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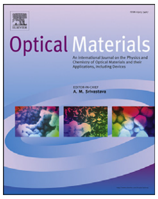

Investigation of the 1D symmetrical linear graded superconductor-dielectric photonic crystals and its potential applications as an optimized low temperature sensors

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ABSTRACT

Based on the Transfer Matrix Method (TMM) and the two fluid model for a superconductor and by taking account of the thermal expansion effect and thermo optical effects, we theoretically investigates the transmittance spectra of a one dimensional superconductor −dielectric photonic crystal (PC) designed as $((HLS)^5/(SLH)^5)$ made up of a $BiGeO_{12}$(H), SiO_2(L) and $YaBO_2CuO_7$ (S). The transmittance spectra shows that the system realizes a tunable filter which depends on a nonlinear relation with temperature. It's found that the symmetrical application of a linear deformation $d(m) = d_0+(m\text{-}1).\delta d(m)$ where d_0 is the initial thickness of the layer m, $\delta d(m)$ is the elementary added thickness at each layer. This linear gradation of the thickness permits to improve the temperature sensitivity of the system which acts as an optimized low temperature sensor.

1. Introduction

The far field of photonic crystals devices has attracted a considerable attention in last decades thanks to the existence of the photonic band gap (PBG) which consists on a range of frequencies where the photon can be controlled and manipulated effectively which leads to a new age for optical devices [1,2]. The experimental requirements exhibit the modification of the angle of incidence of light which can not only disturbing the system setting specially at smaller angle but also limiting the system performance [3]. The dependence of the PBG behavior's on the polarization restricts the industrial application of the PC so we may turn the attention to the tunable PC capability [3].

The modulation of the photonic crystals capability can be realized with the intermediary of a variety of non-conventional materials such as semiconductor and magnetic fluid [4,5].

Among the kinds of non-traditional photonics crystals materials, we can cite the dielectric superconducting photonic crystals. In fact the most suitable features of the dielectric superconductor photonic crystals is the achievement of a tunable PBG thanks to the special electromagnetic properties of the superconductor material where the permittivity of the material is dependent on the temperature and the external magnetic field [6–11].

The 1D ternary superconductor dielectric photonic crystal is extensively and deeply investigated [12–14]. In the other hand, it's well known that the dynamical control of electromagnetic wave transmission through a PC depends on the geometry and the refractive index of the photonic crystals components materials. So, by combining the thermal expansion effect and thermal optical effect [11,15,16], we study the optical response of a ternary dielectric superconductor photonic crystal which undergoes a symmetrical linear gradation. In the present work, we try to optimize the temperature sensitivity of the ternary dielectric −superconductor photonic crystal by using the symmetrical linear gradation.

The paper is organized as follows: in the next section we present a brief description of the Gorter Casmir two fluid model and the transfer matrix method.Section 3 is devoted to the discussion of the numerical results. The conclusions are recapitulated in Section 4.

2. The numerical method and the two fluid models

In the present paper we report the Gorter Casmir two fluid model witch describes the electromagnetic response of the superconductor in our structure, we must limit to the lossless superconductor [17]. By adopting some approximations the complex

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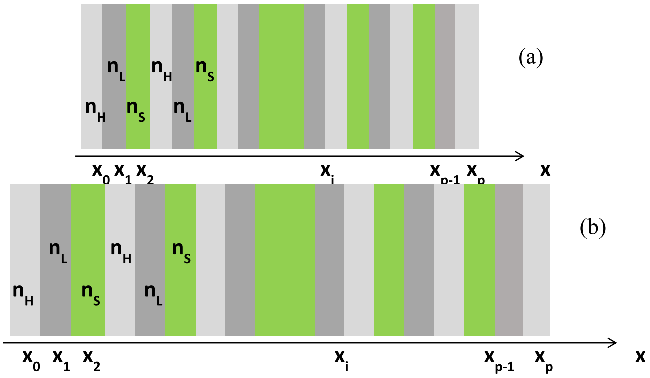


Fig. 1. The symmetrical photonic crystal $(((HLS)^i/(SLH)^i)$ (a). before a linear gradation (b). after a linear gradation.

conductivities of a superconductor can be approached to [18,19]:

$$\sigma = \frac{-i}{\omega \mu_0 \lambda_L^2} \tag{1}$$

where λ_L represents the temperature dependent London penetration depth [15,20].

$$\lambda_L = \frac{\lambda_0}{\sqrt{\left(1 - \left(\frac{T}{T_c}\right)^4\right.}} \tag{2}$$

where λ_0 is the London penetration depth at $T = 0$ K and T_c is the critical temperature of the superconductor. Thus the dielectric function of the superconductor can be written as:

$$\varepsilon_S = 1 - \frac{1}{\omega^2 \mu_0 \varepsilon_0 {\lambda_L}^2} \tag{3}$$

Then the refractive index of the superconductor layer is noted as follows:

$$n_S = \sqrt{\varepsilon_S} = \sqrt{1 - \frac{1}{\omega^2 \mu_0 \varepsilon_0 {\lambda_L}^2}} \tag{4}$$

It's clear that the refractive index of the superconductor is dependent not only on the frequency but also on the temperature. Let us now consider simultaneously the thermal expansion effect and the thermo optical effect which causes the variation of the thickness and the refractive index of the medium as a function of the temperature.

