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Tuning of transmittance spectrum in a one-dimensional superconductor-semiconductor photonic crystal

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A R T I C L E I N F O

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A B S T R A C T

Using, the two-fluid model and the transfer matrix method, we study transmittance spectrum of a one-dimensional photonic crystal made up of alternated layers of a semiconductor (GaAs) and a high-T_c superconductor ($HgBa_2Ca_2Cu_3O_{8+\delta}$) under the effects of temperature, hydrostatic pressure and angle of incidence. We found that increasing the temperature and the angle of incidence, maintaining pressure and materials thickness constant, there is a shift of the transmittance spectrum to lower frequency values, with a bandwidth increase of the photonic gaps and a decrease in the cutoff frequency. In addition, shifting the transmittance spectrum to higher frequency values and the appearance of new photonic gaps varies with hydrostatic pressure and the angle of incidence, maintaining constant temperature, pressure and materials thickness.

1. Introduction

Photonic crystals (PC) are a new type of optical materials with spatial periodicity of the dielectric constant. In PC, photons are the carriers of information. In the same manner as for an atomic crystal, in a PC constructive interference originates bands or allowed states and destructive interference originates photonic band gaps or forbidden states [1]. The frequency bands in which the propagation of the electromagnetic modes is prohibited, are called photonic band gaps (PBG) [2]. The existence of PBG gives rise to optical phenomena like the inhibition of spontaneous emission [3,4], Fabry Perot resonators [5], low-loss waveguides [6] and light guidance through optical circuits [7,8].

PBG tuning opens a new perspective in scientific research and in technological application [9,10]. To obtain a tunable PBG, the dielectric constant or magnetic permeability of one of the materials that constitutes the PC depend on some external parameters, such as magnetic [11,12] or applied electric fields [13], temperature [14] and pressure [15,16]. Among the materials that make up the PC used to tune the PBG, we have semiconductors [17,18], metals [19,20], superconductors [21,22], metamaterials [23,24], and liquid crystals [25], among others.

On the other hand, research on PC composed of superconductor materials (SPC) has increased regarding PC composed of dielectrics and metals. SPC are dispersive and introduce important changes in photonic band structure. In SPC the dissipation is neglected at temperatures below the critical temperature; in addition, it is possible to tune the PBG by changing superconductor thickness and external parameters as temperature and the magnetic field. Devices based on SPC potentially have application in high reflection mirrors, beam splitters, band pass lters, microband filters in the gigahertz systems, high-frequency electromagnetic circuits from microwave until optical regimes, which is very important for lossless communication systems and networks working at liquid nitrogen temperatures [26,27].

Cutoff frequency is the name of the frequency below which electromagnetic modes cannot propagate in PC. A. Aly y D. Mohamed [28], found that the cutoff frequency is sensitive to variations with the temperature in a one-dimensional PC composed of alternated superconductor and dielectric layers. The numerical results found allow the use of these PC as good reflectors and band pass filters. K. Sreejith et al. [29], found that the cutoff frequency is sensitive to thickness of superconducting materials, dielectric layer thickness and operating temperature, in a one-dimensional PC composed of a pair of superconducting materials and a dielectric. In Ref. [30], they researched the transmittance spectrum in a one-dimensional PC made of alternated layers of a superconductor and a metamaterial, found that the cutoff frequency in the gigahertz range is sensitive to increasing metamaterial thickness. A. Herrera et al. [31] found that the temperature and hydrostatic pressure could tune the cutoff frequency efficiently in a one-dimensional PC composed of a high-T_c superconductor and semiconductors. J. Wu y J. Gao [32] proposed a low temperature sensor considering the effects of thermal expansion and thermal optics in a one-dimensional SPC with mirror symmetry. Regarding two-

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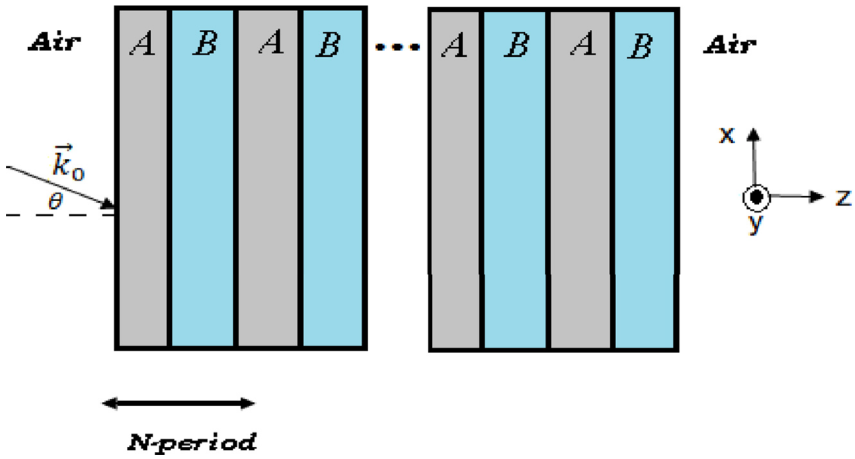

Fig. 1. Structure of 1DPC $Air/(AB)^N/Air$.

