Optik - International Journal for Light and Electron Optics 172 (2018) 401–405

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.com/locate/ijleo

Original research article

Design of the multichannel filter based on one-dimensional defect plasma photonic crystal

Guan Xia Yu[a,b,*], Jingjing Fu[b], Wenwen Du[b], Junyuan Dong[b], Min Luo[a]

[a] College of Science, Nanjing Forestry University, Nanjing 210037, PR China
[b] College of Information Science and Technology, Nanjing 210037, PR China

ARTICLE INFO

Keywords:
Plasma photonic crystal
Defect layer
Defect modes

ABSTRACT

The transmission properties have been investigated for the anisotropic plasma photonic crystal (APPC) with defect layer. Based on the transfer matrix method (TMM), the total transmission coefficient for the symmetry APPC with defect layer has been deduced. The numerical simulations shows that transmittance spectrums are the same as those of the general plasma crystal when the thickness of the defect layer is small. With the increasing of the thickness of the defect layer, the transmittance peak is split into more transmittance peaks called as the defect modes, which is different from the general plasma crystal. The defect modes caused by the defect layer in the APPC open up another choices of multichannel filters for EM waves in practice.

1. Introduction

Since the concept of photonic crystals (PCs) has been proposed by John and Yablonovitch in 1987 [2,3], the novel properties of PCs and their unique application in the electromagnetic fields have been received special attention. PCs are the periodic structures made of two or more kinds of dielectric materials with distinct refractive indices, and the unusual structures can create a range of forbidden frequency called a photonic band gap (PBG) in which the electromagnetic waves with a frequency inside the PBG are forbidden to propagate through the structure. One of the most fascinating properties is that PBG can be flexibly adjusted by changing structures parameters [4–7], such as thickness of the dielectric layers, dielectric parameters, or number of layers, which means the width or location of PBG can be tuned. Another interesting property of the PCs is that the generation of some localized defect modes may appear within the PBG by breaking the periodicity of the structure [8–10]. In order to get it, a different layer or a new structure to the PCs would be added by removing a layer from the PCs, or changing the parameters of the constituent layers. This provides immense opportunity to confine [11], manipulate [12,13], and guide photons [14], such as, power limiters, antennas, filters, multiplexers, etc.

Recently, the PCs consisting of plasma layers has attracted intense interest from investigators [15], because of its adjustable electromagnetic parameters by changing the electromagnetic (EM) fields frequencies, plasma frequency, dielectric constant and external magnetic field. Specially in the terahertz region, the relative permittivity is less than zero, the plasma photonic crystal can be designed as a multichannel and tunable filter by the magnitude of external static magnetic field [15]. Although 2D and 3D PCs have many novel tempting properties, comparing with 1D PCs, fabrication and realization of 2D and 3D PBG still remains an arduous task. In this paper, the properties of a PCs consisting of plasma layers have been investigated. Meanwhile, the plasma in essence are anisotropic, so that they have different properties from the isotropic materials, such as anomalous reflection and refraction. Therefore

* Corresponding author at: College of Science, Nanjing Forestry University, Nanjing 210037, PR China.
E-mail address: sys@njfu.com.cn (G.X. Yu).

https://doi.org/10.1016/j.ijleo.2018.06.124
Received 26 September 2017; Received in revised form 17 April 2018; Accepted 27 June 2018
0030-4026/

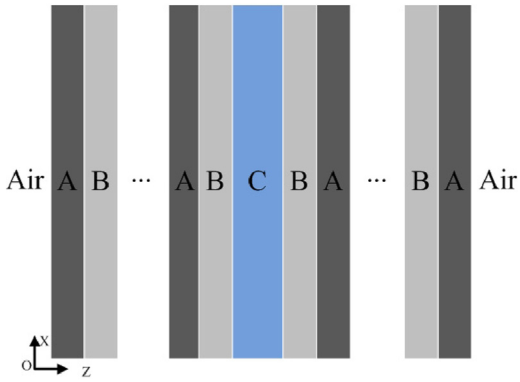

Fig. 1. One-dimensional symmetrical PCs structure Air/$(AB)^N C(BA)^N$/Air is composed of the normal materials layers A, the plasma layers B and defective layer C, where N is the number of periodic unit.

it is necessary to investigate the EM properties of anisotropic materials in the PCs. Different from previous work, an anisotropic mediam layers and defect mediam layer are also introduced in the PCs structure. Inspired by the novel characters of plasma in PSc, in this paper, the propagating properties of a defective PCs composed of plasma and anisotropic layers have been theoretically investigated by the TMM [1]. And the transmittance and reflection coefficient can be tuned by the external magnetic field, number of layer and the thickness of defect layer.

