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All optical NAND gate based on nonlinear photonic crystal ring resonator

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ABSTRACT

In this paper we proposed a new design for all optical NAND gate. By combining nonlinear Kerr effect with photonic crystal ring resonators, we designed an all optical NAND gate. A typical NAND gate is a logic device with one bias and two logic input and one output ports. It has four different combinations for its logic input ports. The output port of the NAND gate is OFF, when both logic ports are ON, otherwise the output port will be ON. The switching power threshold obtained for this structure equals to 1.5 kW/μm^2. For designing the proposed optical logic gate we employed one resonant ring whose resonant wavelength is at 1554 nm. The functionality of the proposed NAND gate depends on the operation of this resonant ring. When the power intensity of optical waves is less than the switching threshold the ring will couple optical waves into drop waveguide otherwise the optical waves will propagate on the bus waveguide.

1. Introduction

The idea of using photonic crystals (PhC), [1] for designing optical devices had revolutionized the field of integrated optics and photonics. The periodic modulation of refractive index in PhC results in a special characteristic called photonic band gap (PBG). Having PBG makes these periodic structures suitable for confining and controlling the propagation of optical waves with desired wavelength. PBG depends on refractive index, radius of rods and the lattice constant of the structure [2], so by choosing appropriate values for these parameters we can obtain the best PBG region according to our requirements. Optical filters [3–6], optical demultiplexers [7–9], optical switches [10] optical decoders [11,12] and optical logic gates [13,14] are some examples of optical devices proposed based on PhC.

Optical logic gates are essential components required for optical signal processing and optical communication networks. Semiconductor optical amplifiers (SOAs) [15,16] is an example of different mechanisms proposed for realizing optical logic gates. Their performance is limited by spontaneous emission noise and complexity of integration. Fu et al. [17] theoretically discussed the realization of optical logic gates in 2D Si PhC using beam interference effect. They proposed OR, XOR, NOT, XNOR and NAND gates. Saidani et al. [18] proposed a multifunctional logic gate in a 2D PhC waveguide structure using multimode interference concept. By switching optical signal to different input waveguides, different functions such as XOR, OR, NOR and NOT gates have been obtained. An all optical NOR gate have been proposed by Isfahani et al. [19]. First of all they proposed a T-shaped optical switch by using nonlinear photonic crystal micro ring resonators. Then they cascaded two of the proposed switches

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to realize optical NOR gate. They showed that the transmission efficiency of the NOR gate in OFF and ON states are 2% and 81% respectively.

In this paper we are going to propose a new structure for implementing optical NAND gate based on photonic crystal ring resonators (PhCRR). In a PhCRR optical waves propagating in the bus waveguide at a certain wavelength – called resonant wavelength – will drop to the drop waveguide [20]. The resonant wavelength of PhCRR depends on the refractive index, radius and dimensions of the core section of resonant ring [21]. High power optical waves trigger nonlinear effect in dielectric materials, which is called Kerr effect [22]. Therefore at high powers, the refractive index of dielectric materials depends on the power intensity of incident light. So we can control the optical behavior of the PhCRR structure via input intensity, and realize switching task [10].

The rest of the paper has been organized as follows: in Section 2 we proposed the basic photonic crystal ring resonator then on Section 3 we discussed the design and results of the simulations for NAND gate. Finally in Section 4 we conclude from our work.

2. Basic filter

As far as we know most of the PhC-based devices like optical switches and optical logic gates are designed by employing an optical filter as the basic structure of the proposed device. Therefore in this paper for designing the proposed NAND gate, first of all we should propose and design a PhC-based optical filter. We used a photonic crystal ring resonator as the wavelength selection part of the filter. The photonic crystal structure used for designing the PhCRR is a 32*18 square array of chalcogenide glass rods with refractive index of 3.1 in air. The radius of the rods is $r = 0.2^*a$, where $a = 640$ nm is the lattice constant of the structure. For this structure the band structure diagram has been calculated and obtained like Fig. 1. This PhC structure has one photonic band gap region at TM mode at $0.31 < a/\lambda < 0.43$ in TM mode this region is in normalized frequency domain, we have to convert it into wavelength domain by dividing it into $a = 640$ nm, therefore the PBG region in wavelength region will be at 1488 nm $< \lambda <$ 2064 nm. This means that, optical waves at this wavelength region will not scatter inside the fundamental PhC structure.

