Designing an Adjustable Optical Multi-Channel Filter in a Triple Photonic Structure Based on Magnetized Materials and Uniaxial Metamaterials

Behnam Kazempour[a,1]
Department of physics, Ahar Branch, Islamic Azad University, Ahar, Iran
Email: behkazempour@gmail.com
Receive Date: 10 March 2022, Revise Date: 15 April 2022, Accept Date: 10 June 2022

Abstract

In this article, the adjustability of the multi-channel optical filter including magnetized materials and uniaxial anisotropic metamaterials in the three-dimensional one-dimensional photonic crystal structure in the GHz frequency range has been theoretically analyzed and designed. It is shown that resonant peaks in the transmission spectrum can be created in the presented structure without adding a defect layer, in the absence and presence of an external magnetic field. Therefore, the presented ternary periodic structure can act as an adjustable multi-channel filter using the transmission spectrum of the photonic crystal. Also, the characteristics of the transmission spectrum of the assumed structure can be manipulated by applying an external magnetic field, so that the frequency of the channels can be red-shifted or blue-shifted depending on the direction of the applied magnetic field. In addition, the effect of the number of periods of the structure, the optical axis angle of anisotropic metamaterials (φ) and the incident light radiation angle (θ) on the filtering characteristics of the channels in both ***TE*** *and* ***TM*** *polarizations have been numerically investigated.*

Keywords: Multi-channel filter, magnetized material, anisotropic, optical axis.

1. Introduction

Nowadays, optical filters are one of the key tools in optical communication networks and systems. The main use of these elements is in wavelength division systems and optical processor systems. Nowadays, due to the high demand for fast data processing, all-optical processors are used instead of electronic circuits due to high speed signal processing and high information routing [1-4]. Meanwhile, photonic crystals have shown their effectiveness for designing all-optical devices, including optical filters, switches, and all-optical diodes. Since the last decade, the demand for the use of adjustable filters for use in wavelength division systems in optical telecommunication systems due to the increase in the capacity of transmitted and received wavelengths in telecommunication channels and the reduction of the dimensions of telecommunication parts to be placed next to other elements is increasing. There has been

[1] Corresponding author:
E-mail address: b-kazempour@iau-ahar.ac.ir (B. Kazempour).

an increase. Also, in recent years, optical filters based on photonic crystals have found a special place in the optical communication and integrated circuits industry due to their unique properties, including forbidden bands, structural volume, high transmission speed, and low loss. [5-7]. one-dimensional photonic crystals,

The structures consist of dielectric layers with different refractive index and the thickness of this layer is compared to the wavelength of the incident light. This structure allows light emission to be controlled through the photonic bandgap and passband. In recent years, using the photonic crystal structure, multi-channel optical filters with special conditions have been introduced and designed.

The main works mentioned are through physical changes such as thickness change, change of constituent materials and number of alternating layers [8-9]. The ability to adjust the transmissive properties and the absorption of photonic crystals with external factors such as temperature, electric field, and magnetic field has made researchers look for materials with changeable parameters inside photonic crystals. In recent years, the use of magnetic materials in the photonic crystal structure has been theoretically investigated to change the frequency position of a single-channel optical filter and control the photonic gap band (PBG) through the controllability of the magnetic field [10, 11].

In this article, in order to achieve an adjustable multi-channel optical filter with high pass and quality, a certain one-dimensional photonic crystal structure with a triple periodic arrangement consisting of plasma magnetized materials, uniaxial anisotropic metamaterials and ordinary dielectric in the GHz frequency range. It has been studied using the transfer matrix method. The numerical results obtained from the simulation for both TE and TM polarizations show that by changing the number of periodic periods, in order to apply the external magnetic field, the optical axis angle of the metamaterial and the incident field angle, for certain frequency ranges, the multi-channel optical filter can be created In addition, the effect of changing the aforementioned parameters on the characteristics of the multi-channel optical filter and its adjustability has been numerically investigated.

2. Models and Theory

In this article, a three-layer one-dimensional photonic crystal with a geometric structure $(ABC)^N$ is seen in Figure (1). The material of layer A is of ordinary dielectric type with electrical permeability $\varepsilon_A = 3$ and thickness $d_A = 5mm$, layer P is of magnetized plasma type and layer B is made of metamaterial with optical axis angle φ compared to z axis [12-14]. Tensors $\bar{\varepsilon}_B$ and $\bar{\mu}_B$ for layer B are shown as below.

$$\varepsilon_B = \begin{pmatrix} P & 0 & F \\ 0 & \varepsilon_\perp & 0 \\ F & 0 & W \end{pmatrix}, \mu_B = \begin{pmatrix} U & 0 & G \\ 0 & \mu_\perp & 0 \\ G & 0 & V \end{pmatrix} \qquad \textbf{(1)}$$