This paper is organized as follows: Firstly, the PCs structure with plasma material and defect layer is introduced, and also the reflection coefficient is deduced by the transfer matrix method. secondly, the numerical results and discussions associated with our purpose are presented. Finally, the conclusion is given in the last section.

2. Physical model and computational method

As illustrated in Fig. 1, one-dimensional symmetrical PCs structure Air/$(AB)^N C(BA)^N$/Air is composed of the anisotropic plasma layers A, the normal materials layers B and defective layer C, which is also the anisotropic plasma materials. N is the number of periodic unit. In the PCs structure, d_A, d_B and d_C are the thickness of layers A, B and C, respectively. The relative permittivity and permeability of layer B and C can be expressed as:

$$\bar{\bar{\epsilon}} = \begin{vmatrix} \epsilon_{\rm rxx} & 0 & i\epsilon_{\rm rg} \\ 0 & \epsilon_{\rm ryy} & 0 \\ -i\epsilon_{\rm rg} & 0 & \epsilon_{\rm rzz} \end{vmatrix} \quad \mu_r = 1 \tag{1}$$

Layer A and C are magnetized plasma materials, which the relative permittivity can be expressed as

$$\epsilon_{{\rm rxxA}(C)} = \epsilon_{{\rm ryyA}(C)} = 1 - \frac{\omega_{\rm pe}^2}{\omega^2\left(1 \pm \frac{\omega_{\rm le}}{\omega}\right)} \quad \epsilon_{{\rm rzzA}(C)} = 1 - \frac{\omega_{\rm pe}^2}{\omega^2} \quad \epsilon_{{\rm rgA}(C)} = -\frac{\omega_{\rm pe}^2\omega_{\rm le}}{\omega^2(\omega \pm \omega_{\rm le})} \tag{2}$$

where ω is incident wave angular frequency, and $\omega_{\rm pe} = \left(\frac{{\rm ne}^2}{m\epsilon_0}\right)^{\frac{1}{2}}$ is the oscillation frequency of electric plasma, which is related to the number density of electrons n, the electronic charge e, electronic mass m and the permittivity ϵ_0 in the vacuum. ω_{le} is gyrofrequency, which is related to the magnitude and direction of the additional static magnetic field B, and can be expressed as:

$$\omega_{\rm le} = \frac{\rm eB}{m} \tag{3}$$

If the direction of additional magnetic field is the same as that of wave travel, we take the minus sign is formula (2). Conversely, if the direction of the static magnetic field B is in the opposite to that of the wave travel, we take the plus sign in the formula (2).

For simplicity, a TM mode incident EM wave is considered. The EM fields of two adjacent layers are connected via a transfer matrix T as [1]:

$$T_{i,j} = \frac{1}{2N_i}\begin{vmatrix} N_i - M_i + N_j + M_j & N_i - M_i - N_j + M_j \\ N_i + M_i - N_j - M_j & N_i + M_i + N_j - M_j \end{vmatrix} \tag{4}$$

where i, j are number of the adjacent layers. For layer B, $N_B = k_{zB}/(\omega\epsilon_0\epsilon_{rA})$ and $M_B = 0$, for layer A and C, $N_{A(C)} = k_{zA(C)}/(\omega\epsilon_0\epsilon')$, $M_{A(C)} = -ik_x\epsilon_{rg}/(\omega\epsilon_0\epsilon')$ and $\epsilon' = \epsilon_{\rm rg}^2 - \epsilon_{\rm rxx}\epsilon_{\rm ryy}$, where the $k_{\rm zB} = \sqrt{\omega^2\epsilon_0\mu_0 - k_x^2}$ and $k_{{\rm zA}(C)} = \sqrt{\frac{\omega_0^2}{c^2}\frac{\epsilon_{\rm rxx}\epsilon_{\rm rzz} - \epsilon_{\rm rg}^2}{\epsilon_{\rm rzz}} - \frac{\epsilon_{\rm rxx}}{\epsilon_{\rm rzz}}k_x^2}$, are the wave vector of z axis in the layer B and $A(C)$,respectively, and k_x is transverse wave vector along x-direction. When the TM mode wave propagates through this multilayer structure, the incident, reflected and transmitted electric fields are connected via a total transfer matrix: