Physica E 75 (2016) 77–85

Contents lists available at ScienceDirect

Physica E

journal homepage: www.elsevier.com/locate/physe

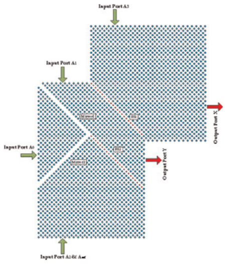
Application of self-collimated beams to realization of all optical photonic crystal encoder

Hamed Alipour-Banaei [a,*], Mehdi Ghorbanzadeh Rabati [b], Parisa Abdollahzadeh-Badelbou [b], Farhad Mehdizadeh [b]

[a] Department of Electronics, Tabriz Branch, Islamic Azad University, Tabriz, Iran
[b] Young Researchers and Elite Club, Urmia Branch, Islamic Azad University, Urmia, Iran

GRAPHICAL ABSTRACT

Summary: in this paper we proposed an optical encoder using self-collimation effect in photonic crystal structures.



ARTICLE INFO

Article history:
Received 17 June 2015
Accepted 5 August 2015
Available online 11 September 2015

Keywords:
Photonic crystal
Self collimation
Encoder
Optical integration

ABSTRACT

In this paper a 4 × 2 optical encoder is proposed by employing the self-collimation effect in 2D photonic crystals. The total structure of the proposed device is a combination of so called "beam splitters" and "mirrors". The simulation result indicates that, this design can operate as 4 × 2 optical encoder, the footprint of structure is about 69 μm × 55 μm and response time is about 1.4 ps.

1. Introduction

Optical encoder together with other optical logic gates can create advanced all-optical processing circuits. A simple encoder circuit can receive a single active input out of $2n$ input lines generate a binary code on "n" parallel output lines. A binary encoder is a multi-input combinational logic circuit which converts the logic level "1" data at its inputs into an equivalent binary code at its output. Encoders may use to detect interrupts in microprocessor. The optical encoder can also be used in the optical disk drive, scanner, mouse, or printer, and all-optical high-speed counting module of all-optical programmable logic controller (PLC).

Photonic crystals (PhCs) which consist of a periodic array of dielectric material has been attracted a lot of attention most recently [1,2]. PhC structures have forbidden propagation frequency ranges which are named photonic band gaps (PBGs). By using the effect of PBGs, the propagation of light can be controlled inside very compact structures [3]. Therefore, realization of so many ultra-compact optical devices such as optical filters [4–10], demultiplexers [11–15], switches [16–21] and logic gates [22–23] have been possible by using PhCs.

Another confinement mechanism of light waves in photonic

---

[*] Corresponding author.
E-mail address: alipour@iaut.ac.ir (H. Alipour-Banaei).

http://dx.doi.org/10.1016/j.physe.2015.08.011
1386-9477/

crystal is self-collimation effect. It exploits the spatial dispersion properties of Bloch waves to achieve the electromagnetic wave without diffraction. It retains spatial width confinement without the line defect waveguide or nonlinearities. The shape of the PhC dispersion surface is an essential feature for determining the self-collimation. This can be optimized and manipulated by lattice symmetry, material parameters and the geometry shape of the constituents. The self-collimated beams of light can propagate with less diffraction in a PC [24–31]. In addition compared with conventional dielectric waveguides and PC waveguides working within the PBGs, self-collimation does not require a lateral confinement to prevent either the beam divergence or diffraction broadening without applying a nonlinear effect. The previous all-optical logic circuits suffered from some limitations, such as power consumption and narrow operating frequency range, low speed, big size and the difficulty in performing chip-scale integration [32]. For these reasons, an encoder logic gate based on self-collimated beams in two-dimensional PC has potential for high density photonic integrated circuits (PICs).

The rest of this paper is structured as follows. In Section 2, we discuss the design procedure of the proposed structure, in Section 3 we discuss the simulation of the structure, finally in Section 4 we draw a brief conclusion.

2. Design procedure

A 2D PhC composed of a square lattice array of silicon rods in air background is considered as the fundamental structure used for designing the proposed encoder. The dielectric constant and the refractive index of the dielectric rods are 11.97 and 3.46 respectively. The radius of the host rod (r) is 0.35^*a where a is the lattice constant of PhC. Using the plane wave expansion (PWE) method [33], the band diagram and equi-frequency contour (EFC) for TM mode is calculated and demonstrated in Fig. 1.

As shown in Fig. 1(b) the curves of the frequencies around 0.194 (a/λ) can be identified as squares with round corners centered at M point, (where λ is the wavelength of light). In the flat square, the direction of light propagation in the PhC is identical to the direction of the group velocity given by $V_g = \nabla_k \omega(k)$, where $\omega(k)$ is the optical frequency at the wave vector k. It means that the group velocity is perpendicular to the EFCs and the waves are collimated. Hence, the self-collimation phenomenon occurs, when the polarized light with the frequencies around 0.194(a/λ) propagates along the Γ–M direction

In digital electronic an encoder is the logic device that converts 2^n input signals to N-bit coded outputs. Out of 2^n input lines only one is activated at a time and produces equivalent code on output N lines. The block diagram of 4×2 encoder is shown in Fig. 2.

