

Designing OR logic gate using two-dimensional optical crystal according to Mach Zehnder filter suitable for all-optical digital integrated circuits

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Abstract

Photonic crystals can be simply defined as an environment with intermittent optical properties which consist of intermittent dielectric and has one-, two- and three-dimensional structures. One of the unique properties of optical crystals is the property of controlling the light passing through the area called photonic band gap which is due to the intermittence of dielectric in optical crystals. Photonic crystal is highly dispersive and its permittivity and reflection are heavily dependent on the wavelength. In this study, OR all-optical logic gates were designed, analyzed and simulated. The basis of the gates is light (electromagnetic waves). These gates were designed as silicon rods in the air by two-dimensional optical crystals with different networks. The basis of the gates are defect and interference of light waves. Controlling the light was done within the gate using the defect. Using interference effect which can be constructive or destructive, the output of logical zero or one was obtained. The advantages of these gates compared to similar electronic gates are lower dissipation, higher speed (at the speed of light), simpler structure, zero power consumption in a relaxed state and etc. which are investigated later. To simulate these gates, two methods of finite difference in the time domain and the expansion of plane waves were used. The first one was used to calculate the electric field distribution and the second one was used to calculate the photonic band. The results of simulation using Rsoft software contains graphic charts.

Key Words: photonic crystal, band gap, OR optical gate

Introduction

Although the studies on photonic crystals were started since 1887 but no one used the term photonic crystal until over 100 years later—after Eli Yablonovitch and Sajeev John published two milestone papers on photonic crystals in 1987. Applications of photonic crystals have been expanding rapidly during the past decades. Some of the latest and greatest were highlighted here. Probably, theirs most interesting and most important application was the use of them in fiber-optic communications. The unique feature of photonic crystals, i.e. reflecting the light completely when its

frequency is within the photonic band gap, increases dramatically the possibility of reducing casualties in the fiber sheath. Also, it is no need that the light spread in the dielectric. The light can be actually guided in a vacuum or air with low pressure which then, nonlinear effects and fiber losses become very low.

1-1- Optical crystal

Any structure that its refractive index intermittently changes, is called optical crystals. If this is repeated in one dimension, the formed crystals are called one-dimensional optical crystals. Repeating the intermittent structure in two or three dimensions will create two- and three- dimensional optical crystals. These structures are in fact dual semiconductor crystals. So, the performance of optical crystals (structures with intermittent refractive index) against photons is similar to the performance of semiconductor crystals (structures with intermittent electric potential) against electrons.

1-2- Optical crystal structure

Photonic crystals can be simply defined as an environment with intermittent optical properties. For example, an intermittent optical environment is shown in figure (1-2) that the dark parts have homogeneous and different electric permittivity ϵ and magnetic permittivity μ compared to light parts. This system can be considered as a simple one-dimensional photonic crystal. Photonic crystal is highly dispersive and its permittivity and reflection are heavily dependent on the wavelength. In the following figure, this property is shown for a photonic crystal that its permittivity coefficient is greater than zero for blue light and almost zero for red light.

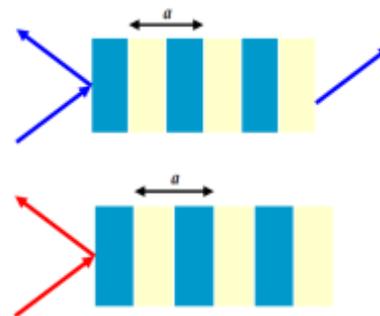


Figure (1-2) : one-dimensional photonic crystal and its response to two different wavelengths [1,2]

In above figure, a is called a constant of network or the period and represents the least spatial length in which the structure of network is repeated. Two types of square and triangular two-dimensional optical crystals are shown in following figure.



Figure (1-2). Two basic geometries of two-dimensional photonic crystal. Right: square structure, Left: Triangular structure.

