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A novel all optical 4×2 encoder switch based on photonic crystal ring resonators

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ABSTRACT

A novel approach to design an all optical 4 × 2 encoder is proposed by employing Kerr effect in 2D square lattice of silicon rods in photonic crystals. The main operation of device is based on the concept of all optical switch. Our proposed encoder consists of two nonlinear ring resonators with L-shape waveguides, characterized by the same resonant wavelength, embedded between four parallel waveguides. The operation of encoder at third optical window ($\lambda_c = 1.5478\mu m$) is verified with Finite Difference Time Domain (FDTD) and Plane Wave Expansion method (PWE) .The proposed structure is simple with clear operating principal, low power consumption, and ultra-small size (18.5 μm × 13 μm) compared with previously reported encoders, therefore facilitate its integration into all optical communication systems.

1. Introduction

Currently, the challenge of diverse researches is to design all optical devices in photonic crystals for all optical signal processing, in order to avoid the complexities and speed limitation of optical/electrical (O/E) conversion [1]. So that, many technologies have been reported to design all optical encoders, practical logic gate in mouse, scanner, printer, optical disk drive and all-optical programmable logic controller (PLC) [2]. Ricardo et al. depicted an all optical encoder based on the Semiconductor Laser Amplifier Loop Mirror (SLALOM) configuration [3,4]. Chattopadhyay and Nath have demonstrated all-optical encoders using the polarization scheme of radix 2 and radix 4 [5].

Based on photonic crystals, many all optical encoders have been designed. Lee et al. supposed 4 × 2 all-optical encoder based on the combination of both line defect Y branch and coupler photonic crystal waveguides [6]. Hassangholizadeh-Kashtiban et al. have designed an all optical reversible 4 × 2 encoder based on photonic crystal structure with non-linear refractive index [7]. All-optical digital 4 × 2 encoder exploiting 2D photonic crystal ring resonators is presented by A. Moniem [4], where the total size of the proposed device is equal to (35 μm × 35 μm). Alipour-Banaei et al. have proposed 4 × 2 optical encoder by employing the self-collimation effect in 2D photonic crystals with an area of about (69 μm × 55 μm) [2].

In this paper, the proposed 4 × 2 encoder switch is simple to fabricate and operate with ultra-compact size of (18.5 μm × 13 μm) and low power consumption. The main operation of device is based on two optical switches, where the structure of the switch is a photonic crystal ring resonator (PhCRR) formed by a nonlinear RR with L shape waveguide

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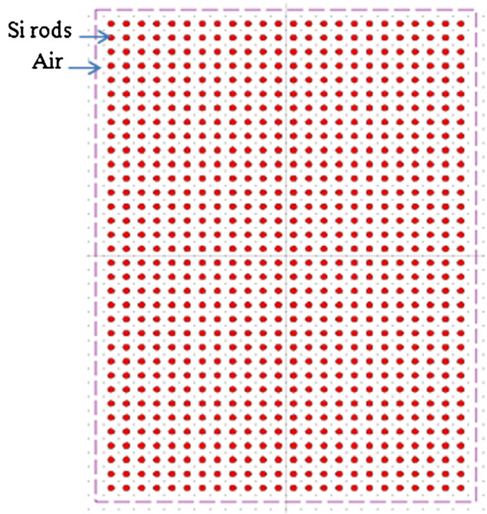

Fig. 1. The initial structure.

created by embedded nonlinear refractive index rods of Polystyrene (PS). PWE method was used to extract the appropriate Photonic Band Gap (PBG) and FDTD method for investigating the light behavior of encoder.

2. Numerical method

In this paper, we have used the Plane Wave Expansion (PWE) method to extract the appropriate Photonic Band Gap (PBG) of the fundamental structure by analyzing the band gap map and dispersion diagram. For investigating the light behavior, resonance and transmission spectra, we have applied 2D nonlinear finite-difference time-domain (NL-FDTD) method with perfectly matched layer boundary conditions (PML) [8]., where a Gaussian pulse is used to excite the fundamental mode along the x direction with a spatial step $\Delta x = \Delta z = {}^{a}\!/_{16}\mu m$, the sampling time $\Delta t = 0.01 fs$is selected to ensure numerical stability of the algorithm, by:

$$\Delta \mathrm{t} \leq \frac{1}{\mathrm{c}\sqrt{\left(\frac{1}{\Delta \mathrm{x}}\right)^2 + \left(\frac{1}{\Delta \mathrm{y}}\right)^2}} \tag{1}$$

3. Kerr nonlinearity

To design the all optical switch, we have exploited nonlinear Kerr properties of Polystyrene (PS). Important third order nonlinear susceptibility, higher laser damage threshold, fast nonlinear optical response time and low cost persuaded us to choose this organic polymer materiel for our device. For Kerr nonlinear mediumElectric field (E), electric displacement (D) and nonlinear polarization ($P^{NL)}$ are associated as follows [9]:

$$D = \varepsilon_0 \varepsilon_L E + P^{NL} \tag{2}$$

$$P^{NL} = \varepsilon_0 \chi^{(3)} \left(|E|^2\right) E \tag{3}$$

By replacing (3) in (2):

$$D = \varepsilon_0 E \left[\varepsilon_L + \chi^{(3)} \left(|E|^2\right)\right] \tag{4}$$

$$\varepsilon_{NL} = \varepsilon_L + \chi^{(3)} |E|^2 \tag{5}$$

ε_L and ε_{NL} are linear and nonlinear permittivities respectively and $\chi^{(3)}$ is the third order nonlinear susceptibility. For PS $\varepsilon_L = n_L^2$ =2.5281 and $\chi^{(3)} = 1.15 \times 10^{-12} cm^2/W$ [10]. From (Eq.(5)) we deduce that nonlinear Kerr effect induce dependency of polystyrene permittivity to field intensity.

4. Design of the proposed structure

The initial structure proposed for designing the all optical encoder switch is a 34*24 square array of silicon (Si) rods with refractive index of 3.5 in air. We exploit the gap-map diagram for different value of (r/a) ratio in order to select the proper values of r and a. We deduce from Fig. 2 that the structure supports the appearance of PBG in TM mode and decrease by