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RESEARCH ARTICLE

Effect Of Dielectric constant On Photonic Bandgap of 1-D Chalcogenide Photonic Crystal

Rajpal Singh[1], Arvind Kumar[2]
[1]Govt. College, Khetri, Jhunjhunu[2]
Department of Physics, University of Rajasthan, Jaipur
Email: rajubkn@gmail.com

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ABSTRACT

The photonic band structure of I-D chalcogenide photonic crystal is calculated using plane wave expansion method. The photonic band gap in these mltilayers has been varied by changing the dielectric contrast. The study is extended to investigate the effect of dielectric constant on the center of bandgap and gap to midgap ratio.

INTRODUCTION

Photonic crystals have attracted a lot of interest these days due to their tremendous control over light. Photonic crystals are periodic arrangement of dielectric materials with alternating regions of high and low dielectric costants (Prasad, *et al,.* 2004; Joannoplous, *et al,*.1995; and Sakoda,2004). Photonic crystals exhibit a photonic band gap where light possessing certain values of wave vector is not allowed to propagate in the material. A simplest photonic crystal structure is shown in figure 1 consists of alternating layers of material with different dielectric constants. The periodicity is in the z-direction. The parameters that define 1 D photonic crystals are dielectric constants of alternating layers ε_1 and ε_2 with relative thickness of one of the dielectric layers d and thickness of unit cell a for photonic crystal (Suthar, *et al,.* 2007). Chalcogenide glasses are infrared transmitting materials containing the chalcogen elements S, Se or Te, combined with one or more elements such as As, Si and Ge. Chalcogenides have generated a great deal of interest because of their attractive properties: glasses can be formed over a wide range of compositions; the refractive index is high, typically between 2.4 and 3. (Siviloglou, *et al,.* 2006) There have been numerous approaches of estimating the band structure of photonic crystals but we have used Plane Wave Expansion method (PWEM) in this work (Suthar, *et al,.* 2006 and Maksymov, *et al,.* 2004). The photonic band equation for 1 D photonic crystal has been derived using Kronig-Penney model (Suthar, *et al,.* 2006).

NUMERICAL METHOD

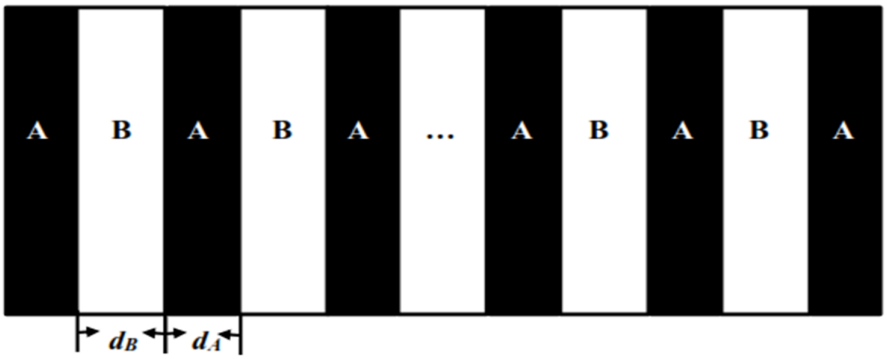

Fig. 1: The schematic diagram of 1-D Photonic Crystal

The theoretical approach was previously used by us for calculation of photonic band gap (Suthar, *et al*,. 2007). The 1-D photonic crystal structure has two layers as layer A and layer B as shown in Fig 1. The width of layer A and B are taken as d_A and d_B respectively. The unit cell has size as $d_A + d_B = a$, known as lattice constant. The dielectric constant of layer A and B are taken as ε_A and ε_B, respectively.
The wave equation for 1-D photonic crystal is given as

$$-\left(\frac{d^2}{dx^2}E_y + \frac{d^2}{dz^2}E_y\right) = \frac{\omega^2}{c^2}\varepsilon E_y \quad (1)$$

