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Effect of Double Defect Layer on the Localized Modes in Chalcogenide Photonic Crystal Multilayers Structure

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Abstract

A one-dimensional photonic crystal is formed using As_2Se_3/air one dimensional (1-D) multilayered chalcogenide photonic crystal, we have introduce a single and dual layer defect, by replacing As_2Se_3 with another dielectric material As_2S_3. Using the transfer matrix method (TMM), the transmission spectra is obtained both for the 1-D multilayered chalcogenide photonic crystal with a single defect and dual defect. It is found that defect modes appear for the single-layer defect as well as dual-layer defect structures. The normalized frequency shifts to lower values with increasing thickness of the defect layers for both cases. The behavior of defect mode for two defect layers is similar to the one defect layer structure and is discussed.

INTRODUCTION

Photonic crystals (PCs) are intersting materials due to their tremendous control over light. Photonic crystals are periodic arrangement of dielectric materials with alternating regions of high and low dielectric constants [1, 2]. These materials exhibit a photonic band gap where light possessing certain values of wave vector is not allowed to propagate in the material. Mostly, Photonic Crystals have been made from Si or III–V semiconductors. Their active functions have typically exploited thermal or free-carrier nonlinear effects, both of which are relatively slow [3]. 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 very attractive properties: glasses can be formed over a wide range of compositions; the refractive index is high, typically between 2.4 and 3, linear absorption losses are low over a wide wavelength range and a large $\chi^{(3)}$ nonlinearity [4]. Previously, we have exploited the chalcogenide glass PC platform to constent architecture for confining and guiding light [5]. In this work, we have presented the results obtained by introducing one and two defect layer of $As_{40}S_{60-x}Se_x$ in the symmetrical multilayered As_2Se_3/air one dimensional photonic crystals and analyze the frequencies of confined states developed as a result of architecture.

THEORETICAL METHOD

The structure for one defect layer $(AB)^nC(BA)^n$ and two defect layer $(AB)^nC(BA)^mBC(BA)^n$ is drawn, where A and B stand for the different layers with high and low refractive indices n_A and n_B, respectively, C is defect layer with refractive index n_c and n and m are the number of layers. Here, we have chosen As_2Se_3 (chalcogenide glass in annealed form) and air representing n_A = 2.832 and n_B = 1 with $d_A = 0.2a$ *and* $d_B = 0.8a$, respectively, where the parameter a is the lattice constant. The thickness of defect layer d_c varies in the range from about $0.3a$ to $1a$. The defect layer C is taken to be annealed glasses $As_{40}S_{60-x}Se_x$ with refractive index varying from 2.405 to 2.832 at wavelength of 1550nm [6]. We have taken normal incidence of monochromatic light of wavelength λ on the crystal surface. The transmission of the structure is obtained by transfer matrix method using the standard codes [7].

The structure for one defect layer $(AB)^nC(BA)^n$ and two defect layer $(AB)^nC(BA)^mBC(BA)^n$ is shown in figure 1 & 2.

