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Design and Characteristics of Photonic Crystal based Optical NOT Logic Gate

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Abstract: In this paper two –dimensional square shaped photonic crystal ring resonator based NOT logic gate is proposed. The numerical, structural, theoretical analysis is performed using 2D-FDTD method where simulation is done through an optical switch. This switch is composed of nonlinear PCRR and T-type waveguide. The dielectric rods used in air is of Indium Phosphide with refractive index of 3.1. Band gap is calculated by plane wave expansion method (PWE) to analyse the structure at resonant wavelength a/λ =0.3116 to a/λ = 0.4365. The structure works on the wavelength of 1.55µm, with 'a' (lattice constant) = 0.5943µm. Size of the square lattice is 12µm x 12µm.

Keywords: NOT logic gate, Photonic crystal, Ring resonator.

I. Introduction

To overcome the problem of future computation and communication in area of telecommunication systems the all-optical logic gates are useful which offers more beneficial efforts as compared to digital electronics. Alloptical logic gates provide high performance in signal processing, computer networks and optical networks. From among the various structures thathave been proposed most common are optical logic gates based semiconductor optical amplifiers(SOA), Mach-Zehnder Interferometer (MZI) based on self-collimation, periodically poled lithium noibate (PPLN) waveguide, photonic crystal self-collimated beam with a phase lag, semiconductor saturable absorber etalons, nonlinear ring resonators inserted between three parallel line defects, etc. There were some shortcomings such as latency time, power consumption, speed and size of structures etc. After these problems photonic crystal based NOT logic was proved to be beneficial [1]. Ultrafast optical logic gates based on nonlinear photonic crystal (NPC) are the key device in the optical signal processing systems and future optical networks. The two dimensional (2-D) NPCs have refractive index changes in two perpendicular directions that play an important role on the photonic components than one dimensional and three dimensional NPCs. It is possible due to case in controlling the propagation modes, accurate calculation of photonic bandgap (PBG), efficient light confinement, simple design and easy fabrication capability. Beside, optical waveguide using photonic crystals have been the attractive attention because of their small dimension and low loss structure[2]. Photonic crystals are defined as dielectric material wherein the dielectric constant is varied in periodical nature. Forbidden band gap is formed which is defined as the range of frequencies through which the light waves could not propagate through the photonic crystals. The propagation in the cavity takes place in Γ–X direction [3]. In this paper, the design of a NOT gate using photonic crystal has been discussed. Also, we focus on different characteristics of logic gate performance with the improvement in spectrum and electric field propagation.

II. Structure Design and Analysis

In this paper, a NOT logic gate is proposed based on two dimensional square lattice photonic crystals composed of cylindrical Indium phosphide (InP) rods in air having refractive index of 3.1and operates at wavelength of 1.55µm . The dielectric constant of 9.61and radius equals r=0.2a and ring radius is 3a, where a=.5943 µmis the lattice constant has been calculated using plane wave expansion as shown in fig.1.[4]

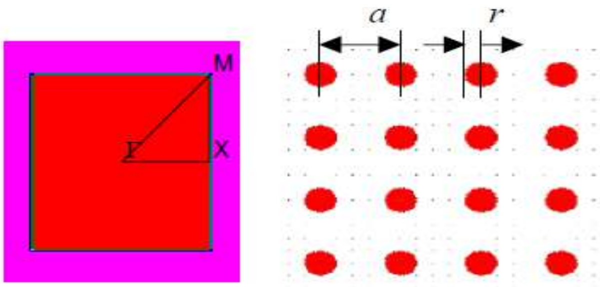

Figure 1. A two dimensional square lattice photonic crystal composed of cylindrical Indium phosphide rods in air, where r is the radius and a is the lattice constant of the Indium phosphide rods, respectively.

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Shown below in fig.2 is the band diagram from which it is clear that the forbidden gap calculated by PWE method occur in the range $0.3116 \leq a/\lambda \leq 0.4365$ for TE mode and hence 0.37405 is the normalised central frequency[5].

