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DESIGN OF ALL-OPTICAL NOT LOGIC GATE USING InP 2D PHOTONIC CRYSTAL

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Abstract

For the future computation optical technologies will be the next generation of communication system because of its very high speed. Gates are the key elements which are used to realize all-optical functions. All-optical logic gates are core logic unit to implement various all-optical systems for the purpose of optical signal processing. To design the optical gates it is essential to implement a nonlinear medium which modulates the signal to produce the desired results. The nonlinearity may be generated in many ways such as using nonlinear loop mirror, nonlinear fiber, photonic crystal, filter, waveguide, thyristor, acoustic waves, or the semiconductor optical amplifier. Here Optical NOT gate is designed using the photonic crystals. Photonic Crystals (PCs) are dielectric structures with the periodic spatial alternations of the refractive index on the scale of wavelength of light. Many optical devices, which is based on PCs have been proposed. The finite difference time domain (FDTD) and plane wave Expansion (PWE) methods are used here to analyze the behavior of the structure. In this paper, Indium Phosphide rods are used which has the refractive index as 3.1. It is used in high power and high frequency electronics. Output of the NOT gate is extracted using 2D photonic crystals.

Keywords:

Optical NOT Gate, Non Linearity, Photonic Crystals, Finite Difference Time Domain, Indium Phosphide

1. INTRODUCTION

To overcome the problem of future computation and the communication in area of telecommunication systems the all-optical logic gates are useful which gives more beneficial efforts as compared to digital electronics [1]. Light has many advantages over the electron. It travels through a dielectric material at much greater speeds than an electron in a metallic wire. Light can also carry a large amount of information per second. The bandwidth of dielectric materials is significantly larger than that of the metals: bandwidth of fiber optic communication systems is typically of the order of one terahertz, while that of electronic systems (such as telephone) is only a few hundred kilohertz.

Furthermore, light particles (or photons) will not interact strongly like electrons, which help reduce energy losses. Photonic crystals are periodic optical nanostructures which affects the motion of photons in a similar manner as the ionic lattices affects electrons in solids. Photonic crystal occurs in nature in the form of structural coloration and promises to be useful in the different forms in range of applications. Photonic crystals can be fabricated in one, two, or three dimensions. One-dimensional photonic crystals is made of layers deposited or stuck together; two dimensional ones can be made by drilling holes in the suitable substrate, and three-dimensional ones, for example, stacking spheres in a matrix and dissolving the sphere. Photonic crystals are considered as periodic dielectric structures that have a band gap that forbids propagation of a certain frequency range of the light [4]. This property enables to control light with amazing facility and produce effects that are impossible with conventional optics.

Photonic crystals are described exactly by Maxwell's Equations, which we can solve by the application of massive computational power. Electromagnetic wave propagation in the time domain was simulated using Finite difference time domain (FDTD) and photonic bad gap has been calculated using plane wave expansion (PWE). FDTD is used to solve the Maxwells equation [11]. Opti FDTD is a comprehensive tool that enables the design and simulation of advanced passive and nonlinear photonic components. It is used to analyze the design and test the photonic components for wave propagation, scattering, reflection, diffraction, polarization and non-linear phenomena.

Researches have been done for the last years using the optical NOT gate. Optical logic gates are elementary components for optical network and optical computing. The gates are demonstrated numerically by computing electromagnetic field distribution by finite difference time domain (FDTD) method. The ON-OFF contrast ratio is about 6 dB. Numerical simulations are verified successfully by means of the finite difference time domain (FDTD) method. The designed structure can perform the logic gate functions in the same pattern only by adjusting the input power levels.

Under some conditions, PCs creates a Photonic Band Gap (PBG). So, photonic crystals are named as Photonic Bandgap Structure. PBG [10] can control beams of light in the same manner as semiconductors control electric currents and photonic crystals cannot support photons in photonic bandgap. By blocking or permitting light to propagate through a crystal, light processing can be made. The PBG of the material can be designed by plane wave expansion (PWE) method. Usually, the crystal defects like point or line or both can be introduced over the periodic structure by altering the position and the quantitative of dielectric materials for manipulation of light propagation. Low loss in the photonic crystal (PC) structure makes them one of the best candidates for constructing ultra-fast All-optical logic gate.

Logic gates realized by photonic crystals have been researched and attracted much attention, recently. Logic functions are usually implemented through different ways such as using closed packed 2D photonic crystal structure, self-collimated beams [5] in 2D photonic crystal, single-mode wave interference for on-off keyed signals and multi-mode interference for BPSK signals in the photonic crystal waveguides [3]. Waveguides are well known for their operating frequency of the photonic band gaps (PBG) which can control the light propagation of the electromagnetic wave.

