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Thermal tuning of photonic band gap in Ge-based 1D photonic crystal

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Abstract

1D photonic crystal in the form of Ge/Air multilayer structure has been studied and investigated the effect of temperature on photonic band gap. The optical transmission spectra and band gap of 1D photonic crystal is obtained by using transfer matrix method. In this communication, refractive index of Ge and width of Ge-layer are considered as a function of temperature. The variation of bandwidth with temperature has been investigated. The result can provide theoretical guideline for the design of temperature sensor, narrow band optical filter.

1. Introduction

Photonic crystals have been a topic of major research interest since the seminal papers of Yablonovitch [1] and John [2] in 1987. Photonic crystals are periodic dielectric structure that has a band gap which forbids propagation of electromagnetic waves in certain range of frequency. The existence of band gap is the characteristic features of photonic crystal known as photonic band gap (PBG). The initial interest in this area came from the proposal to use PBG crystals to control spontaneous emission in photonic devices, leading to more efficient light emitters like threshold less semiconductor lasers and single-mode light-emitting diodes. Originally, photonic crystals were introduced in the context of controlling spontaneous emission of atoms. It was then suggested that in many respect the behavior of light in periodic dielectrics is similar to the behavior of electrons in the periodic potential of a crystal, therefore, one can manipulate the flow of light in photonic crystal circuits in a similar manner as one can manipulate the flow of electrons in solid-state circuits [3, 4]. Since then, photonic crystals has become a very dynamic field of research with many novel applications and fabrication methods discovered very small and the lattice constant of the structure does not change with the variation of temperature because the expansion in Ge layer can be so far. For The purpose of many photonic applications a wide PBG is necessary. The PBG(s) of a photonic crystal can be extended by several methods. It can be widened by increasing the refractive index contrast in the constituent material in a typical distributed Bragg reflector or by using a disordered PC [5] or by using a hetrostructure PC [6] but in this paper we investigate the increasing of PBG by introducing the effect of temperature. However, in earlier communication the researchers considered that the refractive index of dielectric media is independent of temperature and wavelength which may not to be considered physically more realistic. Here, we consider a Ge/Air multilayer system in which refractive index of Ge layer is considered to be function of both temperature and wavelength.

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2. Theoretical Analysis

We consider a multilayered structure [air/ $(AB)^{10}$/air] where A is the Ge and B is the air films along the x- axis, as shown in Fig 1. The refractive index for a certain range of temperature taken as n (λ, T) and thermal expansion of any material is given as $\Delta d(T) = \alpha d(T)$ where, α represents the thermal expansion coefficient of the medium and ΔT indicates the variation of the temperature. We consider the contribution of second and higher order coefficient of thermal expansion are accommodated by shrinkage of the air medium in the photonic crystal so the thickness of the Ge layer is taken as

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$d_1(T) = d_1 + \alpha d_1 \Delta T$ & the thickness of the air layer can be written as $d_2(T) = d_2 - \alpha d_1 \Delta T$ The modified dispersion relation for 1D Ge/Air multilayered photonic crystal is [7]

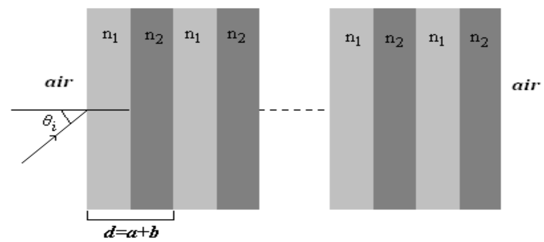

Fig: 1. Schematic diagram of 1-D photonic crystal structure.

$$k(\lambda,T) = \frac{1}{d(T)}\cos^{-1}[\cos(k_{1z}(\lambda,T)a)\cos(k_{2z}(\lambda,T)b) - \frac{1}{2}\left(\frac{k_{1z}(\lambda,T)}{k_{2z}(\lambda,T)} + \frac{k_{2z}(\lambda,T)}{k_{1z}(\lambda,T)}\right)\sin(k_{1z}(\lambda,T)a)\sin(k_{2z}(\lambda,T)b)]$$

3. Results and Discussion

In this section, the numerical analysis of the proposed PC structures is presented. We consider Ge/air multilayered structure in which refractive index of Ge is the function of temperature and wavelength. The material parameter used in our calculation is a=250 nm, b=350 nm thickness of the Ge and air layer respectively, number of periods n=10 and linear thermal expansion coefficient for Ge is taken to be at293K $\alpha=6.1\times10^{-6}$/k.[9] Refractive index of Ge in the ranges of wavelength 1.9 to 18 μm and temperature can be written as [8]

$$n^2(\lambda,T) = \varepsilon(T) + \frac{L(T)(A_0 + A_1T + A_2T^2)}{\lambda^2}$$

Where $\varepsilon(T)=15.2892+1.4549\times10^{-3}T+3.5078\times10^{-6}T^2-1.2071\times10^{-9}T^3$