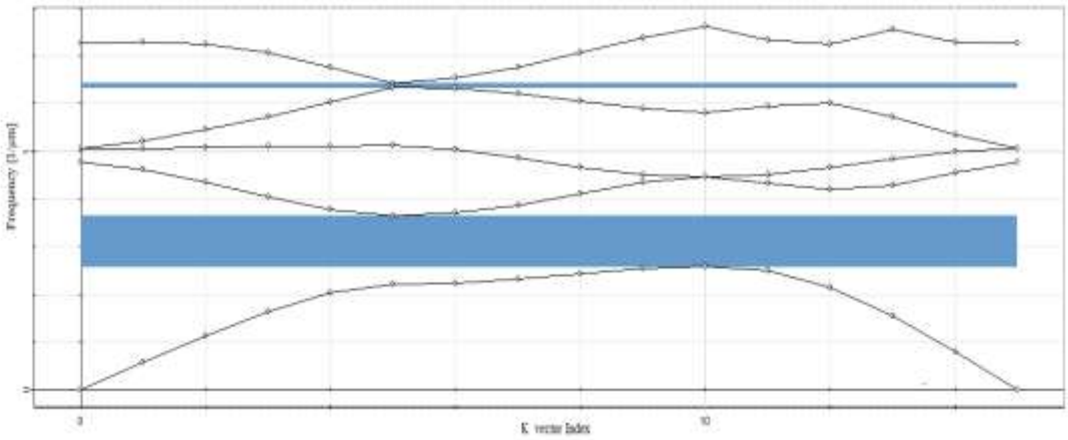

Figure 2. Band gap for NOT logic gate without defect for TE mode

In the structure of NOT gate four InP (indium phosphide) rods are shifted by .707a at the corners so that propagation becomes smooth and easy and effect of inverse scattering of waves in the corners of the ring is reduced. Four rods of radius 0.05 are placed around the cavity in four directions which are used for fine tuning of NOT gate. This is depicted in fig.3. We have to prove the working of NOT logic gate. So from the structure in fig. 3 it is revealed that 'C' is control signal, 'I' is input signal and 'NOT' is output.

Table1. Truth Table for NOT logic gate

Control (C)	Input(I)	Output(NOT)
1	0	1
1	1	0

According to the truth table 1 the control signal is always 'ON'. So for fig.4 if input is at logic level '0' or said to be 'OFF' then control signal passes through the waveguide and output at 'NOT' becomes 'ON' or logic level '1' appears. For fig.5 the control signal is 'ON' i.e. at logic level '1' and similarly '1' logic level is applied at input 'I'. So at output 'NOT' these two signals interfere destructively and hence output at 'NOT' is 'OFF' or logic level '0' appears [6].

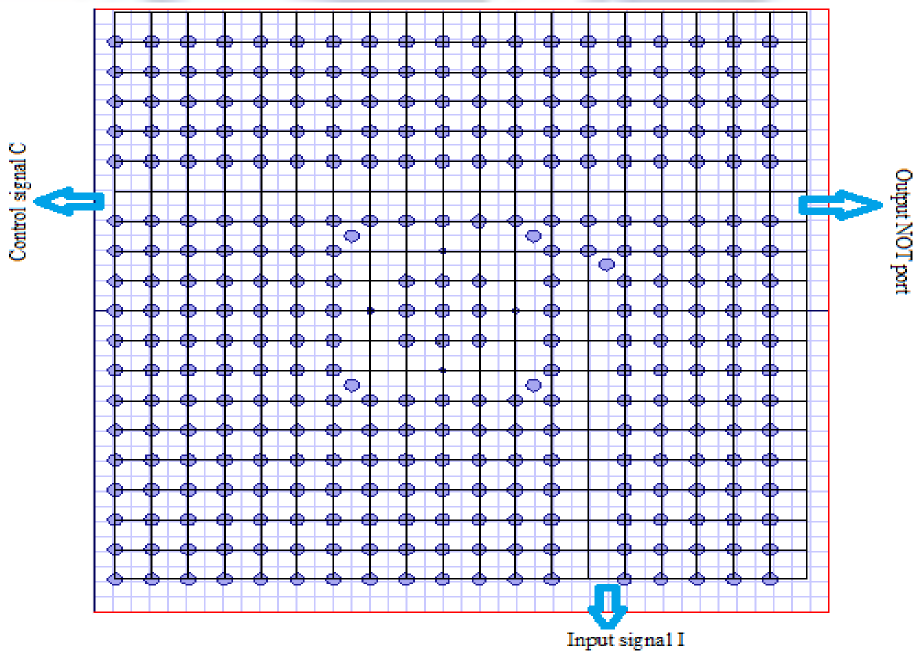

Figure 3 Photonic crystal NOT logic gate structure.