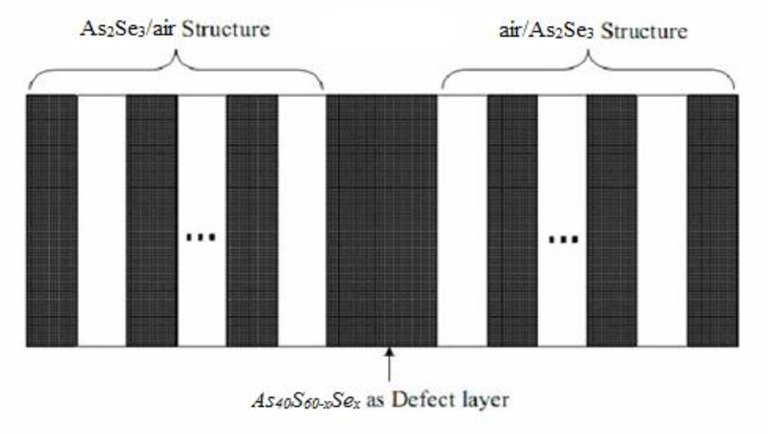

Figure 1. Schematic diagram of one Defect layer in 1-D Photonic crystal

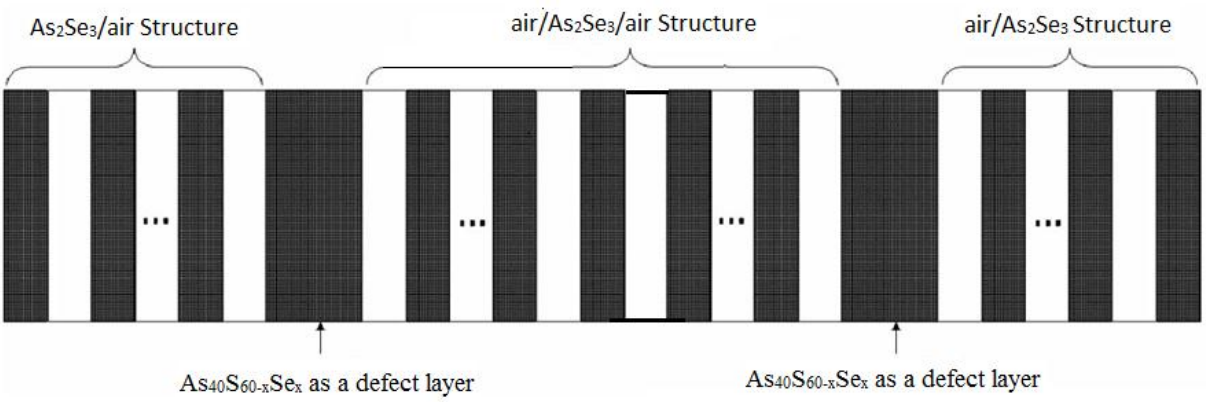

Figure 2. Schematic diagram of Two Defect layer in 1-D Photonic crystal

RESULTS AND DISCUSSION

The transmission spectra for As_2Se_3/air 1-D multilayered structure without defect layer is plotted as $(AB)^nA$ with n =10 at $d_A = 0.2a$ and $d_B = 0.8a$, as shown in Figure 3. The first photonic bandgap lies between normalized frequencies 0.252 and 0.4746 within the band gap. In this case, no propagating modes exist. By perturbing the structure, we can create localized modes that have frequencies in the band gap.

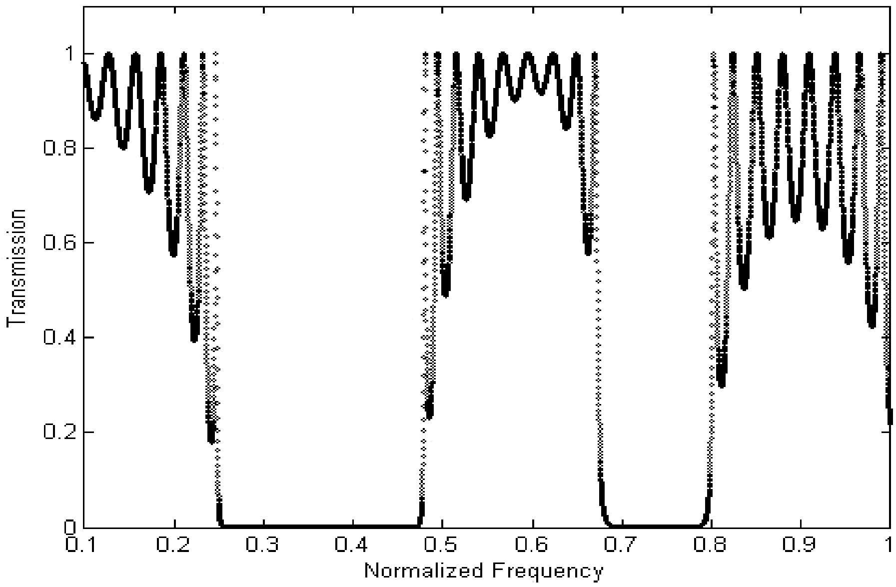

Figure 3: Transmission spectrum for As_2Se_3/air 1-D multilayered structure without defect.

