A Review on all optical Logic Gate using 2-D Photonic Crystal

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Abstract— Optical logic gates are key elements of optical network. This paper reviews different types of All Optical logic gates, various methods and materials used for construction of logic gates using photonic crystal (PhCs), discusses their novel properties, and reports recent advances in PhC components. We present a study of various structures used for construction of optical gates and methods used for construction like finite difference time domain and beam propagation method adapted by various researchers. By analyzing these comparisons we conclude that using 2-D PhC and finite difference time domain method we can improve the performance and reduce the size of optical logic gates.

Key words: All optical logic gates, Photonic Crystal (PC), Photonic Band Gap, FDTD simulator

I. INTRODUCTION

Nowadays demand for high data transfer speeds and capacity is increasing. Semiconductor electronics suffer from the limitations like high heat generation, time delay, speed, area [1, 2]. All-optical communication is one of the solutions to overcome these limitations. In the all optical signal processing all optical devices are used along with photonic integrated circuits. All optical logic gates are one of the key elements used in optical network. By using All optical devices in the optical networks the transmitted data will remain exclusively in the optical domain without optical to electrical and electrical to optical conversions. Electrical to optical and optical to electrical conversion limit the speed of optical networks. In recent years, researchers have demonstrated all-optical basic logic gates, AND, NAND, OR, and XOR [8–12] using different schemes based on nonlinear effects in optical fibers. Currently photonic crystals (PhCs) are the best platform on which we can design all-optical gates suitable for integrated optical circuits. All-optical logic gates are an indispensable part of integrated optical circuits. All-optical logic gates can be constructed by many ways: the first one is based on nonlinear optical effects in Semiconductor optical amplifier (SOA) whose performance is limited by spontaneous emission noise and complexity of integration or periodically poled lithium noibate (PPLN) waveguide. This type of optical logic gates requires large space, power consumption and is not feasible for micro or nano integration. The second one is based on Photonic crystals.

II. THEORY OF PHOTONIC CRYSTALS

Theory of Photonic crystals is composed of periodic dielectric, microstructures or nanostructures that affect wave propagation. Photonic crystals contain regularly repeating regions of high and low dielectric constant. Photons either propagate through this structure or not, depending on their wavelength. Wavelengths that propagate are called modes, and groups of allowed modes form bands. Disallowed bands of wavelengths are called photonic band gaps. PBG property of PhCs gives the ability to confine and control the propagation of optical waves inside spaces and waveguides, the ability which makes then suitable for designing very small size optical devices. Photonic crystals can be fabricated for one, two, or three dimensions. Among different categories of PhCs–1D, 2D and 3D structures–2D PhCs are more popular than other categories. Because unlike 1D structure they possess complete PBG, Also their design and fabrication process is much easier than 3D structures. 2D PhC structure is regarded as infinite and they provide confinement of light in the vertical direction by total internal reflection and allow control of light with the PhC in the plane of the slab. There are several parameters to manipulate: lattice pitch, air hole shape and diameter, refractive index of the glass and type of lattice. The FDTD method used for simulation is universal, robust, and methodologically simple.

III. ALL OPTICAL LOGIC GATES

All-optical logic devices will be the key elements used in optical network. All-optical logic gates perform many logic functions. These are used in optical communication, photonic microprocessors, optical signal processors, optical instrumentation, etc. All-optical AND-gates can be used as sampling gates in optical sampling oscilloscopes due to their ultrafast operation compared to traditional electrical methods. All-optical NOT-gates are used as inverter and switches. Combination of logic gates may be used to perform arithmetic functions such as binary addition, subtraction, comparison, and decoding, encoding and flip flops. For packet switching, generation of pseudorandom patterns, parity checking and data encryption/decryption XOR logic gate can be used.

IV. DESIGN STRUCTURES FOR OPTICAL LOGIC GATES

Size and Performance of optical logic gets change with different structural design of optical logic gates. Here, we review some design structures like linear, nonlinear, Y-shaped coupling, T shaped waveguide and their performance adapted by various researchers.

A. Reconfigurable All-Optical Logic AND, NAND, OR, NOR, XOR AND XNOR Gates Implemented By Photonic Crystal Nonlinear Cavities

Young jin jung,et al [3] have proposed an all-optical logic gates such as AND, NAND, OR,NOR, XOR AND XNOR gates constructed by combining cross-waveguide geometries. The structure consists of silicon rods and a defect rod cavity. Designed structures has rectangular lattice constant of 1 µm and the diameter of silicon rods is 0.4µm. defect rods has x-axis and the y-axis diameter of 0.6 µm and 0.5 µm respectively. This structure can be converted into any kinds of logic gates by appropriate tuning of defect rods. Numerical FDTD simulation was carried out.

