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LOCALIZED MODES IN CHALCOGENIDE PHOTONIC MULTILAYERS WITH As-S-Se DEFECT LAYER

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Interesting results on the development of localized modes due to a defect layer sandwiched between symmetrical multilayered 1-D photonic crystals have been reported. The number of resonant peaks increases with increases with the slab thickness. It is shown that the normalized frequency shifts to lower values with increasing selenium concentration of the defect layer. The frequency can be adjusted coarsely by changing the defect concentration. The spectral efficiency can be increased without increasing the total volume of the optical devices.

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1. Introduction

Photonic crystals (PCs) attracted much scientific interest in the last decade due to their electromagnetic properties and their potential applications as optical limiter and switch, optical diode etc. [1, 2]. The reason to form a photonic band gap (PBG) is the inference of Bragg scattering in a periodic dielectric structure. When the periodicity is broken by introducing a defect into a PC, a localized defect mode will appear inside the PBG due to change of the interference behavior of light. The defect modes lead to the selective transmission in the 1D PCs and they can be utilized as filters and splitters [3]. Therefore, the study of the properties of defect modes in PCs is one of the most attractive subjects since photons can be localized [4, 5]. To achieve suitable defect modes, there are great efforts to obtain tunability of the position and intensity of the defect modes.

Mostly, Photonic Crystals have been made from Si or III–V semiconductors. While their active functions have typically exploited thermal or free-carrier nonlinear effects, both of which are relatively slow [6]. Chalcogenides have generated great deal of interest due to their attractive properties: can be formed over a large range of compositions; refractive index is high, linear absorption losses are low over a wide wavelength range and a large $\chi^{(3)}$ nonlinearity (much larger than Si). Therefore, the chalcogenide glass PC platform appears to be a promising architecture for confining and guiding light [7]. In this paper, we have presented the results obtained by introducing a defect layer of $As_{40}S_{60-x}Se_x$ in the symmetrical multilayered As_2S_3/air one dimensional photonic crystals and analyzing the frequencies of confined states which can be tuned properly.

2. Theoretical Method

The Structural configuration used in this work may be expressed as $(AB)^mD(BA)^m$, where A and B stand for the different layers with high and low refractive indices n_A and n_B, respectively, D defect layer with refractive index n_D and m is the number of layers. We have chosen As_2S_3

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(chalcogenide glass in annealed form) and air representing n_A=2.405 and n_B=1 and d_A=d_B=0.5*a*, respectively, where the parameter *a* is the lattice constant. The thickness of defect layer *d* varies in the range from about 300nm to 2000nm. Here D is taken to be annealed glasses $As_{40}S_{60-x}Se_x$ with refractive index varying between 2.405 and 2.832 at wavelength of 1550nm [8]. Consider a monochromatic light of wavelength λ incident normally on the crystal surface. The transmittance of the structure was obtained by the well known transfer matrix method using the standard codes [9].

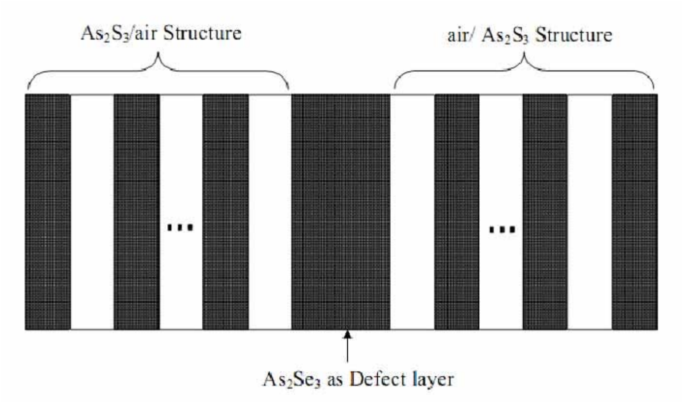

Fig. 1. Schematic diagram of 1-D Defect Photonic crystal.

3. Results and discussion

We first calculate the transmission spectrum for the perfect truncated $(AB)^mA$ PC with m =10, as shown in Fig.2 (a). The reason why we chose m = 10 is that there is no significant difference in transmission spectra when m is much larger than 10. It is clearly shown that the first PBG is from 0.22 to 0.35, in which light possessing certain values of wave vector is not allowed to propagate. Fig.2 (b), (c), (d) display transmission spectra of $(AB)^5D(BA)^5$ with d_D = 0.8*a, a, 1.2a* for defect layer as $As_{40}Se_{60}$ with refractive index n_D=2.832.

