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Tunable complete photonic band gap in anisotropic photonic crystal slabs with non-circular air holes using liquid crystals

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ABSTRACT

In this study, we analyze the tunability of complete photonic band gap of square and triangular photonic crystal slabs composed of square and hexagonal air holes in anisotropic tellurium background with SiO_2 as cladding material. The non-circular holes are infiltrated with liquid crystal. Using the supercell method based on plane wave expansion, we study the variation of complete band gap by changing the optical axis orientation of liquid crystal. Our numerical results show that noticeable tunability of complete photonic band gap can be obtained in both square and triangular structures with non-circular holes.

1. Introduction

Photonic crystals (PCs) have been one of the major subjects of research in physics and engineering, due to their special and applicable properties. Some of these features are, controlling and manipulating light flow, designing of optical devices with wavelength and subwavelength dimensions and many other peculiar phenomena interacted with light [1–5]. The most prominent property of PCs is photonic band gap (PBG), a region of frequency spectrum where propagating modes are forbidden [6]. PBG giving rise to physical phenomena such as inhibited spontaneous emission [7] and light localization [8]. PCs are mainly studied as photonic crystal slabs,due to the ease manufacturing technology compared to three-dimensional (3D) PCs and the ability to control light propagation in three dimensions [9,10]. PC slabs are 2D periodic structure of finite thickness that light is confined by a PBG in-plane, and by total internal reflection (TIR) in the vertical or out-plane direction. In PC slabs the modes are not purely TE (transverse electric) or TM (transverse magnetic) modes, but according to the symmetry in PC slabs, the propagation modes can be classified in two types of even modes (TE-like) and odd modes (TM-like) [11–13]. An complete PBG exist for PC slabs only when PBG in both polarization modes are present and they overlap each other in frequency [14]. There are several reasons for which a complete PBG would be a desirable feature. For instant, coupling between modes of opposite symmetry is possible in real structures, due to fabrication intrinsic imperfections, or it can be useful to support localized modes for both polarizations of light and the waveguides based on such defects can guide light of both polarizations as well. Thus, existence of a complete PBG, independent of mode symmetry, is very important for practical application. [15,16]

Fathollahi khalkhali et al. [17] have recently demonstrated that square and triangular-lattice PC slabs, created by square and hexagonal air holes in anisotropic Tellurium (Te) background surrounded by SiO_2 as cladding material, represents complete wide PBG.

In recent years, there has been much interest on tuning the optical properties of PBG structures in order to design switchable or dynamical devices. In 1999, Bush and John proposed that by infiltrating three dimensional (3D) PCs with liquid crystal (LC), an applied electric field would tune the PBG [18]. Following this publication, some investigations of band gap tunability have been done by utilizing LCs in one-dimensional (1D) [19–22], two-dimensional (2D) [23–29], and 3D [30–32] PCs.

Therefore, in this letter, we consider PC slabs with square and triangular lattice composed of air hole with different geometrical shape (square and hexagonal) in anisotropic Te background where the regions above and below the slabs are occupied by SiO_2. Then, we infiltrate the non-circular air holes with LC and study the tuning of complete photonic band gap by changing the director of LC.

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2. Structures and computational methods

In this study, we use square and triangular lattice created by square and hexagonal air holes in anisotropic Te background, surrounded by SiO_2 ($n^{SiO_2} = 1.45$) as cladding material, considering that the air holes are infiltrated with LC. The structure under consideration are shown schematically in Fig. 1. The orientation of non-circular air holes relative to the lattice axis is defined by angle Θ, which typically shown in Fig. 2 for square lattice of hexagonal air holes. The anisotropic Te has two different principle refractive indices as ordinary-refractive index $n_o^{Te} = 4.8$ and extraordinary-refractive index $n_e^{Te} = 6.2$ over the wavelength range of $4.50 - 6.25\ \mu m$ with an absorption coefficient of $\alpha \approx 1\ cm^{-1}$ [17]. We assume that the periodicity of the PC slab is in the $X - Y$ plane and the extraordinary axis of Te is considered parallel to the Z-axis. Generally, LCs possesses two kinds of dielectric constants known as ordinary ε^o and extraordinary ε^e dielectric constants. The light waves with electric field perpendicular and parallel to the director of LC experience ordinary and extraordinary dielectric constants, respectively. When the director of LC rotates, the components of the dielectric tensor can be represented as [33]:

$$\varepsilon_{xx}(\vec{r}) = \varepsilon^o + (\varepsilon^e - \varepsilon^o)\sin^2(\theta)\cos^2(\phi) \tag{1}$$

$$\varepsilon_{yy}(\vec{r}) = \varepsilon^o + (\varepsilon^e - \varepsilon^o)\sin^2(\theta)\sin^2(\phi) \tag{2}$$

$$\varepsilon_{xy}(\vec{r}) = \varepsilon_{yx}(\vec{r}) = (\varepsilon^e - \varepsilon^o)\sin^2(\theta)\sin(\phi)\cos(\phi) \tag{3}$$

$$\varepsilon_{xz}(\vec{r}) = \varepsilon_{zx}(\vec{r}) = (\varepsilon^e - \varepsilon^o)\sin(\theta)\cos(\theta)\cos(\phi) \tag{4}$$

