Optics Communications 332 (2014) 359–365

Contents lists available at ScienceDirect

Optics Communications

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

# Reconfigurable design of logic gates based on a two-dimensional photonic crystals waveguide structure

Yu-Chi Jiang [a,b], Shao-Bin Liu [a,*], Hai-Feng Zhang [a], Xiang-Kun Kong [a]

[a] Key Laboratory of Radar Imaging and Microwave Photonics, Ministry of Education, Nanjing University of Aeronautics and Astronautics, Nanjing 210016, China
[b] School of Physics and Electronic Engineering, Changshu Institute of Technology, Changshu 215500, China

ARTICLE INFO

*Article history:*
Received 18 March 2014
Received in revised form
8 July 2014
Accepted 11 July 2014
Available online 23 July 2014

*Keywords:*
Photonic crystals
Waveguide
Reconfigurable logic gate
Finite-difference time-domain method

ABSTRACT

In this paper, a particular two-dimensional photonic crystal reconfigurable structure is designed to realize different logic functions based on the theory of light beam interference effect, and the distribution of the electric field is computed by the finite-difference time-domain (FDTD) method. The results show that five types of logic gates such as NOR, OR, XNOR, $\overline{A}+B$, NOT can be realized by choosing different input and reference port in a two-dimensional PCs waveguide configuration. It is noticed that the logic state of “1” and “0” at output port are defined as the transmission is larger than 0.5 and less than 0.1, respectively.



## 1. Introduction

The Photonic crystals(PCs) were first proposed dependently by Yablonovitch [1] and John [2] almost at the same time in 1987 which are composed of mediums with different refractive index in spatial periodic arrangement. The photonic band gap (PBG) is always observed in the PCs which can control the propagation of the electromagnetic wave, and PBG has very interesting properties of light confinement and localization [3,4]. Many researchers focus on modifying large PBG by covering the rods with other materials [5], changing the rod with different shapes [6] or hybrid scatterers [7]. If one point defect is introduced in the two-dimensional PCs, some frequencies in the PBG are no longer prohibited and the defect mode can be formed in the PCs [8,9]. If one line or several lines of rods are removed in two-dimensional PCs, line defect channel also called waveguide is formed. Waveguide has been extensively studied for applications in wavelength division multiplexer [10], ultrahigh-contrast all-optical diode [11], ultra-fast all-optical switching [12] and logic gate [13].

In recent years, the great efforts have been made to the design and application of logic gates. Fu et al. design different all-optical logic gates [14] with different structure design in two-dimensional (2D) PCs and obtain high contrast ratio between the logic state of “1“and “0”. An all-optical AND gate based on a 2D PCs can operate at various wavelength, which has more flexibility in the applications of logic gate in the optical processing [15]. A new topology for “AND” logic gate with ultra-short transition and delay time is proposed while Kerr nonlinear medium is introduced into 2D triangular PCs [16]. NOR logic gate is realized based on nonlinear PCs micro ring resonators to obtain the higher light contrast ratio between logic state “1” and “0” [17]. However, in these reports, one logic gate is realized with one configuration, which restricts the design and integration of the optical device. Although AND & XOR logic gates are presented based on nonlinear PCs ring resonator [18] and two output ports are used for signal propagating simultaneously, the scheme only can realize two logic gates functions.

In this paper, five types of logic gates are realized based on the theory of light beam interference effect with a same topology by choosing different reference light beam port and input port, meanwhile, the distribution of the electric field is simulated by the FDTD method. The results show that this reconfigurable design of logic gates has the advantages of compactness and potential for photonic device integration and design.

## 2. Physical model

The $x$–$y$ plane diagram of our model is presented in Fig. 1(a), and the inserted silicon rod (marked with white circle in Fig. 1(a)) with axis along $z$ is surrounded by air background (marked with

* Corresponding author.
*E-mail address:* plrg@nuaa.edu.cn (S.-B. Liu).