When defect layer is introduced in the structure, localized modes appeared in PBG region. The number of defect modes and their locations can be controlled by changing either thickness of the defect layer or refractive index of the defect layer [8]. The transmission spectra for $d_c = 0.4a$ is plotted in figure 4 for one defect layer of As_2S_3 with refractive index of n_c=2.405.

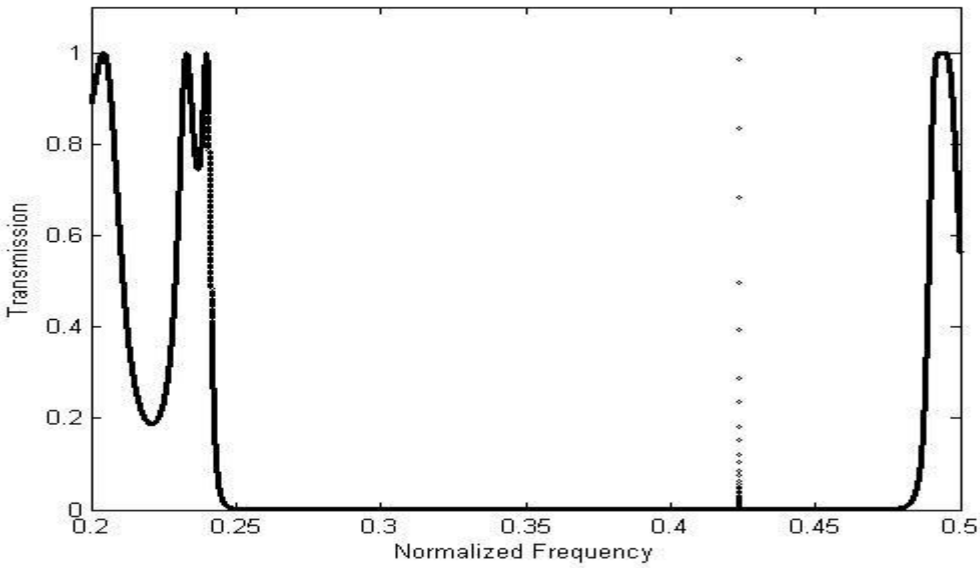

Figure 4. Transmission spectra for 1-D chalcogenide photonic crystal with one defect layer of $As_{40}S_{60}$ of thickness $d_c = 0.4a$.

It is seen that a sharp peak appear inside the PBG due to the defect. This is well known and in accordance with the theory of propagation of electromagnetic waves in dielectric medium [9]. These sharp peaks are ''confined states'', which can be used as high-frequency carriers one-to-one for optical communication systems [10]. The confined states can completely transmit through the defect layer by resonant tunneling. When the energy of the incident photons is matched with the confined state of the defect layer, the tunneling probability is 100%. Thus, the sharp peaks can also be called resonant peaks [9]. For the structure $(AB)^nC(BA)^n$ the frequency of localized mode is found to be 0.4235 on normalized scale corresponding to a wavelength of 1550 nm.

The transmission spectra for two symmetrical defect layers of As_2S_3 (refractive index $n_c = 2.405$) for $d_c = 0.4a$ *is* plotted in fig. 5.