III. Simulation and Results

In the figure 4 and figure 5 the respective DFT (Discrete Fourier Transform), normalised transmission for single wavelength is shown. The transmission spectrum is obtained by the resonant frequency which is 0.37405 in fig.6 and fig. 7 shows combined transmission at both the ports. Simulation is carried by FDTD method by using Gaussian wave and outputs are obtained by FFT and DFT.

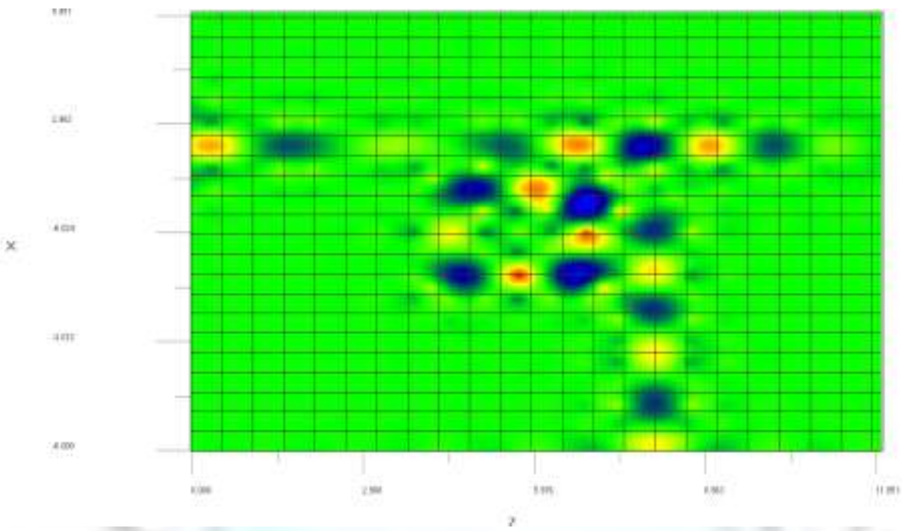

Figure 4.a The electric field propagation for NOT logic gate when input is 'OFF'.

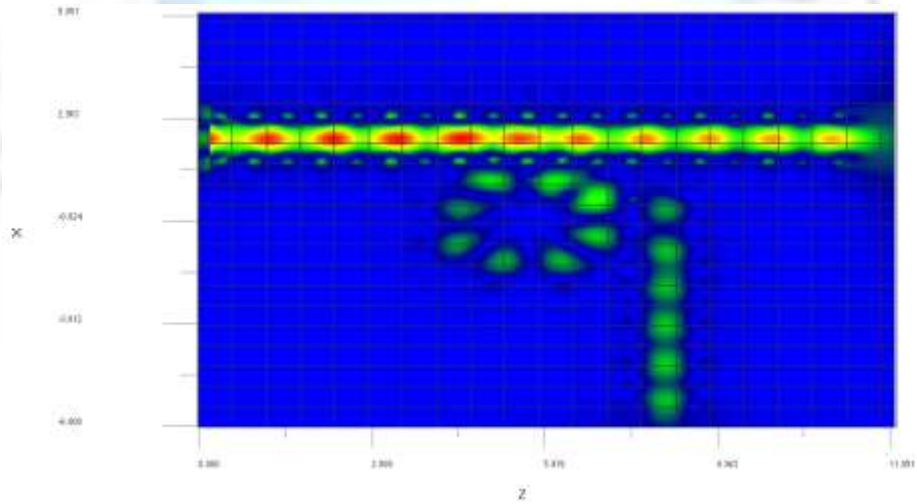

Figure 4.b DFT of NOT logic gate when input is 'OFF'.

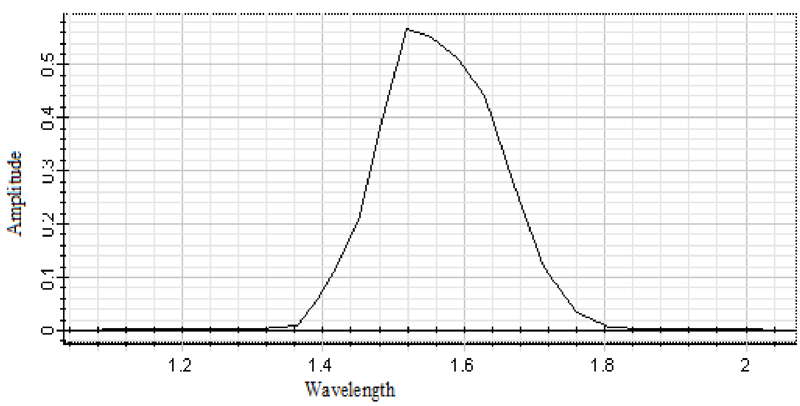

Figure 4 c. Normalised transmission for single wavelength of NOT logic gate when input is 'OFF'.