In certain temperature range, the thermal expansion effect adopt the law [15]:

$$d(T) = d_0(1 + \alpha \Delta T) \tag{5}$$

where α is the thermal expansion coefficient, ΔT is the temperature deviation. d and d_0 are the thickness of each layer under the actual temperature and room temperature. Similarly, by taking consideration of the thermo optical effect the relation between the temperature and the refractive index can be given by Ref. [15]:

$$n(T) = n_0(1 + \beta \Delta T) \tag{6}$$

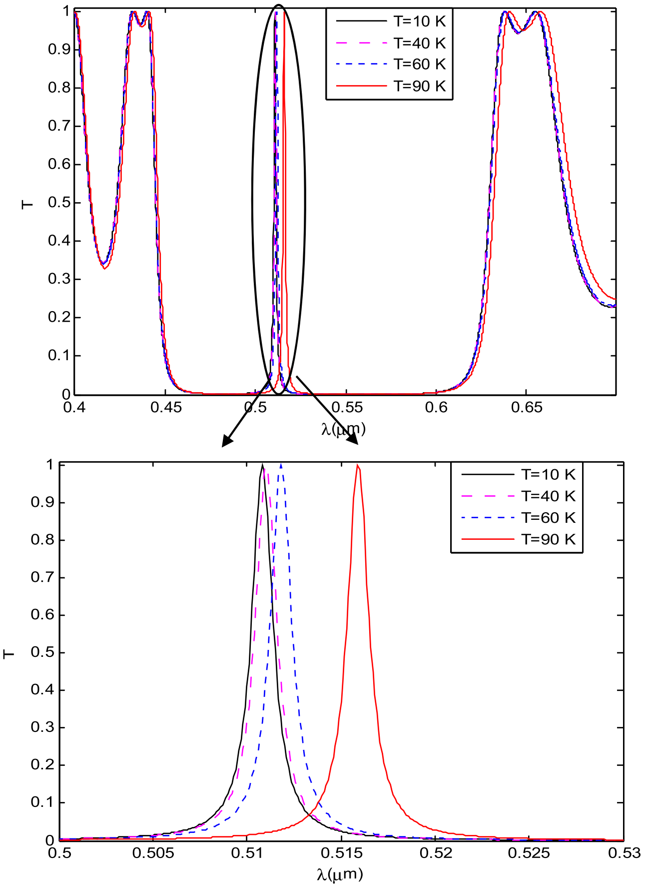
with β the thermo optical coefficient, n is the refractive index of each layer under the actual temperature. n_0 represents the refractive index of each layer under the room temperature.

Table 1
The expansion coefficientα, thermo optic coefficient β and the refractive index of the used materials [26].

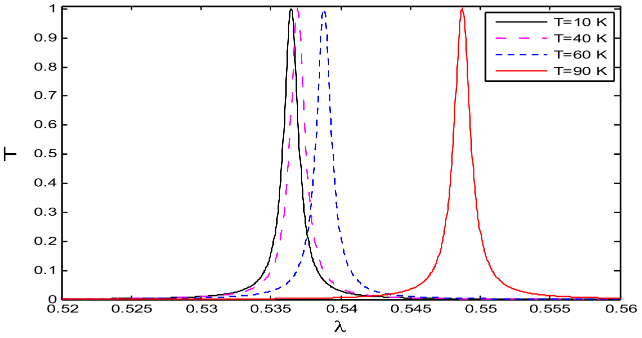
Material	α	β	n
BGO	$6.3 \times 10^{-6}/°C$	$3.9 \times 10^{-5}/°C$	2.3
SiO_2	$5.5 \times 10^{-7}/°C$	$1.0 \times 10^{-5}/°C$	1.45

3. Results and discussion

The (TMM) is the most suitable technique for the study of PBG materials and for solving the standard problem related to the



a. $(\delta d_H = 0, \delta d_L = 0, \delta d_S = 0)$



b. $(\delta d_H = 1\times10^{-4}, \delta d_L = 2\times10^{-4}, \delta d_S = 8\times10^{-4})$

Fig. 2. Transmittance spectra of $((HLS)^5/(SLH)^5)$ at different temperature and a). for simple photonic crystal b). for linearly deformed photonic crystals.