Here a_1 and a_2 are the basic vectors of the network. In the structures which have more than one dimension, locative alternation goes back to the spatial dimensions of the translational symmetry that here represented as $\epsilon(r)=\epsilon(x,y)=\epsilon(r+a_i)$ and in two dimensions and (three dimensions) $i=1,2,3$, it is clear that the resulting exterior product of the network vectors in two dimensions (three dimensions) in a form $|a_1 \times a_2|$ ($a_1 \times a_2 \cdot a_3$), must be non-zero. For both square and triangular two-dimensional structures, basic vectors are equal in terms of length. On the other hand, for the square structure, $(a_1, a_2) = \pi/2$ and for the triangular structure, $(a_1, a_2) = \pi/3$. It can be plainly seen that in addition to translational symmetry which is a property of locative alternation, there is another type of symmetry caused by the rotation around the origin that remains the photonic crystal unchanged.

1-3- Applications of optical crystals

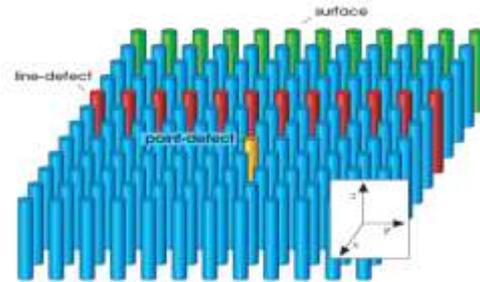
More applications of optical crystals arise from a defect in the optical crystals. For this reason, prior to discussion on the applications of optical crystals, firstly, the defect in the optical crystals is reviewed. Regardless of controlled defect, the charm and applications of photonic crystals are very limited. Defect in photonic crystals creates a localized mode or an allowed frequency level inside the photonic band gap.

1-4- What is defect?

The absence of one or more points of actual network or the change of points in the closed network is called defect that depending on the geometry, there are generally three types of defect: point defect (zero-dimensional defect), linear defect (one-dimensional defect) and plane defect (two-dimensional defect). Two types of point and linear defects are discussed in this study because of their extensive applications. Compared with electron crystal, any holes or dielectric cylinder can be called atom. Then, in general, point defect can be a type of

impurities which is located in the network or an atom which has been removed from a crystal network or moved from its place. In addition to radius, kind of dielectric or reflection, translational symmetry leads to point defect in any way. Plane defect is created by removing a group of crystals in a form of a plane. Figure (1-4) shows the types of defects.

Figure (1-4). Different types of defects

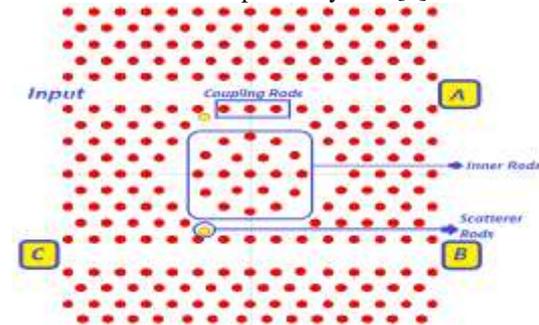


Typical application of optical crystals is the manufacture of optical gate. Compared to electronic gates, the advantages of optical gates are very high speed and more simple structure.

1-5- Designing OR optical gate based on a resonator using two-dimensional optical crystals

The resonator was designed using two-dimensional optical crystals to be used in analog-to- all-optical digital converters. In the design, the quality index was 202 and the efficiency loss was 100%. In the converter, the effects of the changes in the dielectrics of coupling rods and inner dielectrics of the ring and also, the total dielectrics of the network were investigated. The area of the defined structure was $103 \mu m^2$. The simulation was performed based on FDTD method [5]. The studied ring resonator was designed by using of two-dimensional optical crystals with triangular network containing existing dielectric rods in the air and eliminating the number of rods in a form of ring. The studied structure is shown in figure (1-9).