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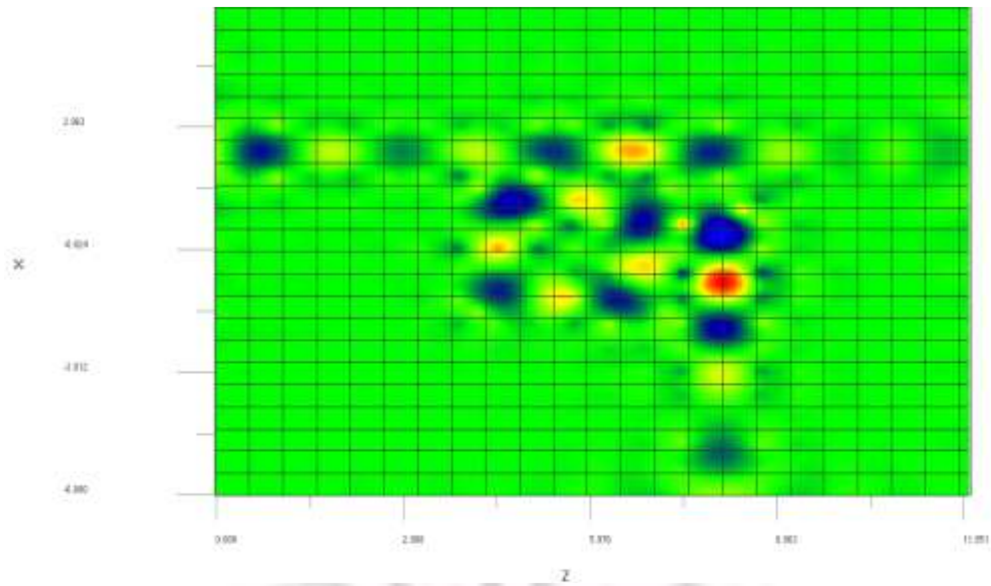

Figure 5 a. The electric field propagation for NOT logic gate when input is 'ON'.

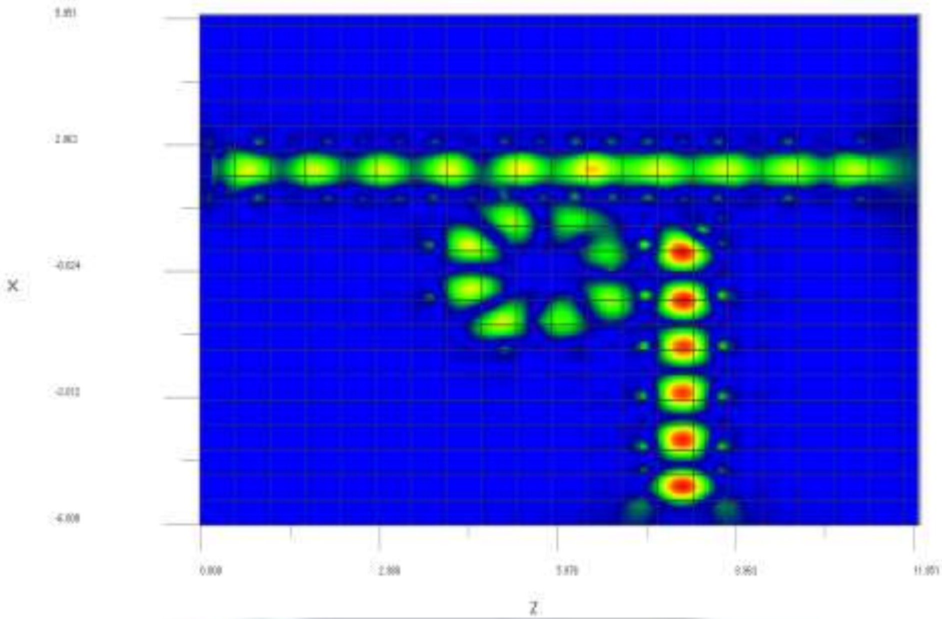

Figure 5.b. DFT of NOT logic gate when input is 'ON'.

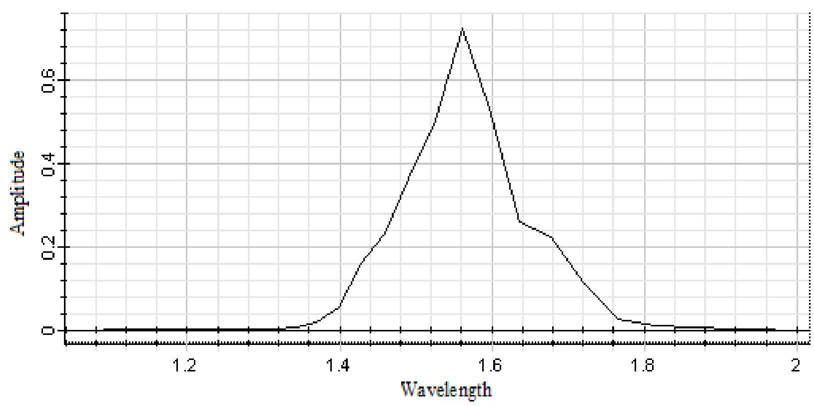

Figure 5 c. Normalised transmission for single wavelength of NOT logic gate when input is 'OFF'.

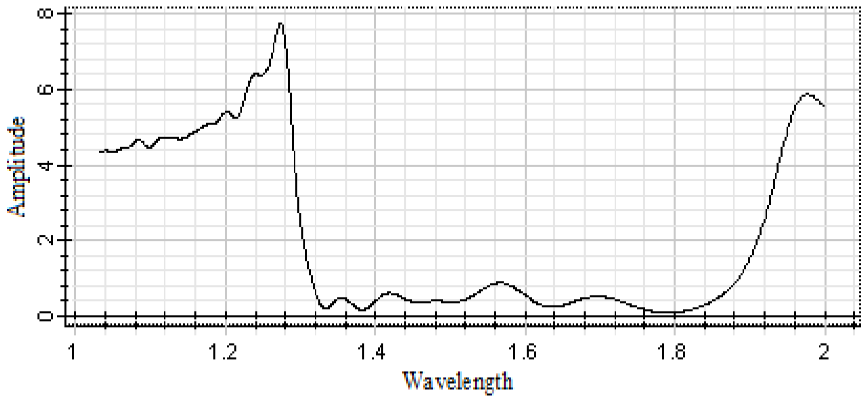

Figure 6. The transmission spectrum of NOT logic gate.

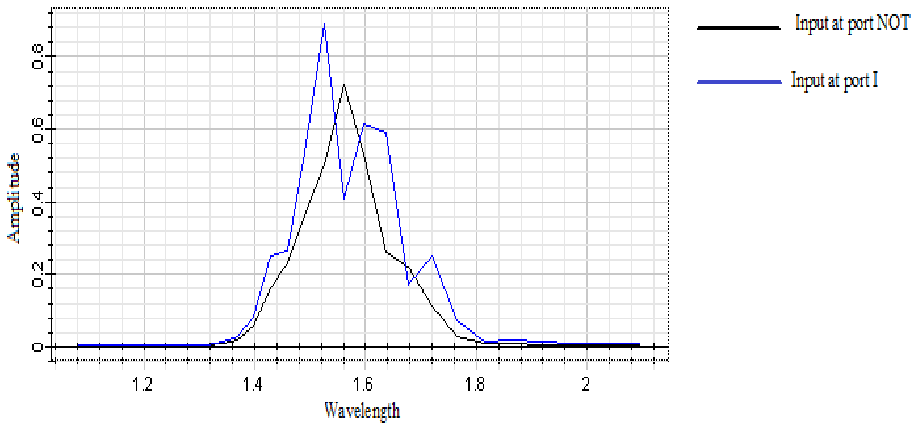

Figure7. Combined transmission at port NOT and I.

Conclusion

The above proposed design achieves all optical NOT logic gate which is made by 2D square lattice of InP dielectric rods having lattice constant ‘a’ as 0.5943µm.compared to other structures. This proposed NOT logic gate is very useful and requires low power consumption. Hence, it is useful for ultrafast optical logical operations and future optical computing components.

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