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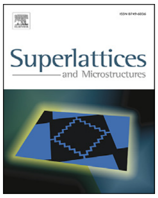

Line defects on As_2Se_3-Chalcogenide photonic crystals for the design of all-optical power splitters and digital logic gates

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ABSTRACT

In this paper, a triangular two-dimensional photonic crystal (PhC) of As_2Se_3-chalcogenide rods in air is presented and its photonic band diagram is calculated by plane wave method. In this structure, an optical waveguide is obtained by creating a line defect (eliminating rods) in diagonal direction of PhC. Numerical simulations based on finite difference time domain method show that when self-collimated beams undergo total internal reflection at the PhC-air interface, a total reflection of 90° occurs for the output beams. We also demonstrate that by decreasing the radius of As_2Se_3-chalcogenide instead of eliminating a diagonal line, a two-channel optical splitter will be designed. In this case, incoming self-collimated beams can be divided into the reflected and transmitted beams with arbitrary power ratio by adjusting the value of their radii. Based on these results, we propose a four-channel optical splitter using four line defects. The power ratio among output channels can be controlled systematically by varying the radius of rods in the line defects. We also demonstrate that by launching two optical sources with the same intensity and 90° phase difference from both perpendicular faces of the PhC, two logic OR and XOR gates will be achieved at the output channels. These optical devices have some applications in photonic integrated circuits for controlling and steering (managing) the light as desired.

1. Introduction

Photonic crystals (PhCs) are dielectric materials that their refractive index is periodically modulated in one dimension (1D), two dimensions (2D) or three dimensions (3D). The properties of complex dispersion in PhCs provide some mechanisms to control the propagation of light, such as self-collimation, superprism effect and negative refraction [1–4]. PhCs have a photonic band gap (PBG) to avoid propagation of a certain frequency range of light in any direction and act as a perfect mirror [5–7]. Due to the application, the structure of these dielectric materials can be set in order to let some frequency components propagate in a certain direction or omni-direction [8,9]. This property enables one to control light and produce effects that are

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impossible with conventional optics. In other words, the PBG can be so adjusted to design the desired devices [10]. In recent years, many efforts have been done for design of photonic devices based on their band gaps [11–13] such as switches [14], logic gates, multiplexers or demultiplexers [15,16], buffers [14], splitters [17], couplers [18], converters [19], resonators [20], waveguides [5], PhC Mach–Zehnder interferometer [21] and PhC fibers with different applications [13,22–27].

Recently, self-collimation phenomenon, in which an incident beam can propagate with nearly no diffraction along a certain direction in a PhC, has attracted particular attention due to its potential for photonic integrated circuits (PICs). Kosaka et al. experimentally demonstrated the propagation of self-collimated beams in PhCs [28]. The propagation of collimated beams was also studied numerically by Witzens et al. [29]. They showed that bending and splitting of self-collimated beams are possible. In the most studies, silica and silicon have been used as background materials of PhCs. The main problem of using silica is its transmission window that is less than 2.5 μm and doesn't cover the mid-infrared wavelength range. However, silicon has too much loss and high nonlinearity.

To take the advantages of the self-collimation, in this paper, a two-dimensional PhC including a large number of As_2Se_3-chalcogenide rods in a triangular lattice is presented and its photonic band diagram will be calculated. By eliminating a row of rods in diagonal direction of PhC, a line defect is created to make a photonic crystal waveguide. Also, it is shown by reducing the radius of rods instead of removing them, a two-channel splitter has been achieved in which an input beam is divided into two output beams with equal powers. Then using two input beams with the same power but with 90° phase difference in both sides of the PhC, two logic gates, OR and XOR are achieved that can be applicable as a photonic logic switches. Based on this result, optical switches and logic gates are considered as key components in future PICs.

2. Two dimensional photonic crystals

2.1. Two dimensional photonic crystal with triangular lattice

Fig. 1(a) shows a two-dimensional photonic crystal with triangular lattice consisting of many circular As_2Se_3-chalcogenide rods with radius $r=0.35$ μm and the lattice constant (the center to center distance of two adjacent rods,) is 1.45 μm. Moreover, the length of PhC in each side is assumed by 36.25 μm. Due to a large number of rods in air substrate, E polarized mode has been considered in which electric field is parallel to the rod axes.

To find the frequency range in which the self-collimation phenomenon occurs, we computed the equifrequency contours (EFCs) as a function of wave vector (**k**). In inhomogeneous media, the light propagation direction is identical to the direction of group velocity which means the group velocity is perpendicular to the EFC [30]. We employed the plane wave expansion (PWE) method to plot the EFCs of the two dimensional photonic crystal. Using the PWE, the PBG of the presented PhC has been calculated and shown in Fig. 1(b). In this simulations, the material refractive index is assumed by 2.78. As can be observed in this figure, there are two PBG windows $1.53 < \lambda < 1.69$ μm, and $2.26 < \lambda < 3.27$ μm. In these windows, signal propagation is impossible in every direction of the lattice. By choosing the central frequency outside the PBG windows, input signal can propagate inside the PhC structure depending on the beam direction. So, a Gaussian optical pulse was considered at the central wavelength of 4 μm which is used as a suitable source for mid-infrared applications.

The numerical analysis was carried out using the finite difference time domain (FDTD) method [31]. This method is a direct solution to Maxwell's time dependent curl equations which incorporates the effects of reflection and radiation that commonly neglected by other methods. The FDTD method can also model wave propagation in complex media, such as time varying, anisotropic, lossy, dispersive and nonlinear media. The implementation of this numerical method is easy and can be applied to both materials with any conductivity and the three-dimensional, arbitrary geometries [32]. Other simulation assumptions are as follows:

The perfectly matched layers (PMLs) in the x and y directions were chosen to study the transmission and reflection properties of the electromagnetic field at normal incidence. The calculation grid resolution (i.e., mesh cell size) was as small as 10 nm in the x and y directions in the simulation cell.

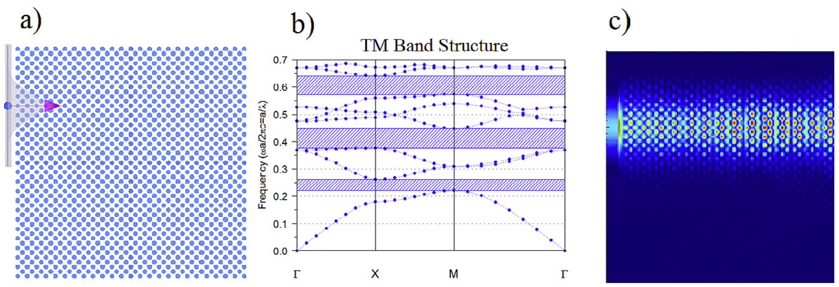

Fig. 1. a) Triangular two-dimensional photonic crystal of As_2Se_3-chalcogenide rods (blue circles) in air b) photonic TM band diagram for two PBG windows in $1.53 < \lambda < 1.69$ μm, and $2.26 < \lambda < 3.27$ μm c) light propagation with central wavelength of 4 μm outside PBGs.