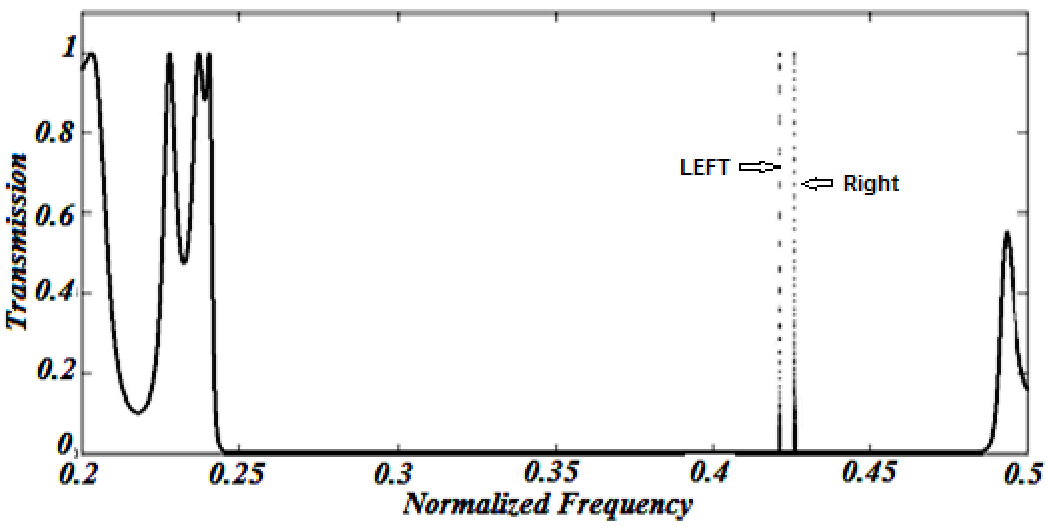

Figure 5: Transmission spectra for 1-D chalcogenide photonic crystal with two defect layer of $As_{40}S_{60}$ of thickness $d_c = 0.4a$.

It is observed that two defect modes which are closely spaced appear in the PBG region. Similar results have been obtained in grapheme based photonic crystal by Li et. al. [11]. The normalized frequencies of defect modes are 0.4213 and 0.426 corresponding to wavelength of 1541nm and 1558nm. This structure can be used for designing mechanically multichannel filters as shown for 1-D photonic Quantum well structure for angles of incidence [12].