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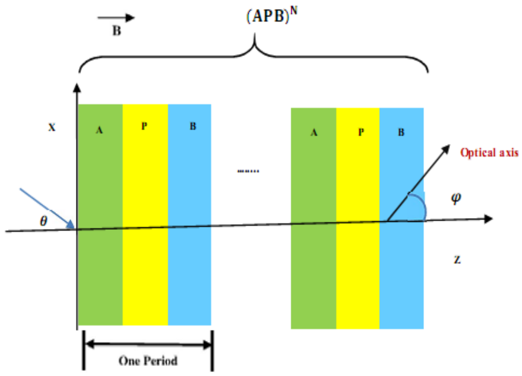

Fig.1. Schematic design of the investigated structure of the ternary photonic crystal in the presence of a magnetic field in the positive z-axis direction.

$$P=\varepsilon_{B\perp}cos^2\varphi+\varepsilon_{B||}sin^2\varphi$$
$$W=\varepsilon_{B\perp}sin^2\varphi+\varepsilon_{B||}cos^2\varphi\ ,$$
$$F=-(\varepsilon_{B\perp}-\varepsilon_{B||})cos\varphi sin\varphi \qquad (2)$$
$$U=\mu_{B\perp}cos^2\varphi+\mu_{B||}sin^2\varphi$$
$$V=\mu_{B\perp}sin^2\varphi+\mu_{B||}cos^2\varphi$$
$$G=-(\mu_{B\perp}-\mu_{B||})cos\varphi sin\varphi$$

where the characteristic matrix M_j in individual layer $j\,(j=A,B,ITO.LNO)$ is calculated through the following equation at the incidence angle θ from vacuum to a 1DPC structure:

$$M_j=\begin{bmatrix} cos(k_j d_j) & iq_j^{-1}sin(k_j d_j) \\ iq_j\,sin(k_j d_j) & cos(k_j d_j)\end{bmatrix} \qquad (3)$$

here, k_j and q_j $(j=A,B,ITO)$ are polarization –dependent given by

$$k_j=\sqrt{\varepsilon_j\mu_j k_0^2-k_x^2}\ ,q_j=\frac{k_j}{\mu_j k_0} \quad \text{(TE mode),} \qquad (4)$$
$$k_j=\sqrt{\varepsilon_j\mu_j k_0^2-k_x^2}\ ,q_j=\frac{k_j}{\varepsilon_j k_0} \quad \text{(TM mode)}.$$

As for the defect layer, with the anisotropic feature in Eq. (2), the expressions polarization-dependence of optical properties of LNO layer for k_j and q_j, can be expressed as

$$k_j=\sqrt{\varepsilon_x\mu_j k_0^2-k_x^2}\ ,q_j=\frac{k_j}{\mu_j k_0}$$
(TE mode), (5)
$$k_j=\sqrt{\varepsilon_x\mu_j k_0^2-\frac{\varepsilon_x k_x^2}{\varepsilon_z}}\ ,q_j=\frac{k_j}{\varepsilon_x k_0}$$
(TM mode).

where $k_0=\omega/c$ is the free space wave number, and $k_x=k_0\,sin\theta$ with θ being the angle of incidence. All of the materials are assumed nonmagnetic, so in the numerical calculations, the permeability of the layers is set to be unit. With the matrix elements in Eq. (5), the transmission coefficient of the multilayer system is calculated by

$$T(\omega)=|t|^2=\left|\frac{2p}{(M_{11}+M_{12}p)p+(M_{21}+M_{22}p)}\right|^2 , \qquad (6)$$

where, $p=\sqrt{k_0^2-k_x^2}/k_0$.

3. Nunmerical Results and Discussions

In the first step, the traxil spectrum shows the assumed structure in terms of frequency for the state where the plasma layers are in RHP mode, for the four states, the photonic crystal cycle number in Figure 2, as can be seen by increasing the number of cycle cycles of the crystal layers photon, the possibility of creating a number of photon gap bands increases. The optimal state for the structure is obtained for N=8.