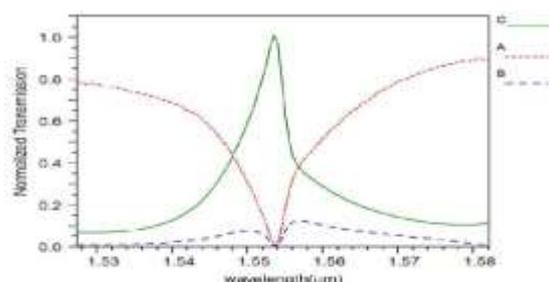
Figure (1-9). A structure of ring resonator consisting of two-dimensional optical crystals [5]



In this structure, one input and three output of A, B and C were embedded. The rods inside the structure are shown by Inner Rods. The main structure shows

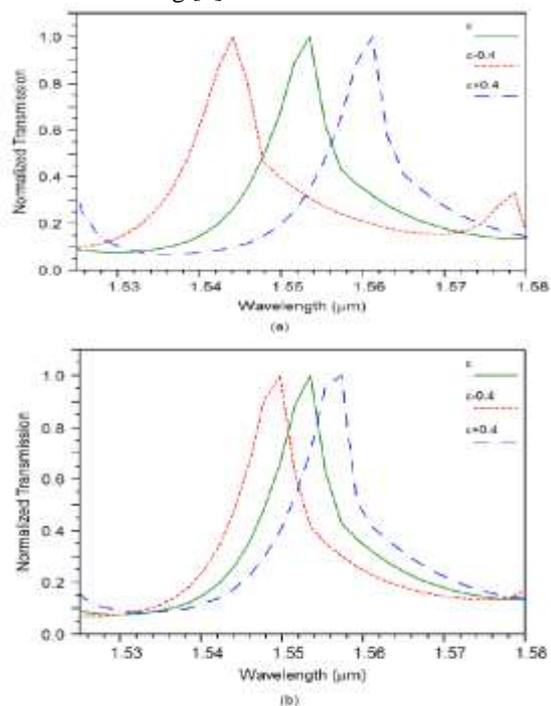
the ring resonator. There are rods for coupling the light to the existing desired outputs which are shown by Coupling Rods. Also, two yellow rods were put to prevent returned scattered moods which are shown by Scattered Rods. The results of simulation are shown in following figures.

Figure (1-10). Spectrum of the passing optical power transmitted through the structure of the ring resonator [5]



In figure (1-10), the optical power passing the wavelength 1.522 μm was equal to zero percent for the outputs of A and B and 100% for the output of C. for the output of C with sharp Gaussian shape, the quality index can be calculated which is defined as $Q_c = \lambda / \Delta\lambda$ where λ is a central frequency and $\Delta\lambda$ is the full width at the half of maximum value. In this case, the quality index is estimated equal to 202.

Figure (1-11). Normalized passing optical power based on the wavelength of input light with the changes of refractive index, a) the entire network, b) inner rods of ring [5]

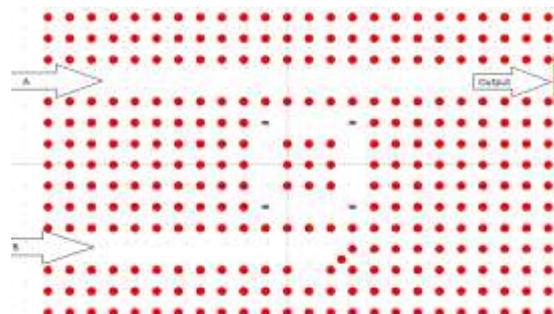


As shown in two charts of figure (1-11), the wavelength of passing light can be changed by changing the refractive index of the structure. This

is a wavelength shift which is very useful in optical gate and analog-to-all-optical digital converters.

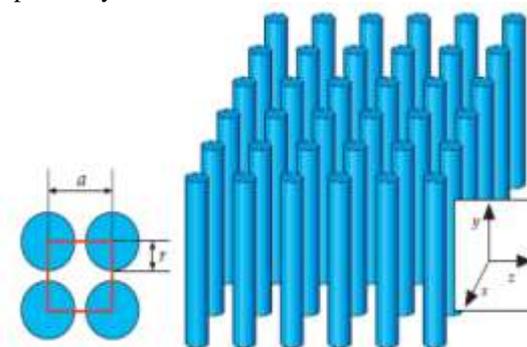
The structure of studied OR gate is formed with silicon rods in the air with square network and refractive index 3.4. It is shown in figure (1-12). This structure includes two inputs and one output and also one resonator to have proper functioning.

