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Design and analysis of an all-optical Demultiplexer based on photonic crystals

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HIGHLIGHTS

- We proposed an all-optical 1×2 Demultiplexer based on silicon rods in the air PCs.
- We analyzed the operation of the device using analytical model.
- We verified our analytical model using FDTD and PWE methods.
- Power less than $0.25P_0$ is considered as "0" logic value and more than $0.4P_0$ as "1".
- One of the output ports of the device, can be used as an *AND* logic gate.

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ABSTRACT

An all-optical 1of 2 De-multiplexer (D-mux) based on silicon rods in the air, created by two dimensional square lattice photonic crystals (PCs), is proposed and demonstrated. The device operation is because of line and point defects and phase difference between input beams that created by point defects. The device has a selection line, *S*, an input data port, *A*, and three output data ports, Q_0, Q_1 and Q_2. Photonic band gap (PBG) calculation is done by plane wave expansion (PWE) method and electrical field distribution (EFD) in the device by finite difference time domain (FDTD) method. Power levels lower than "$0.25P_0$" is considered as "0" logic value and higher than "$0.4P_0$" as "1" logic value. When $S = 0$, the data of port *A*, is directed to Q_0 and when $S = 1$, is directed to Q_1. Moreover, one of the output ports, Q_1 or Q_2, can be used as an *AND* logic gate. The device is applicable for all-optical processors and integrated circuit.

1. Introduction

Photonic crystals (PCs) are periodic dielectric structures with specific refraction coefficient [1]. So their photonic band structures are periodic and propagation of light through them can exhibit behaviors quite different from those of uniform dielectric behaviors [1–3]. Light at frequencies in PC band gap (PBG) cannot propagate but at frequencies in PC pass band can transmit with or without dispersion [1–3]. By employing defects in the PCs, light can steer in specific direction and consequently in the most of PC applications, defects are used in their structures [4–17]. More remarkable applications are: ring resonators [4–5], waveguides [6–8], multimode interferences [9–10], polarization beam splitter [10], creation of negative refraction index [12], and all optical logic gates [13–17].

All-optical logic gates are basic devices for optical processors and photonic integrated circuits that possessing many properties like low power consumption, high speed near light velocity and simple structure. Those will be important component of logical processors and computations and telecommunication networks in the near future. As a result, they are proper alternative for electronic logic gates [13–17]. One of the all-optical logic devices can be 1 of 2^n line Demultiplexer (D-mux) that operates as an optical switch. A 1 of 2^n line D-mux will let us select only one using n-bit address or channel-select input. In this paper we have proposed a 1 of 2 line D-mux. Our proposed D-mux is made of two-dimensional (2D) PC consist of silicon (Si) rods in the air. The foundation of the device is a line defect and a few point defects. Line defect is used for steering light in desired direction and point defects are used for creating phase difference between incident beams to cause constructive or destructive interference in them.

The paper is organized as follow: The basic structure of the device and its operation are presented in Section 2. Theoretical analysis and models are stated in Section 3. Simulation results

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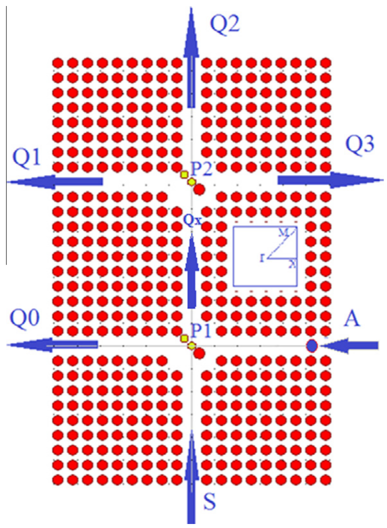

Fig. 1. Schematic of the all-optical device as a 1 × 2 D-mux and an *AND* logic gate. Input ports *S* and *A* are the selection line and data port of the device respectively. Q_0 and Q_1 are desired data output ports. Q_1 or Q_2 can be considered as an *AND* logic gate output port equally. Q_3 output value is zero eternally and indeed it is not necessary.

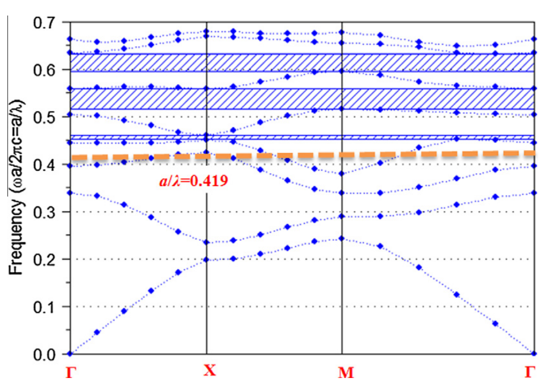

Fig. 2. PBG of the all-optical device and selected frequency of input beams.

and discussion are offered in Section 4. The paper is concluded in Section 5.

