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All-optical NOT and AND gates based on 2D nonlinear photonic crystal ring resonant cavity

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ABSTRACT

In this paper we propose a structure based on nonlinear photonic crystal ring resonant cavity (NPCRRC) that can mimic NOT and AND gates. Operating powers in our proposals are significantly lower compared to earlier proposals which is very much desired and essential for practicability for any all-optical device.

1. Introduction

Yablonovitch [1] and John [2], predicted a new class of artificial materials called Photonic crystals (PCs). PCs are mainly composed of two different dielectric materials having different refractive indices. These artificial structures can be demonstrated in three categories: one, two and three dimensional (1D, 2D and 3D) according to the periodic arrangement of dielectric materials [3]. As a result of periodicity, the transmission of light is absolutely zero in certain ranges of frequencies/wavelength which is called as Photonic Band Gap (PBG) [4]. The majority of PC applications utilize the phenomenon of PBG that opens the new road to design the optical components in micrometer (μm) range.

Proposals/demonstrations of number of PC based optical devices are existing in literature such as optical filter [5–7], all optical logic gates [8–10], optical decoder [11–12], optical multiplexer [13], optical junction [14], asymmetric reflector [15] and three port asymmetric router[16]. A majority of explorations is focused on all-optical logic gates as those can play crucial role in future optical communication, signal processing and optical computing [17–19]. NPCRRC based logic gates [20–22] are of recent interest due to their compact size and lower operating powers.

In this paper, we propose All-optical NOT and AND gates using a structure based on NPCRRC with Kerr effect. With Perfectly Matched Layers (PMLs) (to avoid unwanted reflections from the simulation boundaries) and chosen parameters, light propagation in the purposed structure is analyzed using 2D Finite Difference Time Domain (FDTD) method [23] and dispersion diagram is extracted by Plane Wave Expansion (PWE) method [24]. In our investigation, the proposed structure seems to be better in terms of operating power and ON/OFF contrast compared to earlier proposals.

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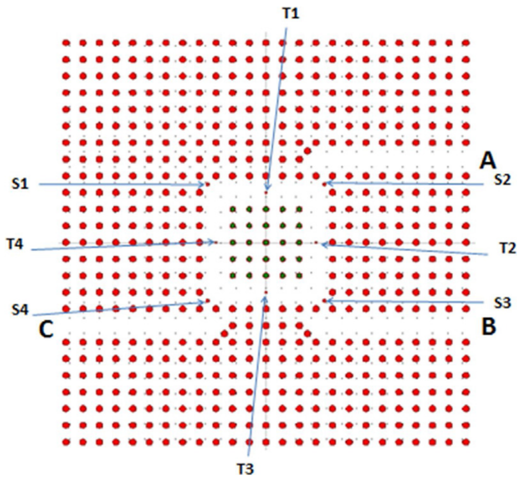

Fig. 1. Schematic diagram of structure base on nonlinear photonic crystal ring resonant cavity (NPCRRC). As shown 25×25 square array of dielectric circular rods are immersed in air. Refractive index of the rods is 3.4, Kerr coefficient is$1.5 \times 10^{-17} m^2/w$. The radius of the unperturbed/regular rods and lattice constant are considered to be 102 nm and 550 nm respectively. 7*7 square arrays of rods are replaced by 5*5 square arrays of rods of radius 87 nm to create ring resonant cavity (RRC). Four scattering rods S1, S2, S3 and S4 of radius 51 nm are placed at the corner of RRC and four rods T1, T2, T3 and T4 of radius 30 nm are placed as shown. Three defect waveguides A, B and C are formed by removing rods along X-axis. Waveguides A and B are the input waveguides, while C is the output waveguide.

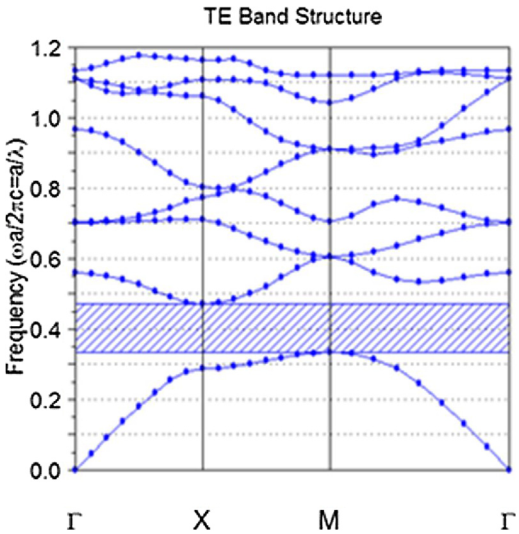

Fig. 2. Band diagram obtained by plane wave expansion method of the considered structure of Fig. 1. A photonic band gap (PBG) can be seen in the range $0.33 < \frac{a}{\lambda} < 0.47$ for TE mode, i.e., $1170\,nm < \lambda < 1666\,nm$.

2. Nonlinear photonic crystal ring resonant cavity (NPCRRC)

We design NPCRRC in order to obtain all-optical NOT and AND gate. We consider 25×25 square array of dielectric circular rods immersed in air (Fig. 1). Refractive index of the rods is considered to be 3.4 with Kerr coefficient equal to $1.5 \times 10^{-17} m^2/w$. The radius of the unperturbed/regular rods and lattice constant are considered to be 102 nm and 550 nm respectively. To create ring resonant cavity (RRC), we replace 7*7 square arrays of rods by 5*5 square arrays of rods of radius 87 nm as shown in Fig. 1. Four scattering rods S1, S2, S3 and S4 of radius 51 nm are placed at the corner of RRC to avoid back reflections. Further, four rods T1, T2, T3 and T4 of radius 30 nm are placed as shown. Three defect waveguides A, B and C are formed by removing rods along x-axis. Waveguides A and B are the input waveguides (ports), while C is the output waveguide (port).

The band diagram of the considered structure of Fig. 1 is obtained using PWE method and is shown in Fig. 2. As can be seen in the Figure, a photonic bad gap (PBG) exists in the range $0.33 < \frac{a}{\lambda} < 0.47$ for TE mode which corresponds to the wavelength range $1170\,nm < \lambda < 1666\,nm$. Hence, the defect waveguides A, B, and C can guide optical inputs of wavelengths suitable for optical communication. [Optical Fields can be classified in Transverse Electric (TE) and Transverse Magnetic (TM)