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Mode filtering aspects of periodic multilayered chiro-ferrite medium

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ABSTRACT

The paper presents transmission and reflection properties of multilayered chiro-ferrite mediums-based structure under the $\pi/4$ oblique angle of incidence of the electromagnetic (EM) wave. The spectral characteristics of bi-layer periodic structure revealed its possible usage as optical filter under the choice of suitable parameters. In particular, the chiro-ferrite structure under consideration can act as band-stop filter without the usage of defects in the configuration. Furthermore, in the case of TM-polarized wave, the structure exhibited strong filtering properties.

1. Introduction

The layered structures have been studied extensively in the field of materials engineering and physics in the context of EM wave propagation [1]. In line with this, the study of transmission, reflection and absorption properties of mediums has been of prime focus. Within the context, one-dimensional photonic crystals have become greatly attractive due to potential applications of these in optics/photonics research [2]. These are generally periodic structures designed with dielectrics, or the combination of metal-dielectric mediums, possessing certain periodicity linked with the incidence wavelength. These exhibit photonic band-gaps where photons of particular frequencies cannot propagate [3]. Further, the group velocity through such structures causes reduced speed of propagation of light [4]. These layered structures would behave as storage devices, and also, have been proved to be prudent for laser, solar cell, filter, resonator, optical buffer and time multiplexing applications [5–10].

Photonic band-gap in periodically arranged chiral-dielectric and/or -metallic structures exists only for one kind of polarization (i.e., left- or right-handed circularly polarized wave). The optical response of such structures satisfies the conditions related to reciprocity and time-reversal symmetry [11]. Also, these would exhibit negative index of refraction and optical activity [12–14]. Moreover, circular dichroism and gyrotropy can be enhanced in the optical regime of EM spectrum [15,16].

In this communication, we investigate chiro-ferrite medium-based one-dimensional periodic structure. Chiro-ferrites represent the chirality control in a Faraday chiral medium, and exhibit both the phenomenon of Faraday rotation and optical activity. Such composites are basically the mixture of chiral and ferrite mediums, wherein the chirality can be controlled through static magnetic field. In the present work, we demonstrate the band-stop feature of chiro-ferrite medium-based structure under certain conditions.

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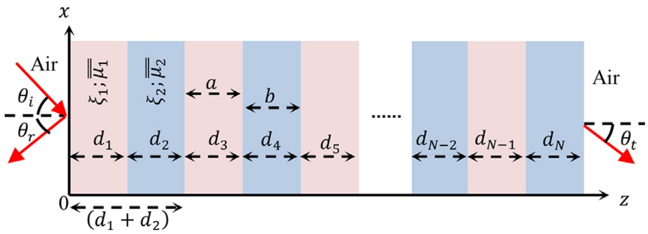

Fig. 1. The layered periodic structure.

Within the context, one may think of the filtering characteristics exhibited by *fairly simpler* periodic dielectric mediums [17–19]. But, generally the features of such configurations do not allow alterations of EM properties – the characteristic which may be attained by using chiro-ferrites in the structure.

The analytical investigation reported in this paper exploits the standard transfer-matrix method, generally used in dealing with the wave propagation through multi-layered mediums. The analyses involve the use of constitutive relations for chiro-ferrite mediums. To the best of knowledge of the authors, studies related to the use of multi-layered chiro-ferrite mediums in optical filtering have not yet been discussed.

2. Analytical treatment

We consider a periodic structure composed of two different kinds of chiro-ferrite layers having the alternate widths d_1 and d_2, as shown in Fig. 1. Here $d_1 = a$, $d_2 = b$, and θ_i, θ_r and θ_t are, respectively, the angles of incidence, reflection and transmission. It is clear from Fig. 1 that the incoming, reflected and transmitted waves propagate in the same medium, i.e., the free-space. $\xi_1, \overline{\overline{\mu}}_1$ and $\xi_2, \overline{\overline{\mu}}_2$ are the chirality admittance and permeability (tensor) values of the two (alternate) mediums in the layered structure. The time t-harmonic incidence waves (i.e., of the form $\exp(-j\omega t)$) of certain polarization fall upon the medium (from the free-space) with the admittance ξ_1, and propagate along the z-direction.