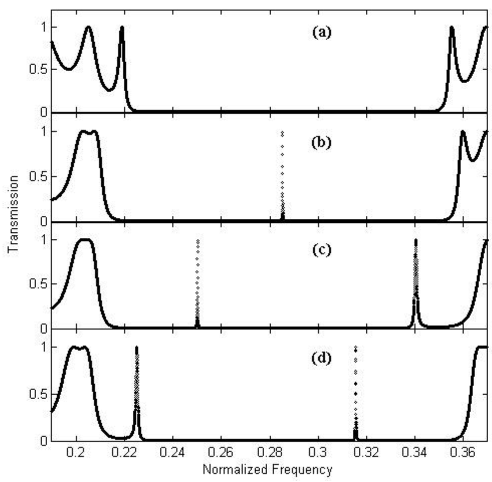

Fig. 2. Transmission spectra for 1-D chalcogenide photonic crystal (a) regular As_2S_3/air periodic crystal and (b), (c), (d) with defect layer of $As_{40}Se_{60}$ of thickness d_D=0.8a, a, 1.2a, respectively.

The break in periodicity causes the defect which may permit localized modes to exist, with frequency inside the PBG. As the mode has a frequency in the PBG, then it must exponentially decay once it enters the crystal. 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 [10]. In the present case the concentration of the defects or the total volume of the defect layer is not changed while increasing the defect layer thickness. In such case, we anticipate that the localized states corresponding to these defect modes are spread out so as to allow fields to be concentrated more and more in the high-ε defect layer. The localized states thus generated cause the shifting of frequency to lower values, as has been displayed. The number of defect mode frequencies in the bandgap also increases with thickness due to the above said reason as shown in Fig. 3. Thus, photonic single quantum well (QW) structures are constructed owing to quantum confinement effects. Here, the defect slab D can be regarded as a well.

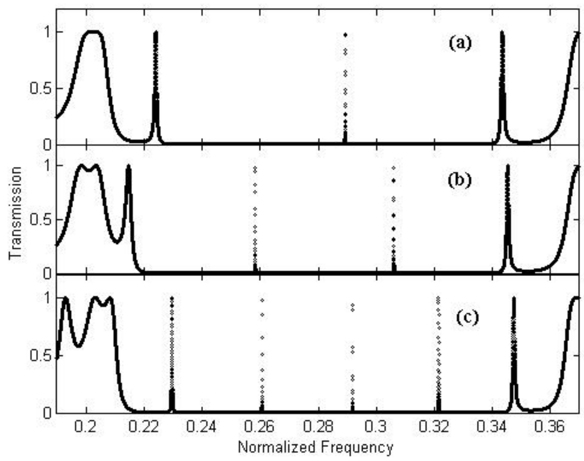

Fig. 3. Transmission spectra for 1-D chalcogenide photonic crystal for (a), (b) and (c) with defect layer of $As_{40}Se_{60}$ of thickness d_D=2a, 3a and 5a, respectively.

The sharp peaks can be clearly seen inside the PBG. These sharp peaks can be termed ‘‘confined states’’, which can be used as high-frequency carriers one-to-one for optical communication systems [11]. It is interesting to point out that the transmissivities of the confined states are close to 1. In other words, the confined states can completely transmit through the quantum well owing to the fact that they pass through the structure not in a usual way, but by resonant tunneling. When the energy of the incident photons is matched with the confined state of the defect layer, the tunneling probability is accessible to 1. On the contrary, if both of them do not match, the tunneling probability is close to zero. Thus, the sharp peaks can also be called resonant peaks.