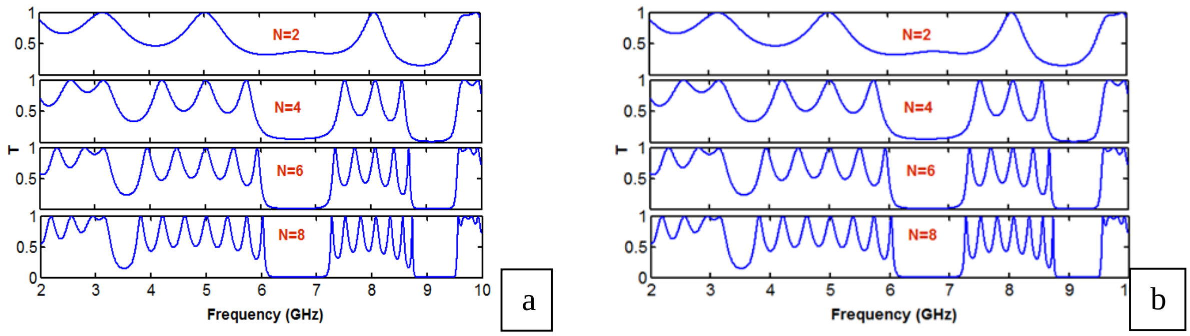

Fig.2. Traxil spectrum in terms of frequency for the presented structure for different values of the period number (N): (a) TE polarization (b) TM polarization.

In this step, we examine the effect of the radiation angle on the performance of the structure with a fixed optical axis angle φ=0 in the presence of a magnetic field B=0.4 T (RHP mode). The tensor of electric permittivity and magnetic permeability for uniaxially anisotropic materials is φ = 0, it is diagonal and the ranges are $\varepsilon_{11} = \varepsilon_{22} = \varepsilon_{\perp}$ and $\varepsilon_{33} = \varepsilon_{||}$. Figure (3) Transmitting spectrum of the alternating structure $(APB)^8$in terms of frequency for the wave in TM and TE polarization at the angles of $\varphi = 0^0$and $\theta = 0^0, 30^0, 60^0, 89^0$ has been drawn. It can be seen that with the increase of the radiation angle for TM polarization, the position of the gap bands is towards higher frequencies shifted and we will have blue transmission, and on the other hand, the width of the gap bands will increase, and at angles greater than $\theta = 60^0$, in the middle frequency range of the filter channels, the transmission intensity is close to unity. Therefore, this structure acts as a multi-channel filter in this frequency range. Also, in TE polarization, the position of the photonic band gap is shifted to higher frequencies and we will have blue transmission, and on the other hand, the width of the gap band increases and at angles greater than $\theta = 60^0$, the structure presented as a multi-channel optical filter It works and the number of channels created in TE polarization is more in different frequencies compared to TM polarization and approximately *s* number of optical channels are created in the range of specific frequencies.

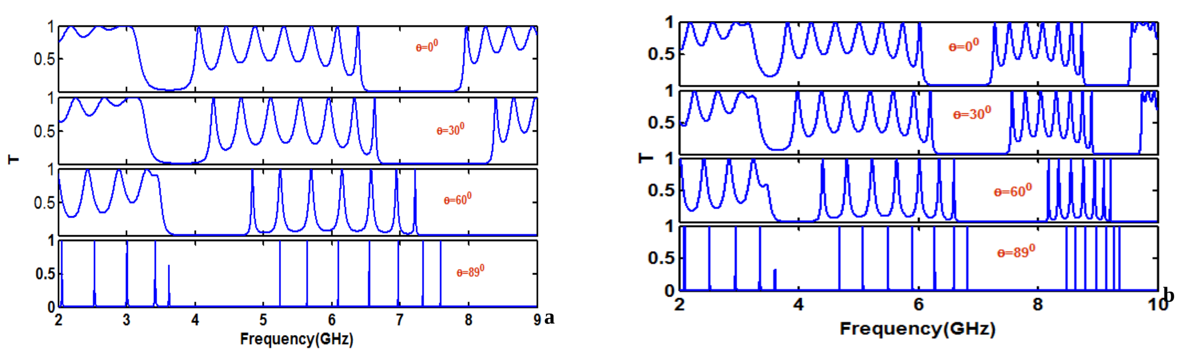

Fig.3. Transmission spectrum in terms of frequency with fixed angle $\varphi = 0^0$ and for different radiation angles in (a) TM and (b) TE polarization.

In this part, the effect of the optical axis angle of the anisotropic layer on the properties of the filter channels of the structure, in the presence of a specific magnetic field with an oblique radiation angle on the transmission spectrum of the structure is shown in Figure (3) for both TE and TM polarizations. In the case of φ≠0, the electric permittivity and magnetic permeability tensor of the layer is not diagonally anisotropic. As can be seen from Figure (4), with the increase of the angle of the optical axis in the RHP mode, at a specific incidence angle, the alternating structure behaves as a multi-channel filter for specific frequency ranges.