The constitutive relations for chiro-ferrite medium can be written as [20]

$$\boldsymbol{D}_v = \varepsilon_v \boldsymbol{E}_v + j\xi_v \boldsymbol{B}_v \tag{1}$$

$$\boldsymbol{H}_v = j\xi_v \boldsymbol{E}_v + \overline{\overline{\mu}}_v^{-1} \cdot \boldsymbol{B}_v \tag{2}$$

where

$$\overline{\overline{\mu}}_v = \begin{bmatrix} \mu_v & -j\kappa_v & 0 \\ j\kappa_v & \mu_v & 0 \\ 0 & 0 & \mu_z \end{bmatrix} \tag{3}$$

represents the permeability tensor, which carries the biasing feature, i.e., to control the chirality through the external magnetic field. In these equations, the subscript v relates to the particular layer (with $v = 1, 2$) in the periodic structure, and the quantities ε, ξ and represent the permittivity, chirality admittance and gyrotropy of mediums.

Under the circumstance, the incidence electric (E-) and magnetic (H-) fields in the region $z < 0$ (i.e., the free-space) can be expressed as follows:

$$\boldsymbol{E_i} = [\hat{a}_y E_{i\perp} + E_{i\parallel}(\hat{a}_x \cos\theta_i + \hat{a}_z \sin\theta_i)]e^{jk_i(z\cos\theta_i - x\sin\theta_i)} \tag{4}$$

$$\boldsymbol{H_i} = [\eta_i^{-1}\{\hat{a}_y E_{i\parallel} - E_{i\perp}(\hat{a}_x \cos\theta_i + \hat{a}_z \sin\theta_i)\}]e^{jk_i(z\cos\theta_i - x\sin\theta_i)} \tag{5}$$

whereas the reflected electromagnetic fields (in the region $z < 0$) can be written as

$$\boldsymbol{E_r} = [\hat{a}_y E_{r\perp} + E_{r\parallel}(\hat{a}_x \cos\theta_r - \hat{a}_z \sin\theta_r)]e^{-jk_i(z\cos\theta_r + x\sin\theta_r)} \tag{6}$$

$$\boldsymbol{H_r} = [\eta_i^{-1}\{-\hat{a}_y E_{r\parallel} + E_{r\perp}(\hat{a}_x \cos\theta_r - \hat{a}_z \sin\theta_r)\}]e^{-jk_i(z\cos\theta_r + x\sin\theta_r)} \tag{7}$$

In these equations, the subscripts i and r, respectively, represent the quantities corresponding to the incidence and reflected waves; $\parallel$ and $\perp$ being the indications of parallel and perpendicular polarizations, respectively. Also, $\hat{a}_x$, $\hat{a}_y$ and $\hat{a}_z$ are the respective unit vectors in the x-, y- and z-directions. Now, inside the chiro-ferrite medium, there are four different waves, two of which propagating along the +z-direction and the remaining two in the $-z$-direction. The E- and H-fields (of the two waves) propagating toward the +z-direction can be written as [20]

$$\boldsymbol{E_{c+}} = A[j\hat{a}_y + \hat{a}_x \cos\theta_{c+} + \hat{a}_z \sin\theta_{c+}]e^{jk_{c+}(z\cos\theta_{c+} - x\sin\theta_{c+})} + B[-j\hat{a}_y + \hat{a}_x \cos\theta_{c-} + \hat{a}_z \sin\theta_{c-}]e^{jk_{c-}(z\cos\theta_{c-} - x\sin\theta_{c-})} \tag{8}$$

$$\boldsymbol{H_{c+}} = -j\eta_c^{-1}A[j\hat{a}_y + \hat{a}_x \cos\theta_{c+} + \hat{a}_z \sin\theta_{c+}]e^{jk_{c+}(z\cos\theta_{c+} - x\sin\theta_{c+})} + j\eta_c^{-1}B[-j\hat{a}_y + \hat{a}_x \cos\theta_{c-} + \hat{a}_z \sin\theta_{c-}]e^{jk_{c-}(z\cos\theta_{c-} - x\sin\theta_{c-})} \tag{9}$$