Structural, morphological, optical and electrical properties of PbSe thin films grown by chemical bath deposition

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ABSTRACT

Lead selenide (PbSe) thin films were processed by chemical bath deposition (CBD) technique. To analyze the structure and the crystallite size of PbSe thin film X-ray diffraction (XRD) analysis was used. Using Scanning Electron Microscopy (SEM) the surface examination of the film was conducted. With the help of UV-Visible absorption spectrum investigation of the optical properties were held. All the optical constants were determined from UV-Visible absorption spectrum. The dielectric examination of PbSe thin films were analyzed for various frequencies and various temperatures. The AC electrical conductivity analysis brought to light that the conduction depended on both the frequency and the temperature. Photoconductivity analysis was carried out to the PbSe thin films. Copyright © 2016 VBRI Press.

Keywords: Lead selenide (PbSe); XRD; SEM analysis; optical; electrical studies.

Introduction

Thin films have received great consideration and serious attention from the research community because of their numerous applications. The main attraction of the thin films is due to their significant properties that differ from those of the bulk. As the film becomes thinner, newer properties are exhibited and these properties become vital in the miniaturization of elements such as resistors, transistors, capacitors and solar cells. For the next generation of low cost substitute, Nanocrystalline based solar cells are well-known as the traditional silicon based solar cells [1]. Electronic devices such as IR-detectors, photographic plate, laser selective and photoconductive absorber and analyzers have established increased because of their practical use in the IV–VI semiconductors [2-4]. The small energy gap is one of the most essential properties of lead chalcogenide semiconductors leading to the huge experimental exploration in these materials. At present, many researchers seem to have a sustained interest on lead chalcogenide nanocrystalline semiconducting materials because of their potential applications [5]. For cooling and power generation applications among the existing lead chalcogenides, PbSe thin film is broadly used as thermoelectric materials [6]. Lead selenide thin films can be analyzed by various techniques [7-10]. We have selected, for our examination, chemical bath deposition (CBD) method. This paper introduces the mechanism of analysis and characterization of PbSe thin films.

Experimental

The PbSe thin films were deposited via simple CBD technique at room temperature using lead nitrate, sodium selenosulphate and sodium hydroxide as the starting materials. For thin film deposition starting materials of (0.5 M) of lead nitrate and (0.5 M) of sodium hydroxide were dissolved in 50 ml of distilled water in a glass vessel. The vessel with reactive solution was kept in the room temperature. The (0.5 M) of Ethylene Diamine Tetra acetic Acid (EDTA) was added into the solution, which easily binds with metal ions. 50 ml of sodium selenosulphate solution was used. The solution was blended well with the help of a magnetic blender to get a homogeneous mixture. At the temperature of 80 °C the deposition was accomplished and the growth time was 3h. Inside the vessel a glass substrate was vertically placed. After some time interval, to clean the glass slide before washing with deionized water, the slide was detached from the bath and dried inside a hot oven. Finally, the homogeneous nature of the end films was observed.

Results and discussion

Structural studies

The phase combination and the structure of the film were determined by X-ray diffraction examination. The XRD patterns of PbSe thin films are shown in **Fig. 1**. The formation of crystallized PbSe thin films was indicated by the strong and sharp diffraction peaks. It could be seen that the other peaks were dominated by the major peak (200). The well-defined peaks were observed in the XRD pattern. The peaks at (200), (111), and (220) showed that the polycrystalline thin film exhibited itself in the cubic phase and, therefore, were indexed according to the cubic structure. The crystalline size was found to be about 22.3 nm using Scherrer formula.
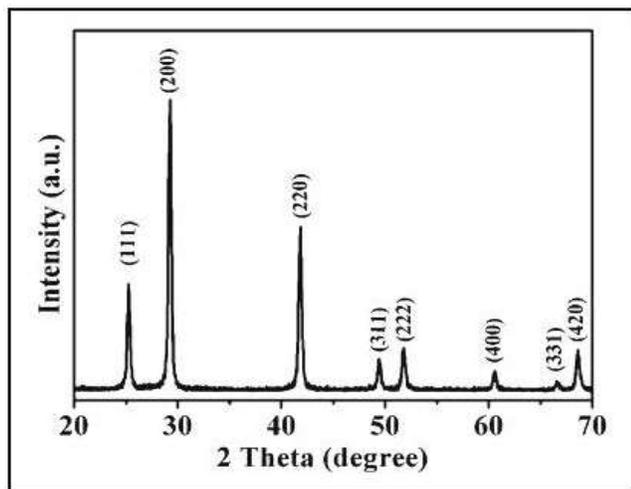
Fig. 1. XRD pattern of the PbSe thin film.