As we mentioned earlier the fundamental structure used for designing the optical encoder is 2D PhC with square lattice, which is composed of an array Si rods immersed in air. The width and length of the structure are $39\sqrt{2}a$ and $49\sqrt{2}a$ respectively. This structure the square lattice is oriented at 45° with the interface parallel to the Γ–M direction with period $a' = \sqrt{2}a$. The circles represent the silicon rods whose radii are $r = 0.35a$ where "a" is the lattice constant and its value is 1 μm.The Fig. 3 illustrates the 2D PhC lattice used for designing encoder.

For designing the proposed encoder we take the advantage of bending and splitting mechanisms of self-collimated beams inside PhC structures. For creating a beam bending structure we should create a mirror structure inside PhC, also for performing power splitting we need appropriate splitters to be realized inside the fundamental PhC. It has been shown that by creating a line defect in path of self-collimated beams inside a PhC we can create power splitters or mirrors.

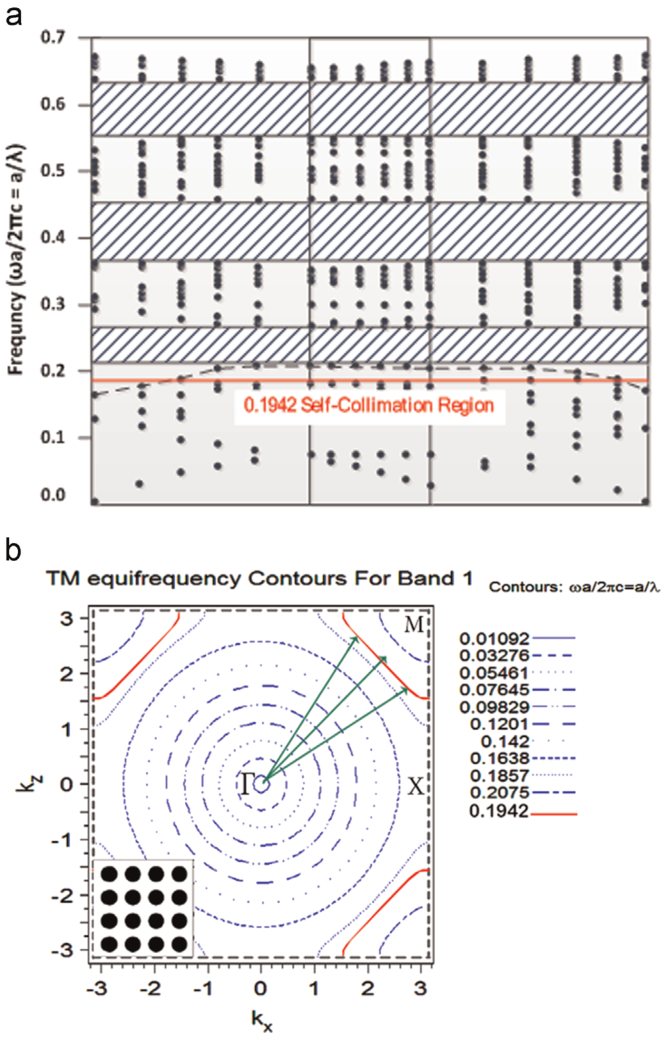


Fig. 1. (a) Band diagram of the square lattice PC structure for TM mode and (b) equifrequecy contours of the PhC.

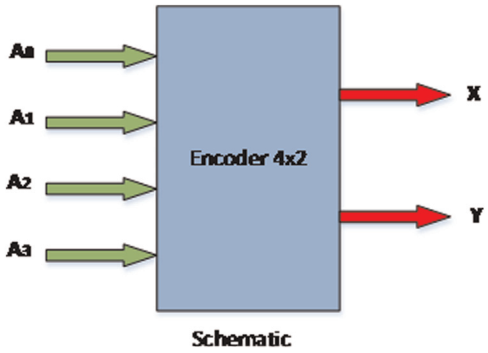


Fig. 2. Block diagram of Encoder.

The variation of transmission and reflection ratio versus the radii of the defect line is shown in Fig. 3. The red and blue curves show the transmitted and reflected power respectively. One can see when the defect line radii is the same as the host rods (i.e. we have no defect in the propagation path), the transmission ratio is very close to unit, and reflection ratio is about zero. By decreasing the defect radii the transmission ratio decreases and the reflection ratio increases. Such that when the defect radii is zero (i.e. the rods have been removed completely) the transmission ratio is about zero and reflection ratio is very close to unit, in other words the