) \exp(jk_n L) \quad (4)$$

The through port field is given by

$$E_t = (1-\gamma) \frac{1}{2} [\sqrt{(1-k_1)} E_{i1} + j\sqrt{k_1} E_{rd}] \quad (5)$$

The drop port field is given by

$$E_d = (1-\gamma) \sqrt{1-k_2} [ \sqrt{1-k_2} E_{i2} + j \sqrt{k_2} E_{r2} ] \quad (6)$$

For simplification let us assume,

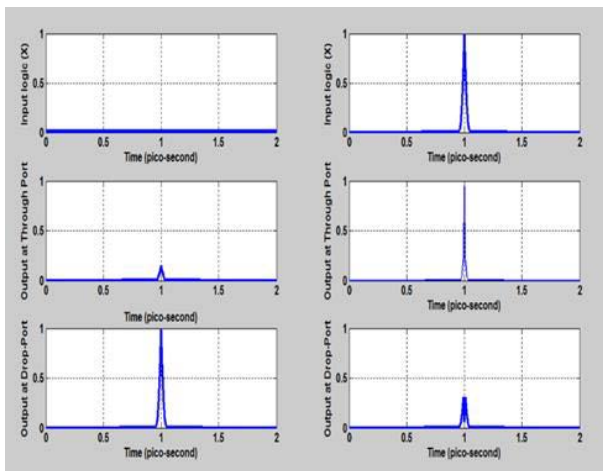
$$D = (1-\gamma) \sqrt{1-k_2}, \quad x = D \exp(-\alpha L) \quad \text{and} \quad \phi = k_n L$$

On solving Eq. (1) through Eq. (6), we get the field at through port (TP) and the drop port (DP) as

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

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

In the simulation process of the cascaded GaAs-AlGaAs micro-ring resonator, an assumption is made that add port is free from the optical input, and a continuous optical signal with wavelength  $\lambda$  is applied to the input of the ring resonator. Coupling coefficients are taken as  $K_s=0.25$ , attenuation coefficient  $(\alpha)=0.0005 \mu\text{m}^{-1}$ , effective cross-sectional area =  $0.25 \mu\text{m}^2$  and the resonator wavelength as  $\lambda=1.55 \mu\text{m}$ .



**Fig. 2: Simulation result of a Micro-ring Resonator architecture**

Fig. 2 represents the proposed micro-ring resonator architecture associated with switching actions. The optical control pump signal is represented in the first row, which carries out modulation in the micro-ring resonator structure. In the second and third-row, the optical signal through the micro-ring resonator structure's port and drop port are represented, respectively. The above image gives an overview that, when the MRR is modulated with an optical control pump signal as  $X=0$ , we can observe the presence of wave optical input signal of continuous nature at

the drop port of the MRR structure with the absence of the optical signal. Similarly, when the optical control pump signal is enforced to the micro-ring resonator, the CW optical input signal is detected at the through port of the MRR structure.

**CONCLUSION**

The paper elaborates an effective mechanism for implementing the optical NOT logic gate, using the concept of switching activity of (MRR) architecture. In this piece, we have explained the proper diagrammatic layout of MRR and its application as an optical OR/NOR logic gate. The paper also contains the MATLAB simulation result of the defined layout diagram, which eventually works on the switching activity principles of Micro-ring resonator architecture. The simulation output concludes that the above-described layout diagram is suitable for designing an all optical NOT logic gate. Henceforth, the discussed method can be the accomplishment in achieving a high-speed communication network.

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