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Simultaneous effects of the hydrostatic pressure and the angle of incidence on the defect mode of a one-dimensional photonic crystal of $GaAs/Ga_{0.7}Al_{0.3}As$

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ABSTRACT

In this work by using the transfer matrix method we calculated the transmittance spectrum of a one-dimensional photonic crystal composed of alternating layers of *GaAs* and $Ga_{0.7}Al_{0.3}As$ with a *GaAs* defect. We found the presence of a defect mode within the photonic band gap with a maximum transmittance value, where the position of the mode depends on the angle of incidence. As the angle is increased, the position of the mode is smaller compared to that of the normal incidence accompanied by a decrease in the width of the defect mode. Additionally, we found that by increasing the applied hydrostatic pressure, the dielectric constant of the *GaAs* decreases, causing an additional shift of the spectrum at short wavelengths.

1. Introduction

Photonic crystals (PC) are composed of nanostructures with high and low dielectric constants, which are repeated regularly in space. In PCs the propagation of light is affected in a similar way to that of the periodic atomic potential in a semiconductor that affects the electrons, defining allowed and prohibited energy bands [1]. The regions where light is allowed to propagate are known as modes, the groups of modes form the bands. The regions where light cannot be propagated are called photonic band gap (PBG). This gives rise to different optical phenomena such as spontaneous emission inhibition, omni-directional high reflection mirrors, low loss waveguides, Fabry Perot resonators, among others [2,3]. By breaking the spatial periodicity of the PC by introducing defects: point, linear or planar, they produce the location within the PBG of electromagnetic modes allowing the confinement or guidance of light modes with high efficiency [4–9].

The optical response of the constituent materials of the PC can be modified by an external agent such as operating temperature [10,11], hydrostatic pressure [12,13], electric and magnetic fields [14,15], with which it is possible to tune the PBG and its implementation in wavelength division multiplexing devices [16,17]. In this work we are interested in studying the dependence on applied hydrostatic pressure and the angle of incidence for the TE mode of the transmittance spectrum of a defective one-dimensional photonic crystal (1DPC), composed of alternating layers of *GaAs* and $Ga_{0.7}Al_{0.3}As$ by using the method of the transfer matrix (TMM). We consider that the defect is *GaAs*, where the dielectric constant depends on both the hydrostatic pressure and the temperature. The work is organized as follows: Section 2 presents the theoretical model

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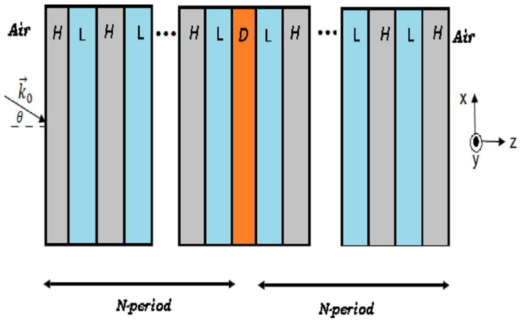

Fig. 1. Defective one-dimensional photonic crystal $Air/(HL)^N D(LH)^N/Air$, with a homogeneous pattern in the xy plane and periodicity in z.

to calculate the transmittance spectrum by using the TMM of the defective 1DPC. In Section 3, the numerical results of the transmittance spectrum for different values of the angle of incidence and pressure. The conclusions are presented in Section 4.

2. Theoretical model

In Fig. 1 we present the defective 1DPC surrounded by air and composed of alternating layers of high n_H and low n_L refractive index materials, with thicknesses d_H and d_L, respectively. The number of periods of the two-layer HL is N, $\vec{k}_0$ is the wave vector of the incident medium and θ the angle of incidence. The defect is given by D with refractive index n_D and thickness d_D. For the TE modes that will be the focus of our attention in this work, the monochromatic electric field of frequency ω linearly polarized propagating in the plane (x, z) is,

$$\vec{E}_j(x,z) = \vec{e}_y \left(A_j e^{ik_{j,z}z} + B_j e^{-ik_{j,z}z} \right) e^{-iq_x x} \quad (1)$$

with $k_{j,z} = \sqrt{\left(\frac{\omega}{c}\right)^2 \epsilon_j - q_x^2}$ the z component of the wave vector, ϵ_j the dielectric constant in the jth layer and with a transversal component of the vector of wave $q_x = k_0 sin\theta$. The values of A_j and B_j are calculated by the continuity conditions in the tangential components of the electric and magnetic fields. In the TMM each layer of the 1DPC is represented by a matrix [18]:

$$M_j = \mathfrak{D}_j P_j \mathfrak{D}_j^{-1} \quad j = H, L, D \quad (2)$$

with P_j the propagation matrix given by,

$$P_j = \begin{pmatrix} e^{i\varphi_j} & 0 \\ 0 & e^{-i\varphi_j} \end{pmatrix} \quad (3)$$

where $\varphi_j = k_{j,z} d_j = \frac{2\pi d_j}{\lambda} n_j \cos\theta_j$. In Eq. (2) the dynamic matrix for the TE mode is,

$$\mathfrak{D}_j = \begin{pmatrix} 1 & 1 \\ n_j \cos\theta_j & -n_j \cos\theta_j \end{pmatrix} \quad (4)$$

The total transfer matrix for the 1DPC $Air/(HL)^N D(LH)^N/Air$, is given by [19],

$$M = \begin{pmatrix} M_{11} & M_{12} \\ M_{21} & M_{22} \end{pmatrix} = \mathfrak{D}_0^{-1} (M_H M_L)^N M_D (M_L M_H)^N \mathfrak{D}_0 \quad (5)$$

with $\mathfrak{D}_0$ the dynamic matrix of air. The transmittance $\mathfrak{I}$ is calculated with the matrix elements M_{11} of M,

$$\mathfrak{I} = \left| \frac{1}{M_{11}} \right|^2 \quad (6)$$

3. Numerical results and discussion

In our simulations we will choose that layer H is $GaAs$ and layer L is $Ga_{1-x}Al_xAs$. The dielectric constant of $GaAs$ depends on both the hydrostatic pressure P and the temperature T [20,21],

$$\epsilon_{GaAs}(P,T) = 12.74 e^{-1.73\times10^{-3}P} e^{9.4\times10^{-5}(T-75.6)} \quad (7)$$