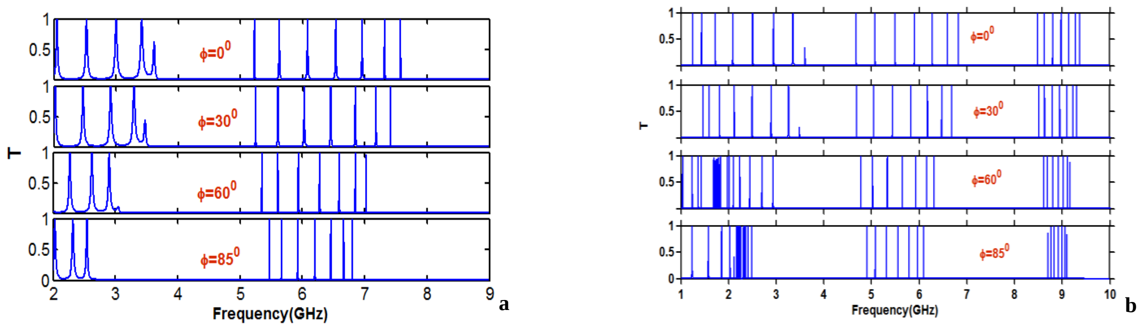

Fig.4. Transmission spectrum in terms of frequency for the structure with fixed angle $\theta = 89^0$ and B=+0.4T at different angles of optical axis (φ): (a) in TM polarization mode and (b) in TE polarization mode.

It can also be seen in the TM polarization in Figure 4, that with the increase of the optical axis, the distance between the channels in the middle frequency range decreases and the quality factor of the channels increases, and the width of the channels created in the low frequencies decreases and towards Low frequencies are transmitted. While for TE polarization, in addition to the optical filter channels created in the middle frequency, several optical channels are created in the high frequency range and the low frequency range. In addition, for TE, the distance of the filter channels is less compared to the TM mode and the quality factor of the channels is higher. Finally, we examine the effect of applying the external magnetic field by considering the direction of its application, that is, in the two modes of RHP and LHP, for polarization and TE and TM in Figures 5.

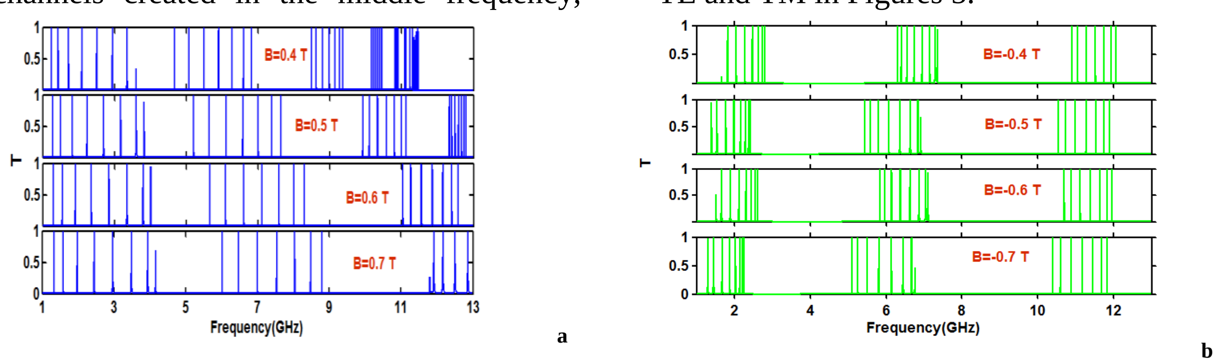

Fig. 5. Transmission spectrum in terms of frequency for the structure with fixed incidence angle θ=〖89〗^0 and optical axis angle φ=0^0for TE polarization: (a) for RHP mode (b) for LHP mode.

As can be seen from Figure 5, with the increase of the magnetic field in the RHP mode, the distance between the optical channels increases and moves towards high frequencies, which will result in blue transmission. While, for the LHP mode, with the increase of the magnetic field in the opposite direction, the frequency position of the optical channels is shifted downwards and we will have the red shift, and in this case, the distance of the filter channels is less than the RHP mode, and the quality factor of the channels is higher. is. Therefore, by changing the size and direction of applying the external magnetic field, the proposed photonic crystal structure can act as an adjustable multi-channel optical filter with a high quality factor in a certain frequency range.

Conclusions

In this article, multi-channel adjustable optical filters containing magnetized materials and uniaxial anisotropic metamaterials in a three-layer photonic crystal structure have been investigated using the matrix method. The simulation results have shown that without adding a defect layer, by changing the angle of incidence, the angle of the optical axis of the anisotropic layer and applying an external magnetic field, the proposed structure can be used as an adjustable multi-channel optical filter in the range of specific frequencies with a close distance. Work together and with high quality factor. In addition, by changing the direction of applying the external magnetic field, the frequency position of the channels, depending on the direction of application of the field, can have a red shift or a blue shift for both TE and TM polarizations. This structure can be a useful suggestion for the design of an adjustable multi-channel optical filter with external controllability suitable for the design of modern optical devices.

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