2. DESIGN PROCEDURE

In this article, a two dimensional dielectric rod type photonic crystal based all-optical NOT gate has been designed. For the crystal design, Indium Phosphide has chosen as dielectric rod with refractive index of 3.1. The wafer dimensions are 17µm × 21µm. The input wave is taken to be a Gaussian Modulated Continuous Wave has the wavelength of 1.55µm. The cell radius *r* = 0.2 and the lattice constant *a* = 1.0. The control signal is given using the vertical input plane and input can be given using the point source in the horizontal input port, output observation point is located in the vertical output port. The lattice structure may be in the form of hexagonal or rectangular. In this design, rectangular lattice structure is used. Based on the application, the size of the cell can be adjusted and the cells can be removed and it can be turned on. Ring resonator principles are used to perform the NOT gate operation. This can be designed by creating any cavity, defects in the crystal structure. The photonic crystal NOT gate structure is depicted in Fig.1.

There are three ports in the photonic crystal NOT gate structure. They are control signal port, input signal port and output port. Four Indium Phosphide (InP) rods are placed at the corners of the ring resonator so that the propagation of the light becomes smooth and it also avoids the inverse scattering. The control signal is given to the NOT gate using the vertical input plane and the input signal is given using point source to the input port, the output is observed using observation point from the output port.

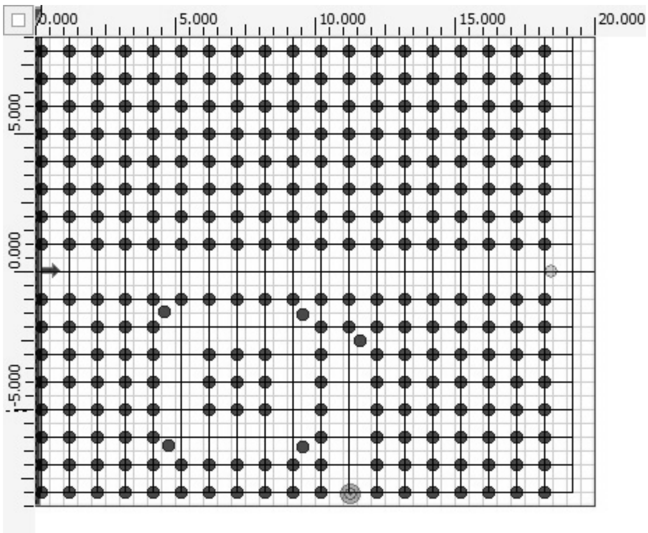

Fig.1. Photonic Crystal NOT gate structure

The distribution of refractive indices of an InP photonic crystal NOT gate structure is shown in Fig.2. The simulation has been performed using Opti FDTD software, where the finite difference time domain method are used to analyze the behavior of the structure and plane wave expansion methods band solver is used to calculate photonic band gap structure.

3. SIMULATION RESULT

From the simulation output, it was concluded that the NOT gate was successfully designed using InP rod type 2D photonic crystal. The band gap for the designed NOT gate structure was found to be 0.0846261 as shown in Fig.3. Refractive index distribution is based on the mesh values in the simulation parameters.

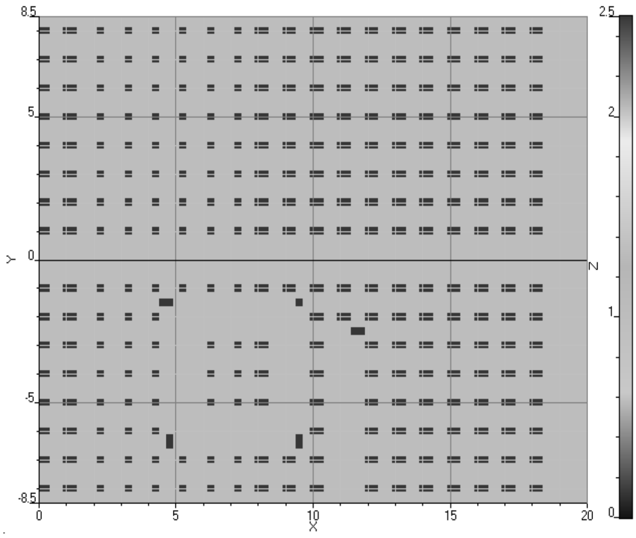

Fig.2. Refractive index Distribution Profile of NOT gate

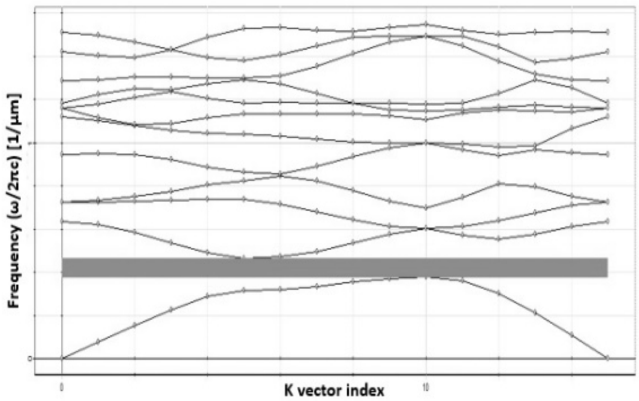

Fig.3. Band Gap diagram of NOT gate structure

Output for the optical NOT gate is obtained by passing the input signal and the control signal to the corresponding ports. By ring resonator principles, only a selected wavelength will be at resonance within the loop, so it may be act as a filter. The main phenomenon called destructive interference is used to design the logic gate. In the photonic crystal optical NOT gate, the control signal always be1 and the input get changes as 1 and 0. When the input is set as 1 the output observed as 0. If the input is set as 0 the output observed as 1.

3.1 VERIFICATION OF NOT GATE DESIGN

The characteristics of NOT gate logic are shown in Table.1.

Table.1. Characteristics table of NOT gate

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

The variables are control signal (C) and input signal (I). The output signal is specified as NOT output. From the characteristics table, it was concluded that, when the control signal is 1 and the input signal is 0, due to destructive interference in ring resonator, the output obtained as 1, that is the optical output is high and the corresponding field propagation is shown in Fig.4. Similarly when the control signal is 1 and the input signal is 1 then the output is obtained as 0 that is the optical output is low and the corresponding field propagation is shown in Fig.5.

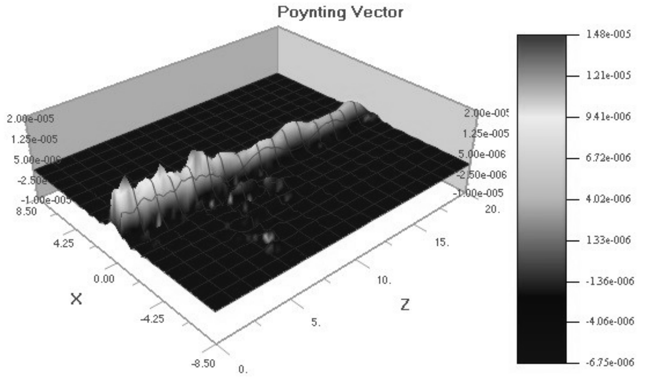

Fig.4. Electric field propagation when the input is 0

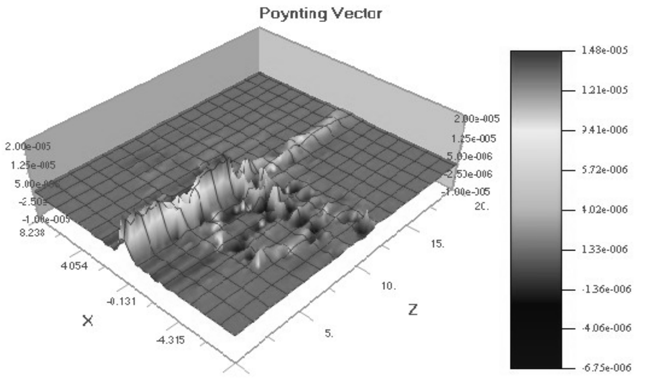

Fig.5. Electric field propagation when the input is 1

From the field distribution of input zero, it shows that the input will not pass through the ring resonator and the control signal will pass through the waveguide and it produces the output one at the output port. From the field distribution of input one, it shows that the inputs pass through the ring resonator and there will be no output present in the output port hence the output becomes zero.

4. CONCLUSION

Thus the all-optical NOT gate for future optical logical computation was designed using InP dielectric rod type 2D photonic crystal. Band gap of 0.0846261 was achieved with the tolerance 0.01. The output from the designed gate was verified as per the characteristics table. The mathematical modeling of the PhC based NOT gate is the future enhancement.

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