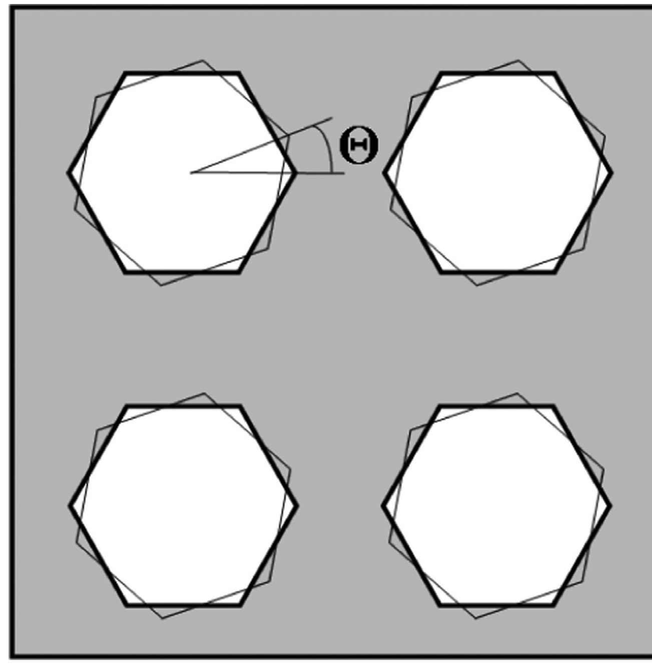

Fig. 2. The rotated hexagonal air holes in a square lattice with angle Θ, which is defined as the angle between axis of the hexagonal air holes cross section and the lattice axis.

$$\varepsilon_{yz}(\vec{r}) = \varepsilon_{zy}(\vec{r}) = (\varepsilon^e - \varepsilon^o)\sin(\theta)\cos(\theta)\sin(\phi) \tag{5}$$

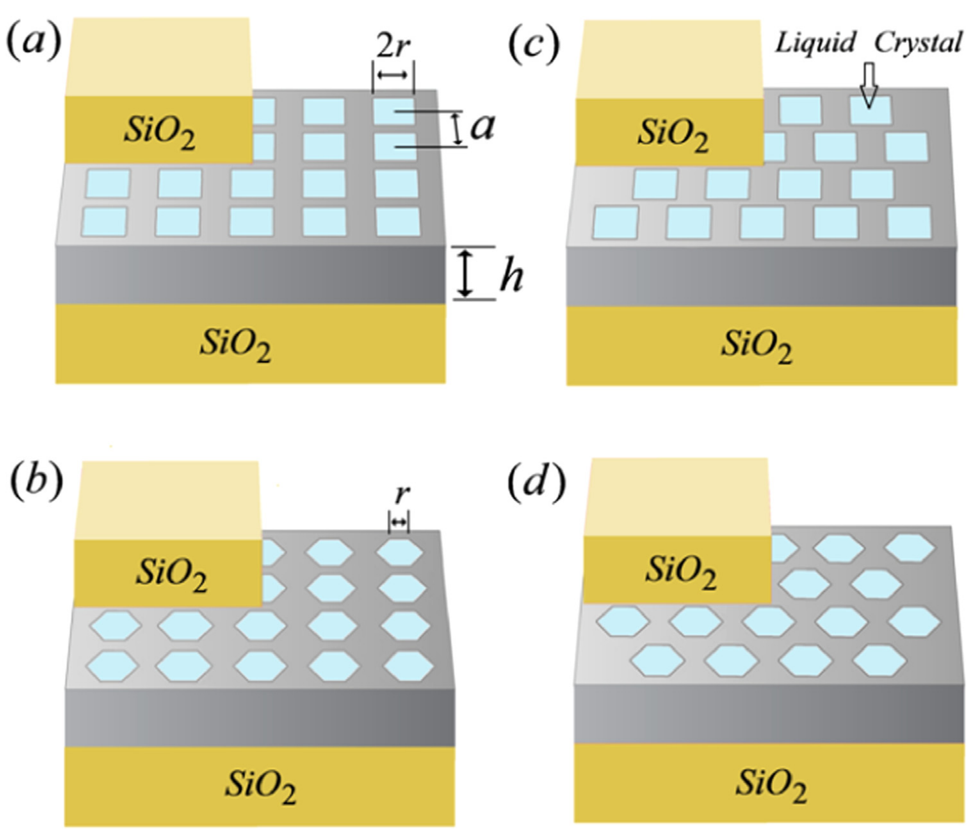

Fig. 1. Schematic representation of PC slab structures with (a and b) square lattice and (d and e) triangular lattice of LC-infiltrated air holes in anisotropic Te background surrounded by SiO_2.