The periodic electric field may be expanded in a Fourier series (for normal incidence)

$$E_y = \sum_n E_n e^{-ik_n z} \quad (2)$$

Since the dielectric constant is also periodic, it may expand in Fourier series too as

$$\varepsilon = \sum_n \varepsilon_n e^{-i\frac{2\pi n}{a}z} \quad (3)$$

On substituting the Fourier expansions for the field and the dielectric into (2) and carrying out the algebraic operations, then multiply an orthogonal function $e^{i(2\pi pz/a)}$ both side, where p is an integer, and integrated over a unit cell. Then, the eigenvalue equation is given as

$$\left(\frac{2\pi n}{a} + k_z\right)^2 E_n = \frac{\omega^2}{c^2}\sum_m E_m \varepsilon_{n-m} \quad (4)$$

Where the ε_n is calculated by inverse Fourier transform

$$\varepsilon_n = \frac{1}{a}\int_{-a/2}^{a/2} \varepsilon\, e^{i\frac{2\pi n}{a}z}\, dz$$

the coefficients $\varepsilon_n$is given as

$$\varepsilon_n = \varepsilon_1\delta_n + (\varepsilon_2 - \varepsilon_1)\frac{d}{a}\text{sinc}\left(n\pi\frac{d}{a}\right) \quad (5)$$

Where $\text{sinc}\,(nx) = \dfrac{\sin(nx)}{nx}$

Now, we have all the information to solve the eigenvalues of equation (4). The iterative process gives the dielectric function Eq. (5), which is then used to calculate the photonic band structure (Suthar, *et al,*. 2007).

RESULT AND DISCUSSION

In this section, the photonic band structure for 1-D PC structure is calculated using eigenvalue equation (4). For this, the parameters of 1-D photonic crystal chosen are: width of layer A as d_A = 0.2a and layer B as d_B = 0.8a, where a is lattice constant. The layer B is chosen as air material with dielectric constant ε_B = 1. Whereas the layer A is chosen as 1-D As-S-Se system material. The first and second photonic bandgap as a function of dielectric constant plotted for As-S-Se/air multilayered 1-D chalcogenide photonic crystal in figure 2.

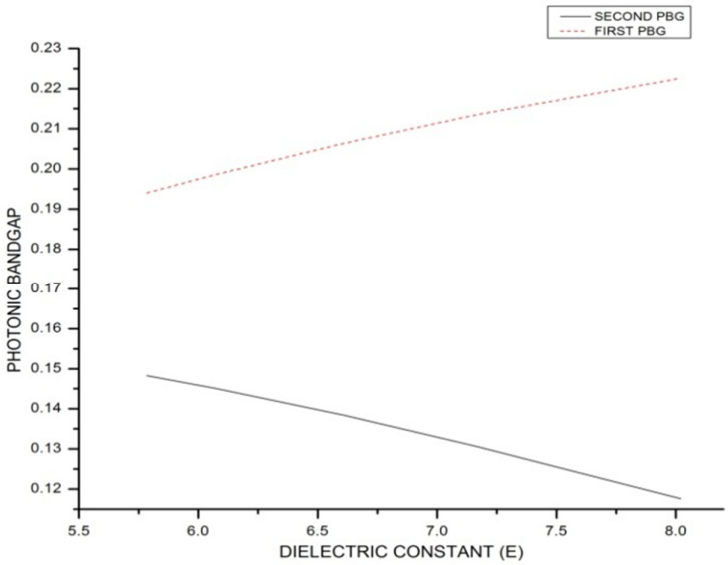

Fig. 2: The variation of photonic band gap with the dielectric constant

It is clear from figure 2 that the first photonic bandgap nearly linearly increases but the second photonic bandgap shifts toward the lower frequency with the dielectric constant. The variation in the first bandgap is more compared to second bandgap. The difference between first and second photonic bandgap increases continuously with the dielectric constant.
In addition the center of bandgap for first and second band also calculated.