SEM analysis

Scanning electron microscopy (SEM) was used for the study of the morphological characteristics of the deposited thin films. The grain size and structure of samples could be studied. The surface morphologies of the PbSe films are shown in **Fig. 2**.These films showed that the grains were very tiny in size with no well-defined grain boundaries. The cubic shaped PbSe films concealed the glass substrate. The granule by some means formed condensed morphology structure over the substrate and was densely packed. The bath temperature performs an important role on the quality of the PbSe films.
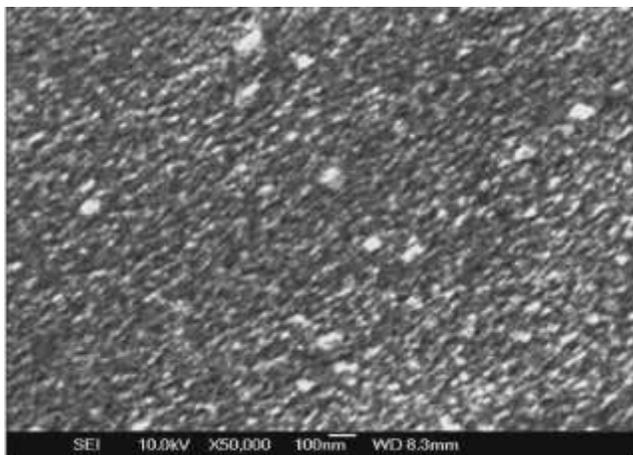
Fig. 2. SEM image of the PbSe thin film.

Optical properties

Optical experiments provide a magnificent way of studying the properties of semiconductors; particularly measuring the absorption coefficient for variable energies gives facts about the band gaps of the material. In the range of 400-1000 nm the optical absorption spectrum of the PbSe films was recorded. The study of the band structure and the class of transition of electrons was made possible by the dependence of optical absorption coefficient on photon energy. Electronic transitions between the valence and the conduction bands split into direct and indirect transitions

due to the absorption of radiation. The absorption spectrum of PbSe thin films is shown in **Fig. 3**. A plot of variation of $(\alpha h\nu)^2$ with $h\nu$ is shown in **Fig. 4**. E_g was computed using the extrapolation of the linear part. Using Tauc's plot, the energy gap (E_g) was calculated to be 1.4 eV.
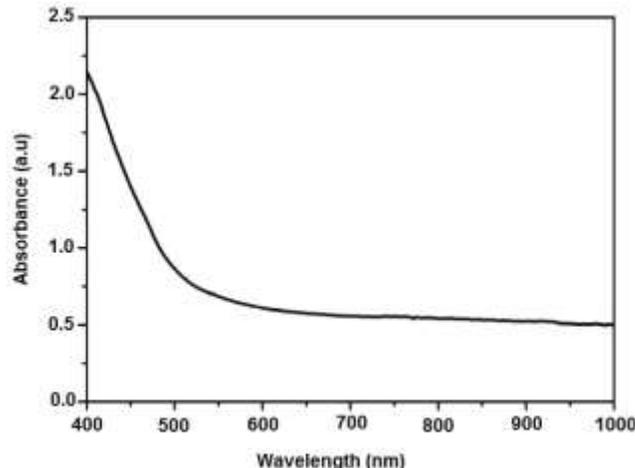
Fig. 3. Optical absorbance spectrum of PbSe thin film.
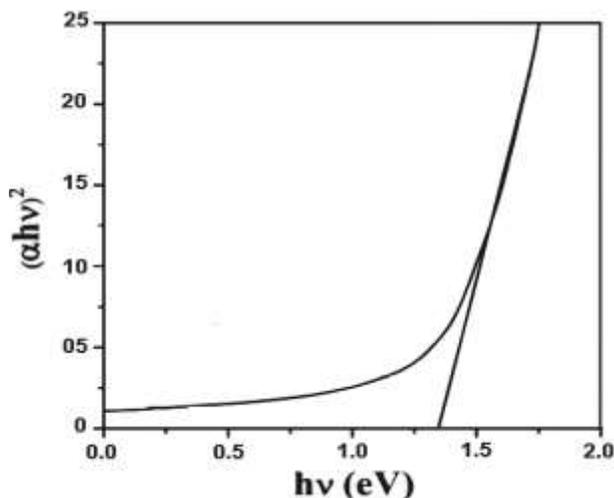
Fig. 4. Plot of $(\alpha h\nu)^2$ Vs $h\nu$.