http://dx.doi.org/10.1016/j.optcom.2014.07.038
0030-4018/

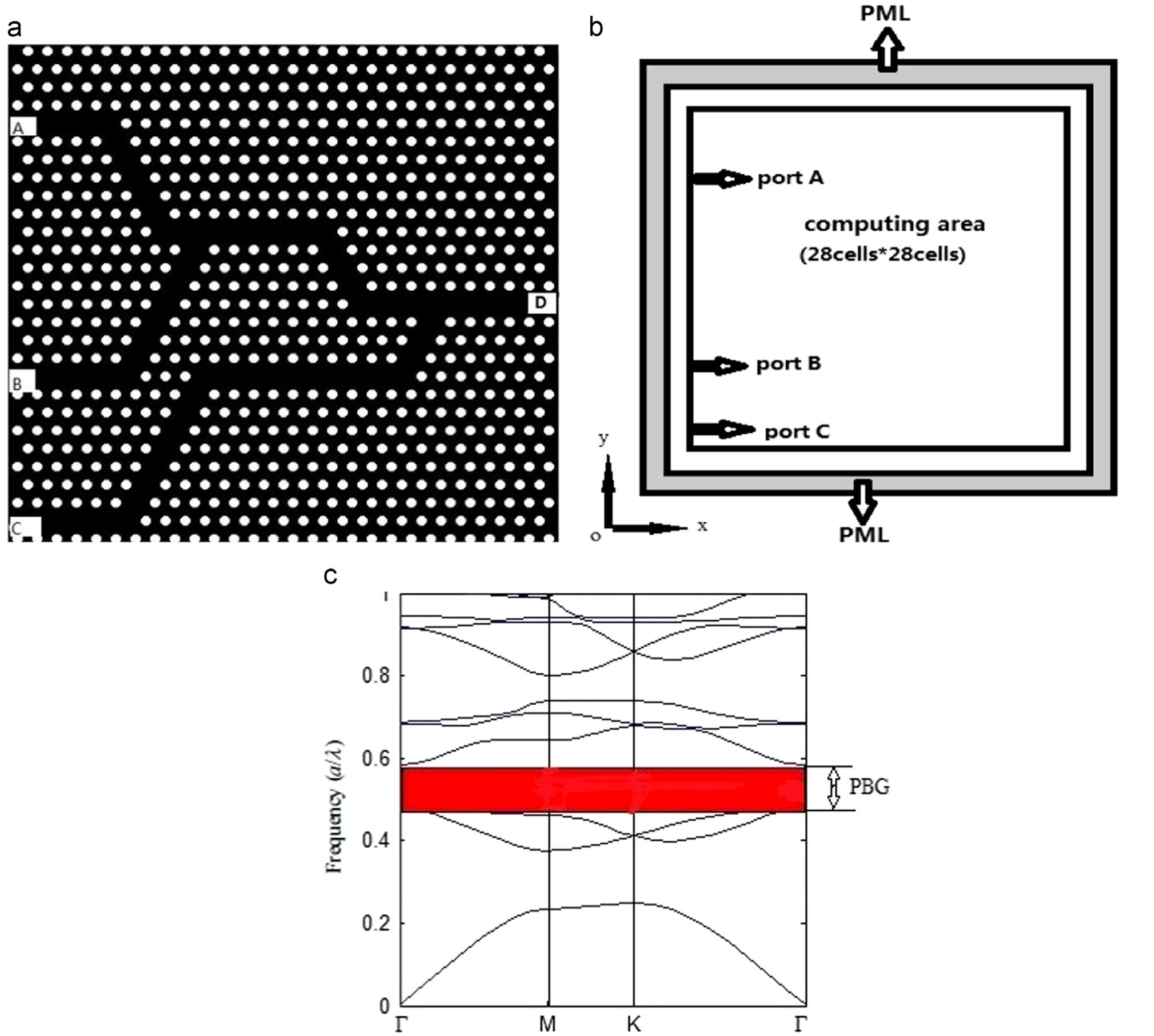


**Fig. 1.** (a) the schematic structure of the 2D photonic crystals waveguide (b) the simplified computing model (c) Band diagram of triangular lattice of infinite silicon rods embedded in air substrate.

black part) in the 2D PCs. The structure is composed of triangular lattice arrays of silicon which can provide a considerably large band gap and be used in many studies as all-optical logic gates [13–15]. The dielectric constant of the dielectric rods is set to 11.56. The radius of the cylindrical rod is 247.5 nm and the lattice constant is 1000 nm. The ports A, B, C could be chosen as the input port or the reference port into which the reference light beam is injected, and the port D is the output port. A continuous wave (CW) light source at a wavelength of 2040 nm further investigated in the part 3.1 is used as the input source in the following calculations. Here, we propose that the input wave excited at any input port has the electrical field amplitude of 100 V/m and original phase of 0. The signal light injected into the input port or reference port is considered as TM wave where the electrical field is kept parallel of the *z*-axis. The distribution of the electric field intensity is simulated and the transmission is computed by the FDTD method. Fig. 1(b) refers to the simplified computing model. The computing space is composed of $28 \times 28$ lattices in the *x* axis and *y* axis and each lattice includes 20 Yee cells. Port D is assumed as the output port. According to the courant stability condition of FDTD method [19,20], time interval ($\Delta t$) is $2.2458 \times 10^{-15}$ S and spatial interval along *x* axis ($\Delta x$) and *y* axis ($\Delta y$) is 50 nm. The boundary absorption condition is considered as the perfectly matched layer (PML) which is 20 layers. The normalized frequency of PBG marked by red zone is $0.475(a/\lambda) - 0.58(a/\lambda)$ according to the band diagram shown in Fig. 1(c) which is obtained by the plane wave expansion (PWE) method [21].

## 3. Simulation and results

According to the wave optics theory [14], if the phase difference between two light beams is $2k\pi$ ($k$=0,1,2…), the constructive interference will occur, and the output light will have high power (corresponding to logic state of "1"). On the contrary, if the phase