2. Structure and operation principle

The main structure of the proposed device is consist of $28a \times 18a$ of two dimensional square lattice PC, created by Si rods in the air, where "*a*" is the lattice constant. It has shown in Fig. 1. The dielectric constant of the rods, ε, is 11.56 ($n = 3.4$) and rods radius are $0.35a$. Line defect in the device is made by remove the Si rods in ΓX and XM direction. Moreover the line defect, the structure has point defects that are shown with yellow[1] color in Fig. 1. The radius of the point defects is $0.265a$ and act as beam splitter in two equal sections. Design manner of splitter's rod's dimensions will be explained in the next section. Using the plane wave expansion (PWE) method [6,9], the PBG of the structure is calculated. Its results are shown in Fig. 2. As shown in the figure, there is a pass band between 0.4–0.45 (a/λ), so we choose the a/λ equal to 0.419, as the incident waves frequency. In this frequency the slope of the authorized mode of PBG (the group velocity of lights) is nearly constant in ΓX and XM direction, and light can propagate with minimum dispersion. To set the wavelength of input ports (λ), equal to 1.55 μm, we select $a = 0.65$ μm. The width of light entrance is equal to a period of the structure. The device has two input ports, *A* and *S*, and four output ports, Q_0, Q_1, Q_2 and Q_3 that Q_0 and Q_1 accommodate our desire output ports for D-mux 1 of 2, and Q_1 or Q_2 can used as an *AND* logic gate output.

3. Theoretical analysis and models

In order to calculate the constructive and destructive interferometer of the incident beams, we consider into account two TE polarized lights at input ports, *A* and *S*, with electric field part, E_A and E_S respectively:

$$E_A = Ae^{-i\phi_1} \tag{1}$$

$$E_S = Se^{-i\phi_2} \tag{2}$$

The coupled light (*CLD*) to the input port reaches to the splitter rods, *P*1 and *P*2, and divides into three parts, reflected part, *R*, transmitted part, *T*, and anti-reflected part, *AR*. Using Finite-Difference Time-Domain (FDTD) numerical method [18], we calculate normalized power of *CPL*, *T*, *R* and *AR* parts of the input lights vs. the radius of the *P*1 and *P*2 splitter rods. The results are shown in Fig. 3. According to this figure, we can choose a desired radius for splitter rods, so that the *AR* part will be zero and *T* and *R* parts will be equal together. The desired radius is $0.265a$. The transmission and reflection amplitude of the incident lights after reach to splitter rods, are $te^{i\varphi}$ and $re^{i(\varphi+\pi/2)}$ respectively and base on $t^2 + r^2 = 1$ and splitter operation, we conclude that $t = r = 1/\sqrt{2}$.

Based on splitter operation, the transmission and reflection parts of the input signals will become:

$$T_A = (te^{i\varphi})E_A = Ate^{i(\varphi-\varphi_1)} \tag{3}$$

$$R_A = (re^{i(\varphi+\pi/2)})E_A = Are^{i(\varphi-\varphi_1+\pi/2)} \tag{4}$$

$$T_s = (te^{i\varphi})E_S = Ste^{i(\varphi-\varphi_2)} \tag{5}$$

$$R_S = (re^{i(\varphi+\pi/2)})E_S = Sre^{i(\varphi-\varphi_2+\pi/2)} \tag{6}$$

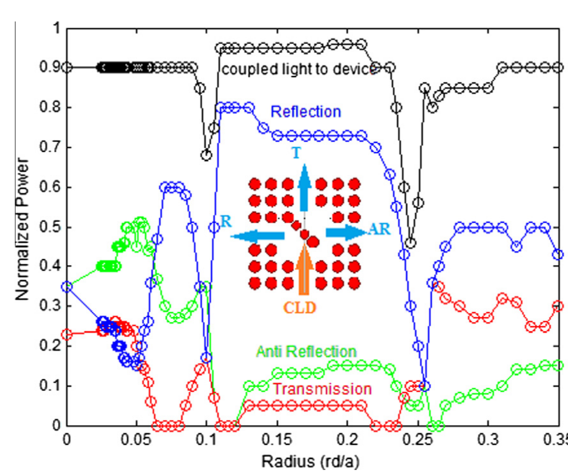

Fig. 3. Normalized power of the coupled light to the device or *CLD* (black curve); transmitted light or *T* (red curve); reflected light or *R* (blue curve); and anti-reflected or *AR* (green curve); vs. the radius of point defects rod, *P*1 or *P*2. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

[1] For interpretation of color in Figs. 1, 4–6, the reader is referred to the web version of this article.