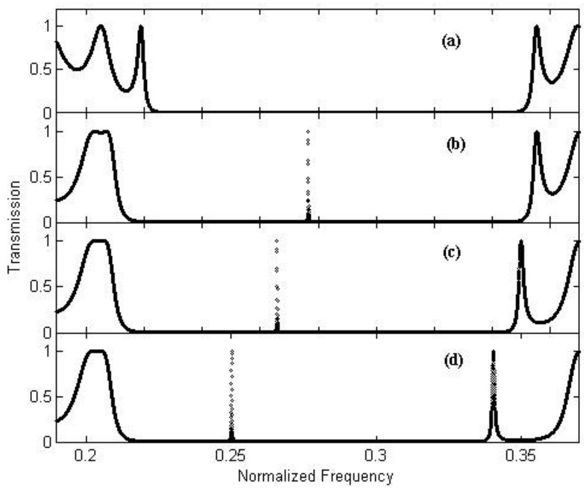

Fig. 4. Transmission spectra for 1-D chalcogenide photonic crystal (a) regular As_2S_3/air periodic crystal and with defect layer as $As_{40}S_{60-x}Se_x$ of thickness d_D= a in (b) for x=0, (c) for x=30 and (d) for x=60.

The transmission spectra for perfect 1D photonic crystal is plotted in fig. 3(a), while for defect layer $As_{40}S_{60-x}Se_x$ with thickness of layer as $d_D=a$ in fig. 3(b), (c) and (d) for x=0, x=30 and x=60, respectively. The variation of normalized frequency as a function of selenium atomic concentration of defect material is shown in Fig.4. The confined state shifts to lower values with increasing selenium atomic concentration. It provides opportunity to control the optical confined modes. This can be thought of as 'coarse' tuning of spectra. The spectral efficiency can be increased substantially. Therefore, the defect layer in PBG crystal works as a single wavelength waveguide for a particular number of wavelengths. The defect mode works as a guided mode for waveguide application in narrow band region. This is extremely useful as a filter device [7].

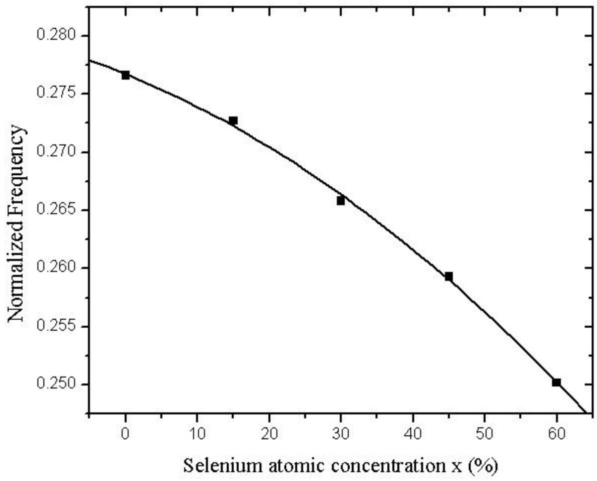

Fig. 5. The variation in Normalized frequency of guided mode with Selenium atomic concentration in defect layer $As_{40}S_{60-x}Se_x$.

The change in the constituent atom results in the reflection from the multilayers. The amorphous chalcogenides are known to have localized states present during their fabrication [12]. This allowed frequencies to be available inside the PBG. The effect of Se concentration can be understood as follows. The value of the band gap in chalcogenide glasses is determined by the energy difference between the non-bonding valence band and the anti-bonding conduction band and not by the bond between the chalcogen and the arsenic atoms. The replacing sulfur atoms by selenium atoms decrease the value of the band gap from 2.1 eV for As_2S_3 down to 1.5 eV for As_2Se_3. The decrease in band gap causes increase in the values of nonlinearity which gives rise to the refractive indices from As_2S_3 for 2.405 to As_2Se_3 for 2.832 [13]. Arsenic based chalcogenides are highly nonlinear compared to Si, in which long range order is possible and is normally used for the study of PC multilayer as a high dielectric layer.

The process of adding slab thickness coupled with the concentration modification can be used to fine tune the spectra. This results in the reduction of frequency interval, so that spectral density is reduced and spectral efficiency is increased.

4. Conclusions

In the present work, it is found that transmission spectra of multilayered structures can be modified by changing the defect layer thickness as well as concentration of slab material. The structures of 1D PCs gives better results using chalcogenides compared to the other conventional materials. Confined States generated within the PBG can be coarsely tuned by changing the defect slab features in chalcogenide/air multilayer photonic crystal. The spectral efficiency can be increased without increasing the total volume of the devices. The work can be useful for improving the optical communication systems and establishing chalcogenides as suitable materials with regards to other materials.

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