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Effect of nondispersive defects on transmission spectrum of GaN dispersive photonic crystals

Fereshteh Rahimi Moghadam, Ali Bahari*

Department of Physics, Lorestan University, Lorestan, Iran

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ABSTRACT

The transmission spectrum 2D GaN dispersive photonic crystal (PhC) has been investigated by using finite element method (FEM). Calculations show that by replacing nondispersive defect instead of GaN dispersive rods in PhC, electromagnetic (EM) waves can propagate in photonic band gap. Transmission spectrum for different types of nondispersive defects for linear and bend PhC waveguide is carried out and compared together. By selecting suitable dispersive PhC material and different nondispersive defects, the number and position of transmission modes can be controlled. Calculations show that number of transmission modes in the band gap depends on kind of PhCs, kind of defects and kind of PhC waveguide.

1. Introduction

Photonic crystals are periodic structures that consist of lattice arrays with different refractive index. Since these structures are designed to guide the light, their dimensions should be in wavelength scale. Most generally used lattice types for 2D structures are square and triangular lattices. In square lattice, bars in PhC structures are placed in a square on the plane and refractive index changes periodically along x and y directions but invariant in *z*. In triangular PhCs lattice, bars are placed at the corners of triangles on a plane. Since there are more symmetry directions than that of square lattice, triangular lattice can support larger photonic band gaps. The periodicity and dimensions of PhC should be on the order of the wavelength of incident light in order to control the photons via band formation just like the periodicity in the solid state crystals which determines the energy band structure [1].

Much research has been done in the field of micro–nano photonics to increase the optical properties of light. One of the branches which have been intensely investigated to improve the optical properties of the devices is photonic crystals. PhCs can be engineered so that light can only propagate in certain directions for certain frequencies. PhCs have promising applications in opto-electronic devices such as light emitters [2], resonators [3], filters [4], polarizers [5], antennas [6], waveguides [7], fibers [8], and non-linear optical devices [9]. Recently GaN PhCs have highly attractive due to their wide band gap and great potential for development of opto-electronic devices in the visible region such as 2D GaN PhCs for photoluminescence and GaN-based surface-emitting lasers [10,11]. GaN PhCs can be used to propagation and dispersion of light. By using of the optical band gap GaN light can be confined to sub-wavelengths. The nitride semiconductor materials can be considered as the appropriate materials for short wavelength and UV nanophotonics [12,13]. In [14] two-dimensional gallium nitride photonic crystal is employed in the telecommunication wavelength.

* Corresponding author.
E-mail address: bahari.a@lu.ac.ir (A. Bahari).

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Defects in PhCs allow photon states to be able to appear in the photonic band gap (PBG) and control the behavior of photons. They can be used to localize light in the optical material. Three types of defects can be created in PhC structure. One-dimensional defects are used to localize light in a single cavity and single mode cavities can be realized. In two-dimensional defects, light with the wavelength in PBG can be guided. Three-dimensional defects are useful to confine the light. The use of defects in the PhC structures can lead to appearance the new effects in photonic band gap and its optical properties. In [15,16] the effect of the light parameter and the defect parameter on the transmission spectrum mode of the 1D PhC band gap has been investigated. The transmission spectrum of the 1D PhC bounded by the nanostructure layer has been investigated in [17,18]. They have shown by changing the size and volume of nanoparticles the transmission spectra of the photonic crystal structure and the number of defect modes in the optical spectra can be controlled.

In this paper the effect of different nondispersive defects on transmission spectrum of GaN dispersive photonic crystal waveguides has been studied. In Section 2 the propagation of electromagnetic waves and transmission properties of dispersive PhCs have been studied. In the last section a brief summary of the result has been presented.

2. Modeling and results of numerical calculations

In periodic structures, as the difference between refractive index is increased, a photonic band gap along certain directions can be created that modes can not to propagate in those directions. These PBGs can be used in order to make narrow-band filter to reject all frequencies but allowing just the one that is desired and directing light in specific directions. The band-gap position can be moved by changing the refractive index. We consider a 2D infinite periodic medium with triangular lattice consist of a series of GaN rods with refractive index $n_2(\lambda)$ [19], that embedded in air (Fig. 1). Lattice constant a is the distance between centers of two adjacent rods and r is the radius of the PhC rod. Our system is periodic in x–y plane but homogenous in z direction, so it is symmetry along this plane. This symmetry can separate modes into TE and TM modes. TE mode basically has electric field component in the x–y plane and magnetic field component is normal to this plane and TM mode has magnetic field in x–y plane and electric field is normal to this plane [20]. Depending on the structure PhC can support TE, TM or both TE and TM photonic band gaps [21].

To investigate the transmission spectra properties of the GaN PhCs finite element method (FEM) can be used [20]. We consider the incident waves that perpendicular to the axis of the GaN rods (TM mode). We apply the proper boundary conditions at the interfaces that necessary in calculations of the periodic PhC lattice. By applying periodic boundary conditions on four boundaries of a unit cell, the band structure of PhC can be calculated [20]. In order to calculate the transmission spectrum in crystal the port boundary condition for input and output ports and the perfect electric conductor (PEC) boundary condition for directions perpendicular to the input and output ports are used. Scattering matrix is a frequency dependent complex expression that describes transmission and reflection of EM waves at port devices such as the filter, the antenna and the waveguide and it can be used to calculate the transmission spectrum [22].

In this work the effect of nondispersive defects on transmission spectrum of GaN dispersive PhC is investigated. The refractive index $n_2(\lambda)$, including a constant term and other terms depend upon the wavelength. For non-dispersive materials only the constant term in refractive index is considered but in dispersive material all terms must be considered.

Fig. 2(a) shows the transmission spectrum of 2D GaN rods perfect PhC, with lattice constant a = 375 nm and the rod radius r = 70 nm. Calculations are carried out for wavelengths in visible range of electromagnetic spectrum. As can be seen from this figure, there is a band gap for TM polarized electromagnetic waves in the frequency range 755–810 THz. By removing a line of GaN rods, the linear PhC waveguide is created. Calculations show that in linear PhC waveguide the transmission modes appear within band gap (Fig. 2(b)). This means that the radiation possessing this frequency can propagate inside the linear PhC waveguide.

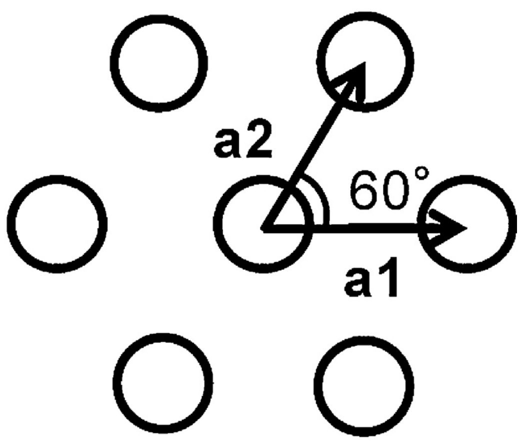

Fig. 1. The geometry of the unit cell for 2D triangular lattice of GaN rods, with lattice constant a = 375 nm and the rod radius r = 70 nm.