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The effect of hydrostatic pressure and temperature on the defect mode in a GaAs/$Ga_{0.7}Al_{0.3}As$ one-dimensional photonic crystal

Francis Segovia-Chaves [a,b,*], Herbert Vinck-Posada [a]

[a] Departamento de Física, Universidad Nacional de Colombia, AA 055051 Bogotá, Colombia
[b] Departamento de Ciencias Naturales, Universidad Surcolombiana, AA 385 Neiva, Colombia

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ABSTRACT

In this work by using the transfer matrix method, we studied the effects of applied hydrostatic pressure and temperature on the defect mode in the transmittance spectrum of a one-dimensional photonic crystal consisting of alternating layers of GaAs and $Ga_{0.7}Al_{0.3}As$. We consider that the defect is GaAs with a dielectric function that depends on both pressure and temperature. We have found that the dependence of the spectrum with temperature is negligible. However, the notable changes are mainly due to variations in the dielectric constant of the GaAs layers caused by the hydrostatic pressure. The defect mode has a shift at short wavelengths, with an increase in the quality factor when increasing the pressure due to the decrease in the dielectric constant of GaAs. The results found are in accordance with the electromagnetic variational theorem.

1. Introduction

The first studies on one-dimensional periodic structures go back to the year 1887, they were carried out by Lord Rayleigh, who found that by varying the angle of incidence it is possible to obtain regions where light is totally reflected [1]. A century later, these regions were called photonic band gap (PBG). In 1987 with the works of Yablonovitch and Jhon [2,3], the first one interested in controlling the spontaneous emission through an adequate engineering of the density of electromagnetic states, and the second one interested in the location of light and its respective control, propose the birth of a new kind of optical materials called photonic crystals (PC).

The functionality principle of the PCs is the spatial periodicity of the dielectric constant; these materials facilitate control in the propagation of light [4]. In the PBG the propagation of light in a specific frequency range is prohibited, the permitted values where the light is allowed to propagate are known as modes, the groups of modes form the bands [5]. The existence of PBG is explained through a completely classical treatment of Maxwell's equations. Among the solution methods of these equations we have: plane wave expansion [6,7], finite differences in the time and frequencies domain [8,9], transfer matrix [10] and dispersion matrix [11], among others.

The possibility of modifying the optical response of the PC constituents materials by external parameters such as magnetic or electric fields [12,13], temperature [14,15] and hydrostatic pressure [16], allow of tuning the PBG and its implementation

* Corresponding author at: Grupo de óptica e información cuántica, Universidad Nacional de Colombia and Departamento de Ciencias Naturales, Universidad Surcolombiana.
E-mail address: francis.segoviac@gmail.com (F. Segovia-Chaves).

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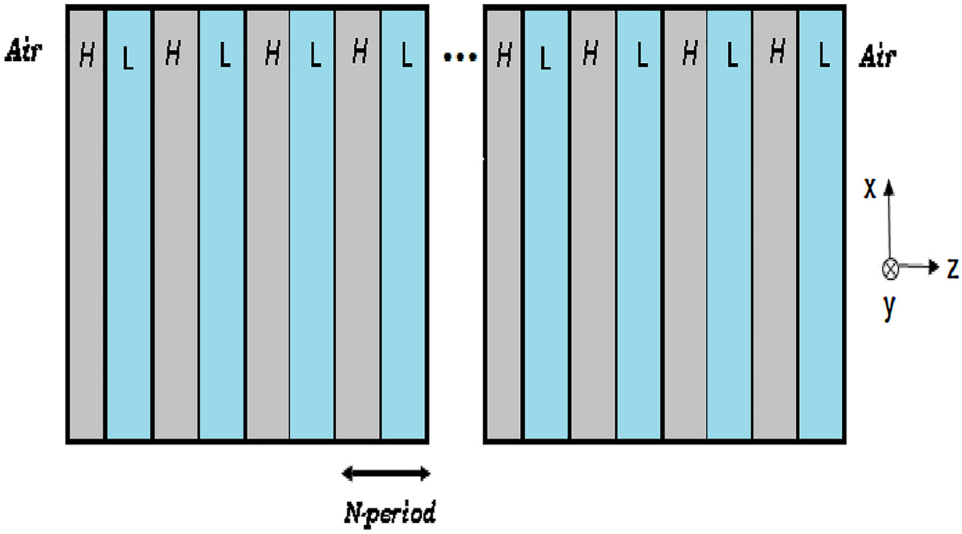

Fig. 1. Finite periodic photonic crystal $Air/(HL)^N/Air$.

in potential applications of modern photonics. For example, in optic switches and tunable filters, important in wavelength division multiplexing [17–19]. The inclusion of defects (geometric or constituents) that break the spatial periodicity of the PC, induces the presence of light modes located within the PBG allowing confinement or guidance with high efficiency [20,21]. It is in this area where PCs are important, since with these systems it is possible to make TE/TM filters, splitters, lasers and light-emitting diodes [22–24].

In this work we investigated the effects of applied hydrostatic pressure and temperature, on the transmittance spectrum of the *TE* mode for a one-dimensional photonic crystal (1DPC) of alternate layers of GaAs and $Ga_{0.7}Al_{0.3}As$ with a GaAs defect. This work is organized as follows: Section 2, presents the general expressions of the theoretical model of the transfer matrix (TMM). In Section 3, we present the numerical results and discussions concerning the calculation of the transmittance spectra of the regular 1DPC and with a defect, for values different of hydrostatic pressure and temperature. The conclusions are presented in Section 4.

2. Theoretical model

In this work, we studied the propagation of electromagnetic waves in a finite 1DPC surrounded by air composed of alternating layers *H* and *L*, non-magnetic and isotropic materials with dielectric constants ϵ_H and ϵ_L respectively, as shown in Fig. 1. The number of periods of the layers *HL* is given by *N*.

Let us consider a linearly polarized electromagnetic wave propagating in the plane (x, z) with wave vector q along the x axis (normal incidence). For the *TE* modes that will be the focus of our attention, the electric field is:

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

where $k_{j,z} = \sqrt{(\omega/c)^2\epsilon_j - q^2}$ and ϵ_j, is the z component of the wave vector and the dielectric constant in the jth layer, respectively. The values of A_j and B_j are calculated by the continuity conditions of the tangential components of both electric and magnetic field.

In the TMM each layer of the 1DPC can be represented by a matrix [25]:

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

In Eq. (2) the propagation matrix is [10]:

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

with the phase φ_j given by:

$$\varphi_j = k_{j,z}d_j = \frac{2\pi d_j}{\lambda}n_j \quad (4)$$