$L(T) = e^{-3\Delta L(T)/L_{293}}$ λ=wavelength in units of μm T=temperature in units of K

$A_0 = 2.5381 \quad A_1 = 1.8260\times10^{-3} \quad A_2 = 2.888\times10^{-6}$

$$\frac{\Delta L(T)}{L_{293}} = -0.089 + 2.626\times10^{-6}(T-100) + 1.463\times10^{-8}(T-100)^2 - 2.221\times10^{-11}(T-100)^3$$

$$100 < T < 293$$

$$\frac{\Delta L(T)}{L_{293}} = 5.790(T-293) + 1.768\times10^{-9}(T-293)^2 - 4.562\times10^{-13}(T-293)^3$$

$$293 < T < 1200$$

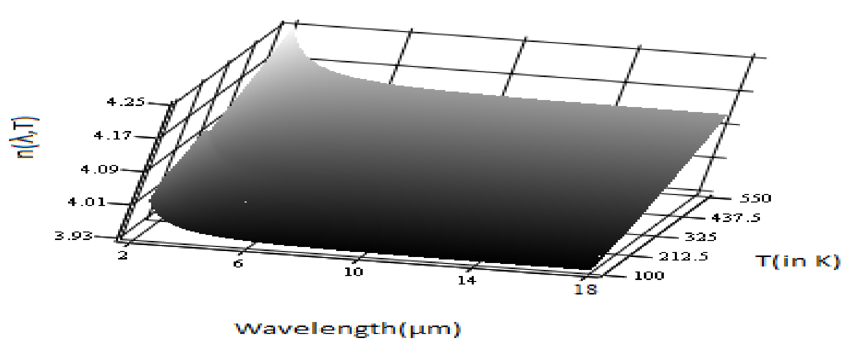

Fig: 2. Variation of refractive index as a function of wavelength and temperature

Ge is more dispersive in the range of 2 to 6 µm due to which we consider that wavelength region to study the effect of temperature range 100 to 550K because at high temperature Ge shows excessive absorption due to increased number of thermally generated holes. Temperature and wavelength dependent refractive index of Ge are computed by using equation (1) and refractive index of air is taken as 1 because it is independent the change of wavelength and temperature then by using equation photonic band structure has been plotted at normal incidence but different temperature T=100 & 550 K which is shown in fig (3).

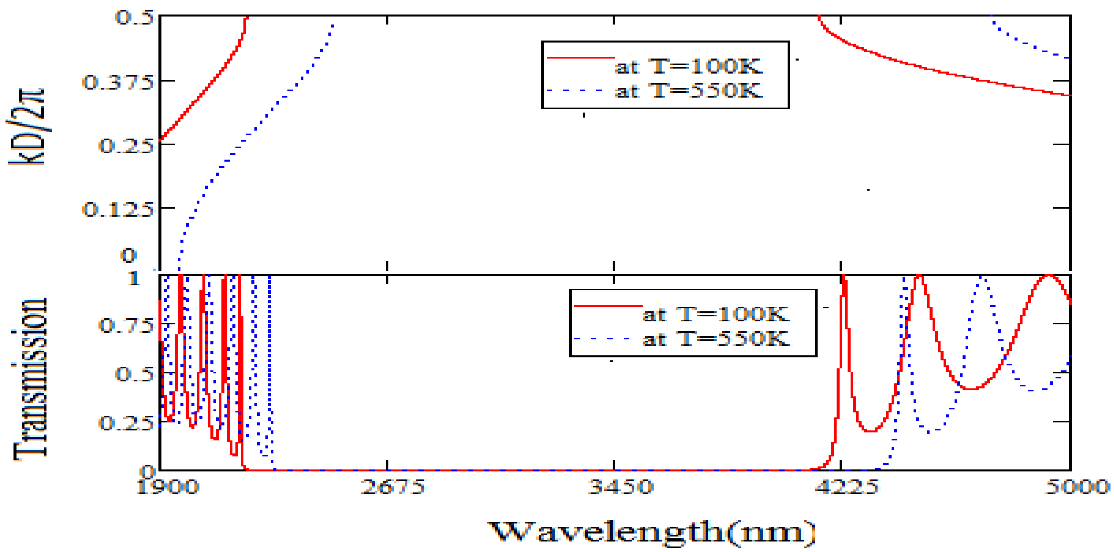

Fig: 3. Dispersion relation and transmittance for TE wave at different temperature T=100K, T=550K

It is found that as the temperature increases photonic band gap increases and it is shifted towards the longer wavelength region to keep the phase unchanged.

4. Conclusion

In earlier communications, dielectric media are taken as the material constituting different layers of PCs by many researchers. This study is useful for observing the optical properties of structure for wider range of wavelength and as well as temperature. The proposed structure worked as a Omni directional reflector. Thus the structure can be used as reflection filters for various ranges of wavelength for a particular choice of design parameters.

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