Figure (1-12). Structure of OR all-optical gate



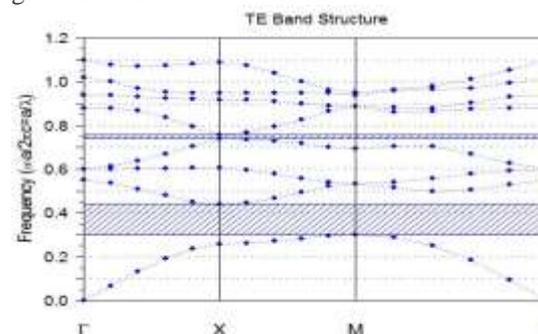
References The radius of the rods and the constant of the network, shown in figure (1-13), were considered equal to 100 and 540 nm, respectively.

Figure (1-13). Radius and constant of the studied optical crystal rods network



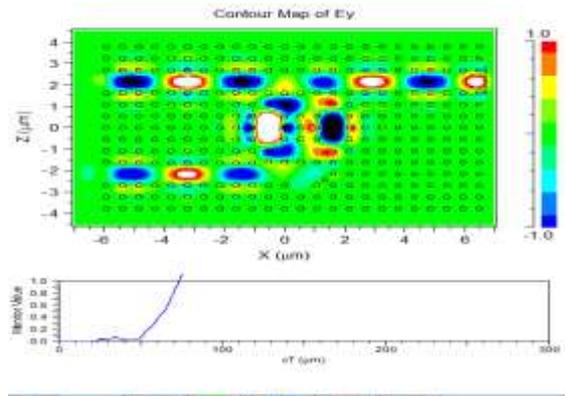
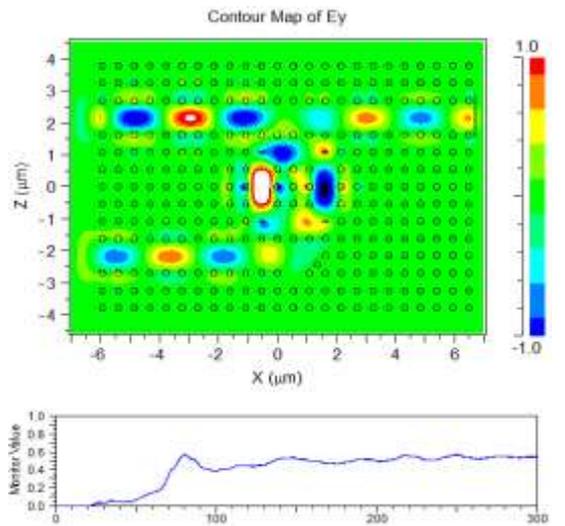
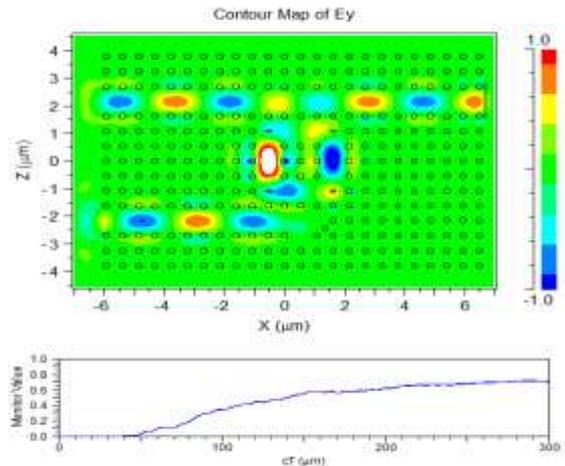
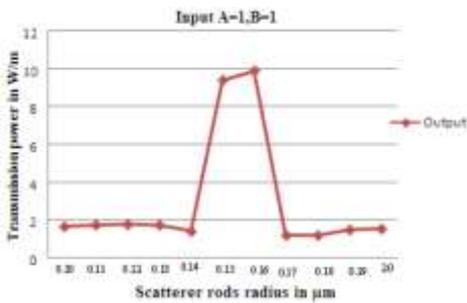
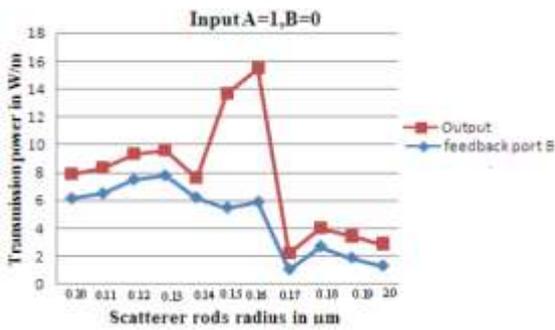
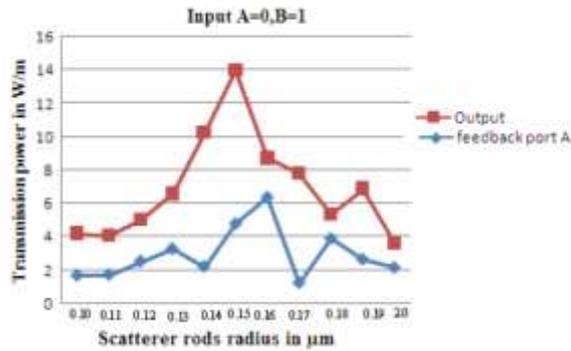
Photonic band structure calculated by the use of PWE method in Rsoft software and TE polarization, is shown in figure (1-14). In this chart, there are two photonic bands that one of them is in the range of 0.3-0.44 (a / λ).

