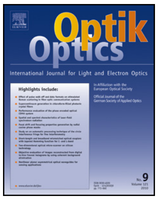
Optik 126 (2015) 950–955

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo



# Design of all optical logic gates in photonic crystal waveguides

Preeti Rani, Yogita Kalra, R.K. Sinha*

*TIFAC-Centre of Relevance and Excellence in Fiber Optics and Optical Communication, Department of Applied Physics, Delhi Technological University (Formerly Delhi College of Engineering), Bawana Road, Delhi 110042, India*

ARTICLE INFO

*Article history:*
Received 24 February 2014
Accepted 3 March 2015

*Keywords:*
Photonic crystals
Logic gates
FDTD method
Optical interference effect

ABSTRACT

In this paper, we report the design of all optical logic gates based on two-dimensional photonic crystal (PhC) composed of triangular lattice of air holes in silicon (Si). The proposed structure has been simulated using finite difference time domain (FDTD) method and it has been shown that all optical logic operations can be achieved if an appropriate initial phase is introduced between the input beams so that they may interfere constructively or destructively. The optical logic gates designed in the proposed structure have a response period of 1.024 ps and can operate at a bit rate of 0.976 Tbit/s.

## 1. Introduction

Logic gates and devices play a basic, critical and important part in modern electronics and integrated circuits. Recently, all optical logic gates have received considerable attention for their applications in optical communication networks, due to their importance in addressing, switching, encryption, data encoding, signal regeneration, header recognition and contention resolution. In recent years different schemes have been demonstrated for the designing of all optical logic gates based on linear optical effects such as, interferometry [1], semiconductor optical amplifier (SOA) [2] and Mach-Zehnder interferometer (MZI) [3] and nonlinear processes which include electro-optical effect [4,5], thermal-optical effect [6], two-photon absorption [7] and third-order nonlinear effect [8,9]. Logic gates are capable of performing many logic functions and have numerous applications in optical communication, such as, AND logic gate is used to perform address recognition, packet-header modification, and data-integrity verification and also serves as a sampling gate in optical sampling oscilloscopes. XOR gate can perform functions like comparison of data patterns for address recognition, packet switching, data encryption/decryption, parity checking and optical generation of pseudorandom patterns. NOT gate can be used as inverter or switch and XNOR logic gate is used to realize the threshold detector functionality. In this paper, we have proposed the design of all optical logic gates based on two-dimensional photonic crystals composed of triangular lattice of air holes in Si. Till now many logic gate designs have been proposed which consist of Si rods in air [10–13] but those designs are not practical from the point of view of sustainability and fabrication. Photonic crystal composed of air holes in silicon is a more practical structure and has been used in the design of optical logic gates [14,15] and nano photonic devices [16,17]. The proposed optical logic gates are based on the phenomenon of optical interference effect and are designed in two dimensional photonic crystal waveguides composed of air holes in silicon. The simulation results show that the proposed all optical photonic crystal waveguide structure could really function as all optical logic gates. By appropriately choosing the size of the air hole at the center of the four PhC waveguides the optimal performance in terms of response time, bit rate and contrast ratio for the proposed optical logic gates has been obtained.

## 2. Design and operating principle of all optical logic gates

In this paper, the design for all optical logic gates has been proposed based on the platform of 2D PhC. The proposed two dimensional photonic crystal structure, as shown in Fig. 1 consists of $15a \times 15a$ two dimensional triangular lattice composed of air holes in silicon having refractive index $n = 3.5$. The radius ($r$) of air holes is $0.3a$, where, '$a$' is the lattice constant equal to 0.352 μm. According to the band diagram of the bulk PhC as shown in Fig. 2, light with wavelength range of (1.291–1.715 μm) for TE modes cannot pass through the uniform PhC structure. In the proposed design four waveguides have been created, from which two of them are considered as input ports indicated as port A and port B. As shown in Fig. 1, one port has been indicated as reference port R which is used to create phase difference between input signals resulting into constructive or destructive interference. Output signals are obtained

---

* Corresponding author. Tel.: +91 9953051499.
*E-mail address:* dr_rk_sinha@yahoo.com (R.K. Sinha).

http://dx.doi.org/10.1016/j.ijleo.2015.03.003
0030-4026/© 2015 Elsevier GmbH. All rights reserved.