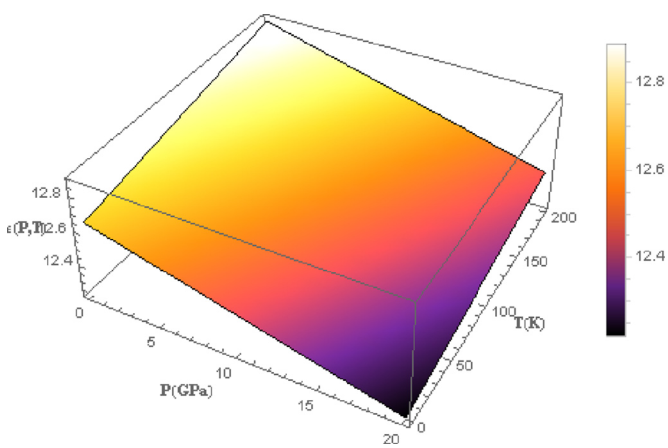

Fig. 2. Variation of the dielectric constant with pressure and temperature.

dimensional photonic crystals, Takeda and Yoshino found that at temperatures below 0.4 T_c just a PBG is formed in the band structure [33].

In this paper, we discuss the effects of temperature, hydrostatic pressure and the angle of incidence, on the transmittance spectrum in a one-dimensional PC (1DPC) composed of alternated layers of a superconductor ($HgBa_2Ca_2Cu_3O_{8+\delta}$) and a semiconductor (GaAs). For the superconductor material in the context of the two-fluid model, we assume that the electronic system is composed of a fraction of normal electrons and another fraction that participates in the condensed superconductor. The dielectric constant is similar to the one obtained in Drude's model for metals, except in the case of the superconductor, dissipation is negligible [34]. This paper is organized as follows: Section 2, we discuss the basic equations used during our analysis. In Section 3, we present the numerical results of the transmittance spectrum of a 1DPC for the TE mode. The conclusions are given in Section 4.

2. Theoretical model

In Fig. 1 we present a finite 1DPC is immersed in air and composed of alternating layers of superconductor and semiconductor materials, with refraction index n_A and n_B, respectively. The thickness of the superconductor and semiconductor are d_A and d_B, respectively. The number of periods of the AB layers is N, the wave vector of the incident medium is $\vec{k}_0$ and θ the angle of incidence. The PC has a homogeneous pattern in the xy plane and the periodicity direction in z.

For the TE modes that will be the focus of our attention in the

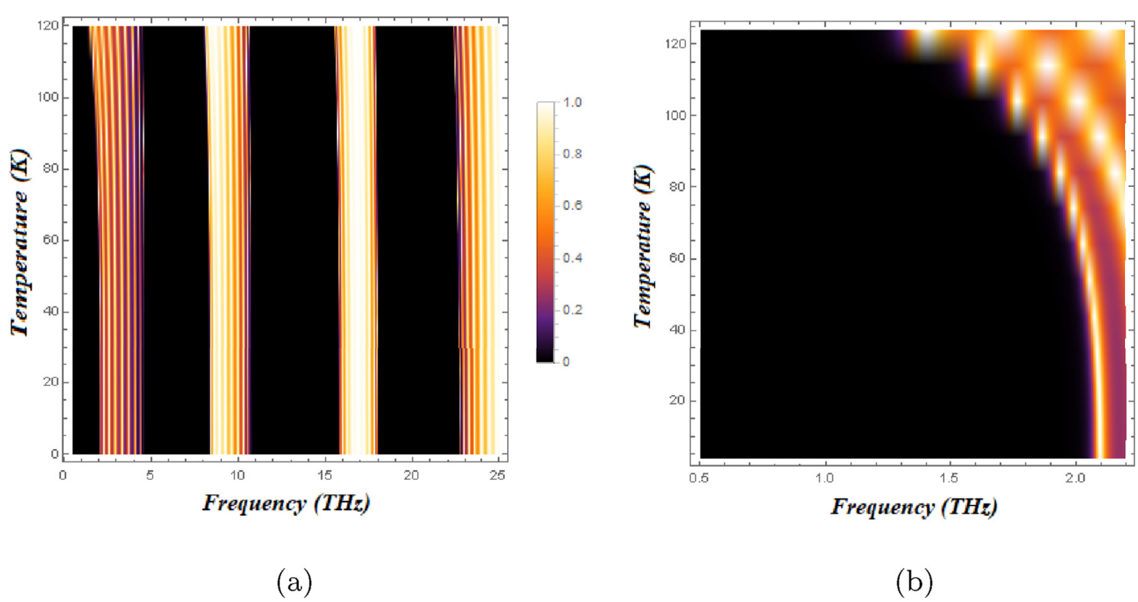

Fig. 3. a) Transmittance spectrum as a function of frequency and temperature for normal incidence, with GaAs layer thickness equal to 5000 nm and P = 0 GPa. b) Cutoff frequency for the first gap.