B. Novel All-Optical Logic Gates Based On Photonic Crystal Structure

Mortazanoshad, et al [4] have designed AND, NOT, and NOR logic gates using 2-D photonic crystal structure employing cross-waveguide geometry. The logical function is based on the frequency resonance shift of the micro cavity caused by Kerr nonlinearity. Gates are realized by using finite difference time domain (FDTD) method. Features of these gates in comparison to other former designed gates are, fast switching speed (about 10 ps), and structure compactness. The structure has 15 × 15µm square lattice with the lattice constant a = 575 nm. The material used for construction of nonlinear rods is AlGaAs.

C. All-Optical Logic Gates Based On Two- Dimensional Low-Refractive-Index Nonlinear Photonic Crystal Slabs

Ye Liu, et al [5] demonstrated design of ultra compact all-optical AND, NAND, OR, and NOR gates with 2-D PhC. Compound Ag-polymer film with a low refractive index and large third-order nonlinearity is used as nonlinear material quality factor of about 2000 PhC cavity is designed on this polymer slab. All-optical logic gates with low pump-power in the order of tens of MW/cm2 can be achieved. Structure is formed by etching periodical air holes on the Ag-polymer film, and cavities are formed by removing some air-holes at required positions.

D. All-Optical and Logic Gate Based On 2-D Photonic Crystal

Kajal bhadel ,rekha mehra, [6] they have proposed All-optical AND logic gate using rectangular lattice of 13µm×8µm in 2-D (two dimensions) photonic crystal. Rectangular lattice has 25 rods in X direction and 15 rods in Z direction. The square cavity is created by removing rods of dielectric GaAs. This square cavity consists of four scattered rods at the corner used to provide high spectral selectivity. The analysis is done by varying the output power with respect to the radius of scattered rods and wavelength of input signal. Band diagram is studied to have the of band gap using the plane wave expansion method (PWE). This gate is designed using opti FDTD simulator. The proposed design has small size the power reaches to about 92% of the input power. And proposed design does not need extra control waveguide and the value of input signal applied is also small i.e. 5.1432mW/mm.

E. Optical Logic Devices Based On Photonic Crystal

Kabilan Arunachalam and Susan Christina Xavier, et al [7] They have designed logic gate using a square lattice 2-D PhC. The proposed structure utilizes bending; splitting and self collimating effects to realize the logic gates. In this structure first line defect is created by removing 15 rods which act as mirror (M) and second defect is created by reducing the radius of the defect rods act as a splitter (S). The proposed design exhibits an on-off contrast ratio around 3 dB and a device size of 10x10 µm2. The device is operated at a wavelength of 1550nm.This structure has simple structure, small size and high speed. The Finite Difference Time Domain method (FDTD) is used to analyze gates.

F. Integrated All-Optical Or Logic Gate Using Constructive Beam Interference In 2d Photonic Crystal

S.Spartagus and S. Ponmalarhas, et al [8] have proposed compact and high speed OR logic gate design in 2D photonic crystals. To realize this, triangular lattice photonic crystal structure with silicon rods are considered as it has high compactness and light confinement when compared to the square lattice structure The basic principle involved in this structure to act as OR logic gate is the property of light confinement using Constructive beam interference. Plane wave expansion is used for analyzing band and the transmittance characteristics and transmittance spectrum of the structure difference in time domain are calculated by Finite difference in time domain method. Resonant wavelength is 1.40µm, The structure size is reduced to 77µm2 which has a size reduction of 86.56% and it operates at high speed of150 fs with high accuracy.

G. Performance Analysis Of 2-D Photonic Crystal Optical Not Logic Gate

Gloria joseph, mrs.Vijaylaxmikaliani, et al [9] The work presented in this paper shows the working of NOT logic gate using Circular ring of PCRR The gate is fabricated on air wafer of 12µm x 12µm.The dielectric used is silicon Circular ring of PCRR is a micro cavity made by varying rods in the corner from centre by 0.2a in XZ directions. Gate is simulated on the wavelength of 1.7µm.They have calculated the figure of merit for the proposed not gate called as quality factor for the circular cavity defined as ratio of resonance wavelength to the difference in wavelength. The contrast ratios and quality factor of the gate is 14dB and 2428 respectively.