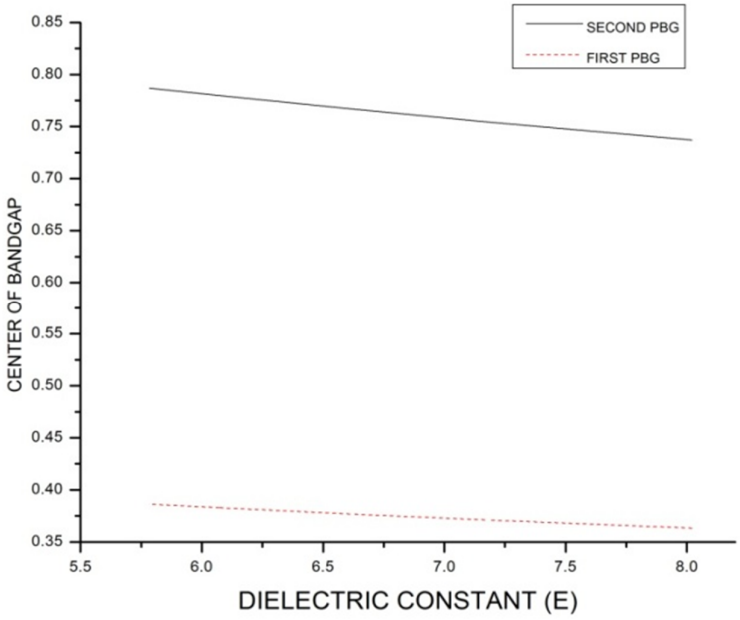

Fig. 3: The variation of Center of Bandgap with Dielectric constant

The center of photonic band gap is plotted with the dielectric constant in figure 3. It is seen from figure 4 that the center of first and second band gap shifted towards the lower frequency with dielectric constant. The variation in the center of second band is more compared to first bandgap.
In this paper we also study the variation of gap to midgap ratio with the dielectric constant. Figure 5 show the variation of gap to midgap ratio with the dielectric constant.

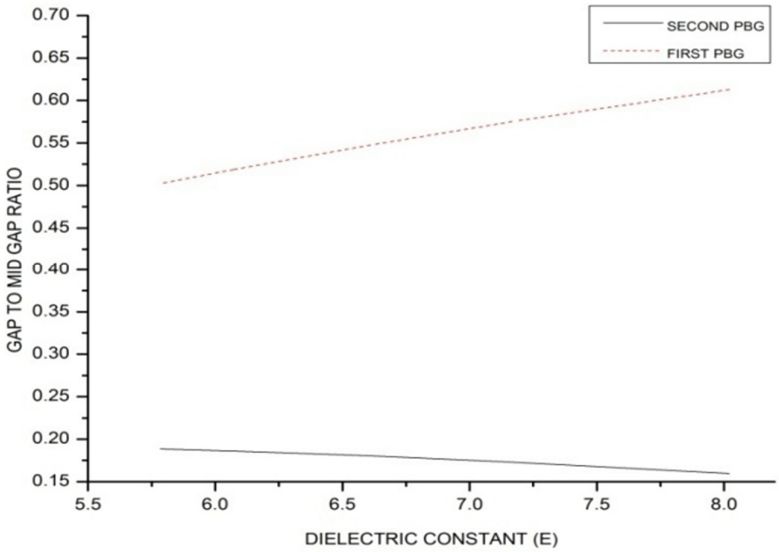

Fig. 4: The variation of gap to midgap ratio with Dielectric constant

Figure 4 shows that in 1 D photonic crystal gap to midgap ratio for first photonic band linearly increases with dielectric constant. The value of photonic bandgap/midgap ratio doesn't get saturated at any value of dielectric constant. Whenever the second photonic bandgap/midgap ratio decreases with dielectric constant.

CONCLUSION

In this paper, the photonic bandgap of 1-D photonic crystal of As-S-Se/air multilayer structure is studied both first and second band is studied with the dielectric constant and found that

1. The first photonic bandgap nearly linearly increases but the second photonic bandgap shifts toward the lower frequency with the dielectric constant.
2. The center of first and second band gap shifted towards the lower frequency with dielectric constant.
3. The first photonic band linearly increases with dielectric constant. Whenever the second photonic bandgap/midgap ratio decreases with dielectric constant.

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