ABSTRACT

This paper explains the design of all-optical 2-input NAND gate based on 2-D photonic crystal. In order to analyze the operation of NAND gate, two resonant rings have been used. Based on the Kerr effect, high intensity optical power is injected into the device. The indium phosphide and gold rod based rectangular lattice photonic crystal structure with refractive index 3.1 and 3.6 is considered. The band analysis and the transmittance characteristics are analyzed using plan wave expansion (PWE) and finite different time domain method (FDTD) are used to analyze the behaviour of the structure. Moreover, the operational wavelength of the input ports is 1.55μm. The consistency of simulation results with different time domain method (FDTD) are used to analyze the behaviour of the structure. Moreover, the operational wavelength of the input ports is 1.55μm. The consistency of simulation results with the logical table of NAND gate confirms the suitable functionality of the device.

KEYWORDS: all-optical NAND logic gate, photonic crystal, plane wave expansion method, finite difference in time domain method.

INTRODUCTION

Photonic crystal is a platform which provides a comfort zone to design the logic gates, by the way many applications are available such as optical memory devices, optical computing units, processors, and controllers. Their all-optical nature adopted with wider bandwidth, higher speed and smaller in size. The idea of using photonic crystals (PhC), [1] for designing optical devices had become the emerging field of integrated optics and photonics.

One of the important characteristics of photonic crystal is that light confinement and controlling property. These characteristics allow the crystal to use in various logical applications. PBG depends on refractive index, radius of rods and the lattice constant of the structure [2], so by using suitable considerations for the parameters can able to attain the best PBG region. Optical filters [3-6], Optical de multiplexers [7, 8], optical switches [9] are some examples of optical devices proposed based on photonic crystals.

The different structures have been discussed in the previous papers to recognize the performance of all-optical logic gates. Initially, all-optical logic gates based on semiconductor optical amplifier properties (SOA) were reported [10-12]. It is one of the ideas of different mechanisms proposed for realization of optical logic gates. The performance of SOA is limited by spontaneous emission noise and complexity of integration, [13,14] theoretically discussed the realization of optical logic gates in 2D Si photonic crystal using beam interference effect.

In the present paper, a structure for designing all optical 2-input NAND gate based on nonlinear photonic crystal ring resonators is proposed. Photonic crystal ring resonators are the fundamental structures composed of two waveguides namely linear and circular waveguide. In a PhC Ring resonator (PhCRR) optical waves

Received 28 February 2017; Accepted 29 April 2017; Available online 2 May 2017

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propagating in the linear waveguide at a certain wavelength-called resonant wavelength—will drop to the ring waveguide [15]. The resonant wavelength of PhCRR depends on the refractive index of the rod material, radius \((a)\) and dimensions of the core structure of resonant ring [16]. The input power of optical waves induces the nonlinear effects in dielectric materials such as Kerr effect [17]. These effects dependent on the refractive index of light wave intensity. Hence the power can be controlled by the structural parameters of the PhCRR structure via input intensity and realize switching task.

**Design Procedures:**

The fundamental platform used to design the proposed optical 2 input NAND gate is a 32*28 square array of Indium phosphide \((InP)\), gold rods with refractive index of 3.1& 0.58 in air substrate. The gold material is applied in rods at the four edges of the inner ring. Gold material is more preferable because it reduces the transmission loss when compared to others. The radius of the rod is \(r=0.1188\) and \(a=0.5943\) is the lattice constant of the structure. The plane wave expansion \((PWE)\) method is used to obtain the band structure of the fundamental structure. For this structure the band structure diagram has been calculated and obtained like Fig 1.

**Fig. 1:** Band structure of the fundamental photonic crystal structure

PBG regions are shown at \(0.31295 < \frac{\alpha}{\lambda} < 0.436207\) in TE mode this region is in normalized frequency domain, we have to convert it into wavelength domain by dividing it into \(\alpha=0.5943\), therefore the PBG region in wavelength region will be at \(1.3525< \lambda<1.8852\). The proposed fundamental platform is suitable to be used for designing optical communication devices. This structure has PBGs only in TE mode so all simulations are done in this mode.

To realize the proposed NAND gate we need 2-input port waveguide, 1-output port waveguide and two resonant rings. These input ports are labelled as port A, B, Bias & port OUT. The first port A waveguide was created by line defect in Y direction and path in B waveguide was created by removing rods in X direction. The another input port Bias waveguide was created by removing rods in X direction. All the resonant rings are designed such that at same resonant wavelength 1550 nm. The resonant ring depends on the refractive index of the dielectric rod constructing the core of the resonant ring, which in turn depends on the power intensity of the incident optical wave due to Kerr effect. Therefore, by launching high power light in to resonant ring, we can control the optical behaviour of ring resonators.

**Fig. 2:** Final sketch of the proposed NAND gate
Simulation And Results:
In this paper, 2D finite different time domain method is used to investigate the performance of the proposed structure. The NAND gate has two input ports and a output port. Therefore it comprises of 4 input combinations with bias. From the table, When both A and B are OFF, (A=B=0) both the inputs are at low state, the output state is 1. In the second state, when A is OFF and B is ON condition (A=0, B=1) hence the output is 1, the one input is in lower state, another state of input is higher state, intensity will be in the range of 0.56.
Table 1: Different working states of the NAND gate

<table>
<thead>
<tr>
<th>INPUT</th>
<th>OUTPUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>BIAS</td>
<td>A</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
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The third condition will be A is ON and B is OFF (A=1,B=0) here B input is low, hence the output is 1, the intensity level of this 0.58. And the fourth condition is A & B is ON (A=B=1), therefore the output condition is 0. In this State both the input powers can cancelled each other the intensity will get reduced to lower level about 0.16 which is lower than other intensity levels in those conditions. The following graph represents the transmission spectrum of NAND gate as show in Fig 3.

![Graph](image)

**Fig.4:** Normalised transmission spectrum

**Conclusion:**

In this design, all optical NAND logic gate based on ring resonator of nonlinear photonic crystal is implemented. An optical two input logic NAND gate and the photonic crystal are comprised of 2D-square lattice of dielectric rods are made of indium phosphide and gold rod in air substrate. The high Kerr coefficient is presented in the resonant rings by launching high intensity optical power in to the resonant ring. Moreover the structure is operated at 1.55 µm wavelength. In this proposed structure, when both logic condition is ON the bias light is not dropped to the output waveguide and is not passed towards the output port and the output condition will be 0, logic ports turned OFF when either one of the port is in OFF condition or either one of the port is in ON condition, the bias light will drop to the output waveguide and gate will become 1.

**REFERENCES**