Figure (1-14). The chart of the photonic band of OR gate structure



Given the following charts, the radius of the dispersive rods (blue rods) can be considered equal to 150 nm so that the studied optical crystal will act as OR gate. Following charts were obtained by FDTD method.

Figure (1-14). Passing power charts in terms of the radius of dispersive rods



The results of simulating the electric field distribution of studied gate are as follows. Figure (12-4). Results of simulating the OR all-optical gate. a) When A=0 and B=1, the output is equal to 1. b) When A=1 and B=0, the output is equal to 1. c) When A=1 and B=1, the output is equal to 1.

Optical crystals consist of intermittent dielectric and has one-, two- and three-dimensional types. Discussed optical gates have two-dimensional structure. One of the unique properties of optical crystals that makes them suitable for designing all-optical logic gates is the existence of photonic band. In photonic band, the frequency of the light which is within the band gap, cannot pass the crystal and the frequency of the light which is within the band pass,

can pass the crystal. Another unique properties of optical crystals is the property of controlling the light passing. This is possible by creating defects in the crystal. Using defects, we were able to design the gates and also determine the path of light. All-optical gates were designed based on both defect and photonic band. To simulate these gates, two methods of finite difference in the time domain and the expansion of plane waves were used. The first one was used to calculate the electric field distribution and the second one was used to calculate the photonic band. Rsoft software (it is a software for simulation of photonic crystal) was used for simulation. The results of simulation include graphic charts and tables which were investigated. Electronic gates need to be on for proper functioning and for this reason, they consume electric power even in normal mode (relaxed mode) but the optical gates built by optical crystals don't need to be on. The input signals of electronic gates are of voltage but the optical gates built by optical crystals use light sources such as laser as their input signals. These are good alternatives for electronic gates due to simpler structure, higher speed, lower power dissipation and etc. So, these gates are suitable for making optical integrated circuits.

Suggestions

In this part, the author suggests some items to readers to continue the study on designing the optical gate using optical crystals. As shown in this study, the aim was to design the all-optical gate with nearly the speed of light, simpler structure, less dispersion and higher output power. So, the readers can continue to study on this issue by improving the parameters of these gates and also they can continue their studies on self-collimated beams and defect methods which are modern and applied methods in optical crystals. As demultiplexer structure has been raised as all-optical gate, the readers can use other methods to design this gate and also, can design other optical gates such as decoder, encoder, multiplexer, ... which are very useful in optical integrated circuits. The readers can also implement these gates on the three-dimensional structures.

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