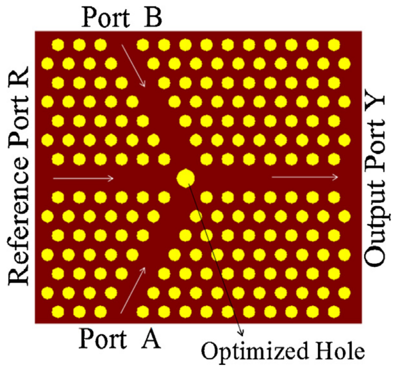


**Fig. 1.** Schematic representation of all-optical logic gates.

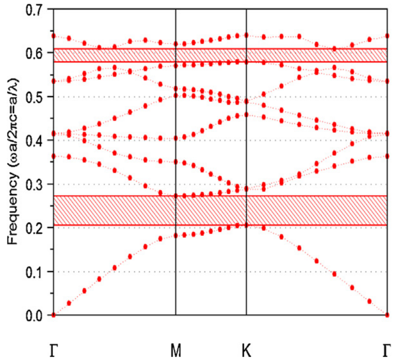


**Fig. 2.** Band gap structure of the photonic crystal layout.

from the right port indicated as output port Y. Further, in the proposed structure a hole has been introduced at the center of the four waveguides. For the design of all optical logic gates the radius of the central hole is optimized in such a way that for a single input (along with reference signal) as well as both the inputs (along with the reference signal) maximum power is obtained at the output port Y. For the proposed structure, transmittance ($T$) which is defined as $T = I_{out}/I_{in}$ has also been calculated, where '$I_{out}$' is the intensity of light received at the output port Y and '$I_{in}$' is the intensity of light launched at the input port. The spectral response of proposed logic gates for TE like polarization of incident light from single input port (with reference signal) as well as for both the input ports (with the reference signal) has been shown in Figs. 3 and 4. Fig. 3 shows the transmittance with respect to the wavelength when the incident light is launched at one of the two input ports with the reference signal having same phase with the input signal. Similarly, Fig. 4 represents the transmittance with respect to the wavelength of incident light launched at both the input ports with the reference signal having same phase as that of the input signals. The contrast ratio defined as $10\log(P_1/P_0)$ (dB) has also been calculated for all optical logic gates, where $P_1$ represents the power for logic-1 and $P_0$ represents the power for logic-0. Fig. 5 shows the defect modes that exist within the band gap range. From Figs. 3–5 it has predicted that the optimized structure can be best worked out at the normalized operating wavelength of 1.55 μm which lies in optical communication range. The response time for the proposed structure has also been calculated and plotted [18,19].

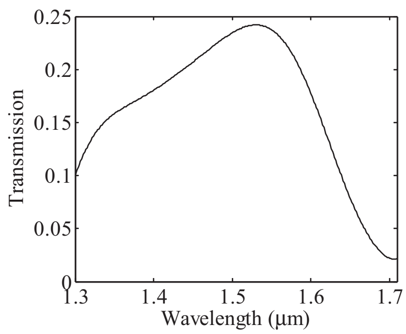


**Fig. 3.** Variation of transmittance with wavelength from the output waveguide for the single input signal along with the reference signal for TE like polarization of incident light.

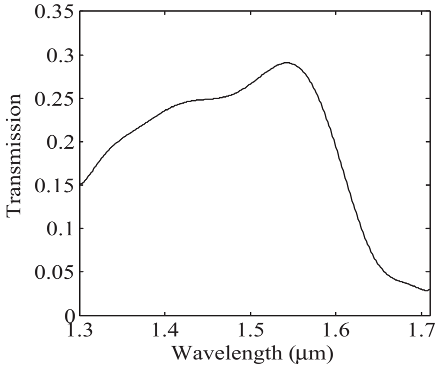


**Fig. 4.** Variation of transmittance with wavelength from the output waveguide for both the input signals along with the reference signal for TE like polarization of incident light.

## 3. Optimization of the radius of the hole at the center of the four waveguides

The radius of central hole has been optimized when one of the input signals as well as both the input signals, along with the reference signal are unity and has zero phase difference. From the optimization curve for the radius of the central hole as shown in Fig. 6, it has been observed that as the radius of the central hole increases, the output power increases to a maximum value and then decreases for both the input signals as well as for the single input signal along with the reference signal. Hence the optimized radius of the air hole at the center of four waveguides has been taken as $r_c = 0.44a$.

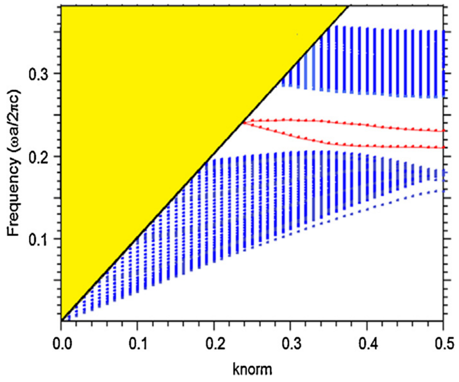


**Fig. 5.** Dispersion relation for all the four involved PhC waveguides. The black solid line corresponds to the light line and the red dotted lines inside the band gap region correspond to the respective guided modes for TE polarization in all the waveguides. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)