H. All-Optical Nand Gate Based On Nonlinear Photonic Crystal Ring Resonators

Somayeseraj mohammadi, et al [10] have proposed a new design for all-optical NAND gate By combining nonlinear Kerr effect with photonic crystal ring resonators. The PhC structure used for designing the PCRR is a 29*22 square array of chalcogenide glass rods. To create the resonant ring, a 7*7 array of dielectric rods was removed and then an octagon-shaped structure with square lattice was replaced at the center of the structure .They have designed a structure, whose optical behavior can be controlled by varying input power intensity. Due to the nonlinear Kerr coefficient the refractive index of the structure will change and consequently will shift the resonant wavelength of the PCRR.

I. Novel All Optic Logic Gates Using 2-D Photonic Crystal Structure

Achary SN, et al [11] has proposed design and simulation of novel all-optical logic gates such as AND, OR, NOT, and NOR based on two dimensional photonic crystals .They have investigated the performance of all gates using the cross waveguide structure.2D PCS is based on 15 ×15 air holes with lattice constant a=0.575 µm and . The silicon substrate having dielectric constant 11.5 is drilled with air holes of radius r=0.115 µm. The proposed device benefits a simple and small structure. Advantage of the proposed optical logic gates is same structure can be used to perform different logic operations by changing the power densities of logic Gates.

J. Realization of XOR And OR Logic Gate With One Configuration In The Two-Dimensional Photonic Crystals

Yuchi Jiang et. al [12] have designed, a new configuration to realize two all-optical logic gates XOR and OR logic gate using 2D photonic crystals. To realize logic gate new configuration is designed based on the theory of light beam interference effect and they have obtained higher light contrast ratio. In this paper they have realized XOR and OR logic gates with one configuration waveguide in 2D photonic crystal. It is helpful in optical device compactness and integration.

K. Design and Simulation Of All Optical Logic Gates Based On 2D Photonic Crystal Fiber

Shakila Naznin, et al [13] has designed all optical NOT XOR gates using 2 D photonic crystal. They have used quasi-square ring cavity. Size of the structure is 13µm *8µm. firstly they have analyzed the performance of NOT gate by using different amplitude concept and realized that transmittance is 36% for logic high. Then they have analyzed the performance of NOT gate by using different phase concept and realized that 1800 and 900 phase difference between two input signal gives transmittance of 69% and 55% respectively.

L. Improved Design of All-Optical Photonic Crystal Logic Gates Using T-Shaped Waveguide

Enaulhaq Shaik, et al [14] have proposed new structures of all-optical logic gates, i.e. T-shaped waveguide with optimized edge rod radius. With proper change in the phase values of logic '1' input this structure can work as a NOT gate and a dual T-shape waveguide can work as NOR, XNOR and NAND gate. New structures are also small and give fast response time of 0.35 ps. The performance of the proposed structures are analyzed and simulated by using Finite Difference Time Domain (FDTD) methods and Plane Wave Expansion (PWE).The time it takes to reach the output power level is cT= 96 µlm ,The output power obtained is 0.795 Pa. and the response time is 0.32 ps. The size of these logic gates is also very small with dimension 5.04 lm 9 5.04 lm for NOT gate and 8.04 lm 9 5.04 lm for the remaining gates.

V. WAVE PROPAGATION METHODS

There are many methods used for designing and realization of Photonic crystal based devices like Finite Element Method (FEM), Finite Difference Time Domain (FDTD), Plane Wave Expansion (PWE) and Beam Propagation Method (BPM).
Finite element method (FEM) is a numerical method for solving a differential or integral equation. It has been applied to a number of physical problems, where the governing differential equations are available.

Finite-difference time-domain (FDTD) method is arguably the simplest, both conceptually and in terms of implementation, of the full-wave techniques used to solve problems in electromagnetic. It can accurately tackle a wide range of problems. It is a numerical technique which approximates simulation of the propagation of light

Plane wave expansion (PWE) a calculation method is necessary to determine how light will propagate through a particular crystal structure. There are several capable techniques, but one of the most studied and reliable methods are the plane wave expansion method. The method allows the computation of eigen frequencies for a photonic crystal to any prescribed accuracy, commensurate with computing time.

Beam propagation method (BPM) is a numerical way of determining the fields inside a waveguide. The dynamic mode profile can be accurately estimated as the wave propagates through the wave guide. The beam propagation method essentially decomposes a mode into a superposition of plane waves, each traveling in a different direction. BPM method involves only a first order derivative in the waveguide axis.

VI. CONCLUSION

This paper describes the relativity of size, method and design adopted to realize the All Optical logic gates and reviews some of the recent developments in optical logic gates using photonic crystal. We have discussed some of the work we are familiar with. The research on PCF is continuing and it is expected that many new developments and applications will come out in the near future. The light guiding mechanisms and properties PBFs will allow the development of all optical devices, used in optical network. Finite difference time domain method gives best result for all structure.

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