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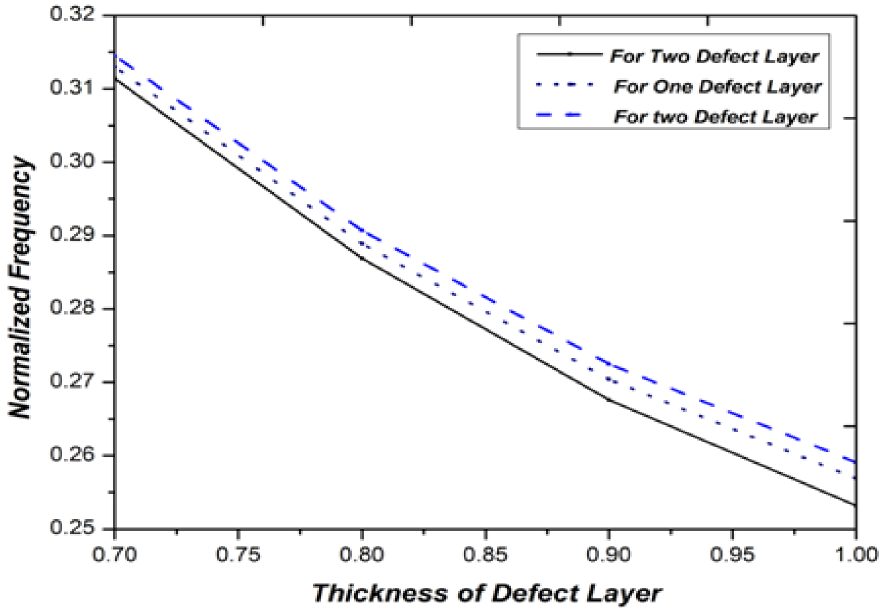
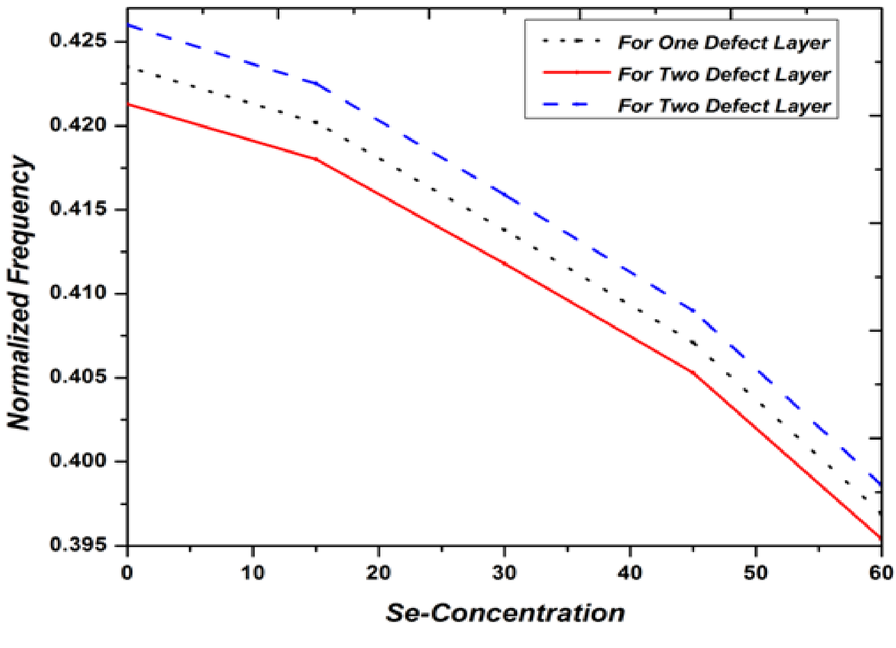
The study the effect of thickness and Se-Concentration on defect modes for both structures the normalized frequency is plotted as a function of thickness and Se-Concentration.



(a) *Solid line for frequencies for left defect mode of two defect layer, dash line for frequencies for right defect mode of two defect layer and dotted line for frequencies for defect mode of one defect layer*



(b) Solid line for frequencies for left defect mode of two defect layer, dash line for frequencies for right defect mode of two defect layer and dotted line for frequencies for defect mode of one defect layer

Figure 6: Normalized frequency of defect modes for one and two defect layer as the variation of (a) thickness of defect layers (b) Se-Concentration.

From figure 6(a) and 6(b), it is seen that the normalized frequencies of defect modes for two defect layers are approximately symmetrical spaced from the defect mode frequency of single defect. Such behavior is also observed for increased thickness leading to formation of a Quantum well [13].

The behavior of defect modes for dual defect is similar to the single defect layer. In addition, for both defect structures, the defect modes shift to lower frequencies with increasing thickness of defect layer and Se-concentration. This is expected as fields are concentrated more in high Ɛ region and varies as 1/√Ɛ, so shift towards lower frequencies. With Se-concentration, the numbers of localized states also increase as a result of lone pair electrons. The decrease in electronic band gap causes nonlinearity with increase in refractive index J. Sanghera et. al. [14]. Thus shifting towards the lower frequencies occurs. This can be used to transmit signals through PBG/Quantum well. This defect structure would provide potential applications in tunable multi-band filters [15].

CONCLUSIONS

In the present work, It is found that a sharp and two sharp transmission peaks named as defect mode appear for the single-layer defect or the dual-layer defect structures, respectively. It is also found that the behavior of defect modes for dual defect is similar to the one defect layer. Confined States generated within the PBG can be coarsely tuned by changing the defect slab features in chalcogenide/air multilayered photonic crystal. The work can be useful for improving the optical communication systems and establishing chalcogenides as suitable materials with regards to other materials. This structure is suitable for designing mechanically tunable (1DPhC)-based narrow pass band filters, multi-band filters and narrow reflectors.

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