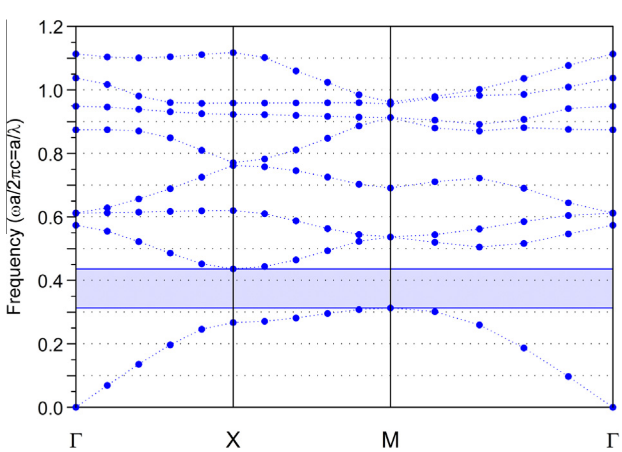
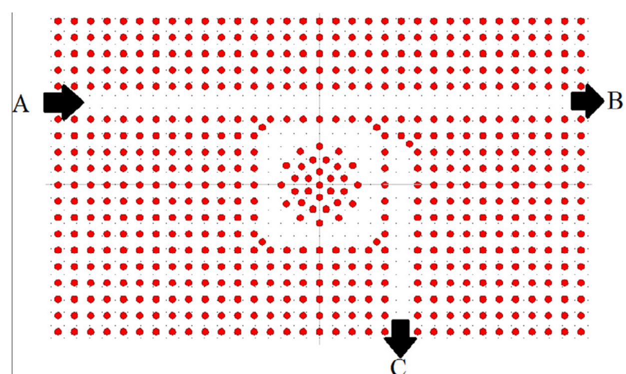


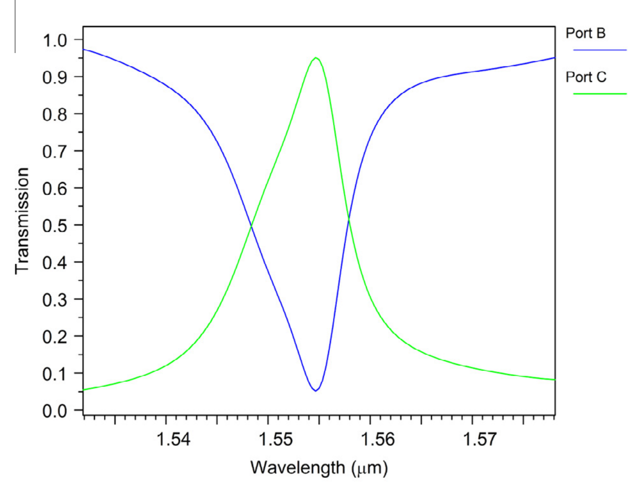
Fig. 1 – The band structure of the fundamental PhC structure.

Our PhCRR structure is composed of a resonant ring sandwiched between two waveguides namely bus and drop waveguides. The bus waveguide was created by removing a complete row of dielectric rods in X direction, also by removing 12 rods in Z direction we created the drop waveguide. For creating the resonant ring, first a 7*7 array of dielectric rods was removed and then a 12-fold quasi crystal was replaced at the center of the structure. The PhCRR structure has three ports; input port (A), forward transmission port (B), and forward drop port (C). Optical waves enter the structure through port A and exit it from port B, however at the desired wavelength the optical wavelengths drop to drop waveguide through the resonant ring and travel toward port C. The schematic diagram of the PhCRR along with its output spectrum is shown in Fig. 2. This PhCRR has resonant wavelength at $\lambda = 1554$ nm.

The output spectra of the PhCRR for different refractive indices of the rods are shown in Fig. 3. According to Fig. 3 by increasing refractive index, the resonant wavelength of the structure will shift toward higher wavelengths. This proves that by changing the refractive index of the rods one can control the optical properties of the proposed resonator. One way of changing refractive index of dielectric rods is making use of the nonlinear Kerr effect, in which one can change the refractive index by launching high intensity



(a)



(b)

Fig. 2 – (a) The basic PhCRR and (b) its output spectrum.