Determination of optical constants: Two of the most vital optical properties are generally called optical constants, namely the refractive index and the extinction coefficient. The refractive index, the extinction coefficient and the electric susceptibility are the optical constants that were computed using the relationship given below: The extinction coefficient (K) could be obtained from the following equation

$$K = \frac{\lambda \alpha}{4\pi} \tag{1}$$

The extinction coefficient (K) was found to be 0.050 at $\lambda =1000$ nm. The transmittance (T) is given by

$$T = \frac{(1-R)^2 \exp(-\alpha t)}{1-R^2 \exp(-2\alpha t)} \tag{2}$$

Reflectance (R) in terms of absorption coefficient could be obtained from the above equation. Hence, we have,

$$R = \frac{1 \pm \sqrt{1 - \exp(-\alpha t + \exp(\alpha t)}}{1 + \exp(-\alpha t)} \quad (3)$$

Refractive index (n) can be determined from the reflectance data using the following equation:

$$n = -\frac{(R+1) \pm \sqrt{3R^2 + 10R - 3}}{2(R-1)} \quad (4)$$

The refractive index (n) was found to be 1.89 at λ =1000 nm. This outcome disclosed that PbSe has high refractive index. The high refractive index of PbSe films makes it most suitable for use in anti-reflection coatings. From the optical constants, electric susceptibility (χ_c) could be calculated according to the following relation

$$\varepsilon_r = \varepsilon_0 + 4\pi\chi_C = n^2 - k^2 \quad (5)$$

Hence, we have

$$\chi_C = \frac{n^2 - k^2 - \varepsilon_0}{4\pi} \quad (6)$$

where, ε_0 is the permittivity of free space. The value of electric susceptibility (χ_c) was found to be 2.572 at λ=1000 nm. When the incident light is more intense, the material can be easily polarized, since electrical susceptibility is greater than 1. The real part dielectric constant (ε_r) and the imaginary part dielectric constant (ε_i) canbe computed from the following relations

$$\varepsilon_r = n^2 - k^2 \quad (7)$$

$$\varepsilon_i = 2nk \quad (8)$$

The values of the real dielectric constant (ε_r) and the imaginary dielectric constant (ε_i) at λ=1000 nm were estimated to be 4.425 and 0.032 respectively.

Dielectric properties

The plots of the dielectric constant against log frequency are shown in **Fig. 5**. It is noticed that with increase in the frequency the dielectric constant decreases. Due to the existence of space charge polarization, there is a large value of dielectric constant at low frequency [11]. At lower frequencies space charge polarization is generally active and signifies the purity and perfection of the nanoparticles. The difference of the dielectric constant with frequency may be elucidated on the basis of space-charge polarization peculiarity. Therefore, compared with the conventional materials the dielectric constant of nanostructured materials should be larger [12]. **Fig. 6** shows the frequency with respective variation of the dielectric loss at different temperatures. It is noticed that with increasing frequency, the dielectric loss exhibits decreasing trend. In nanophase materials, inhomogeneities similar to defects and space charge formation occurring in the inter phase layers create an absorption current, resulting in a dielectric loss [13].
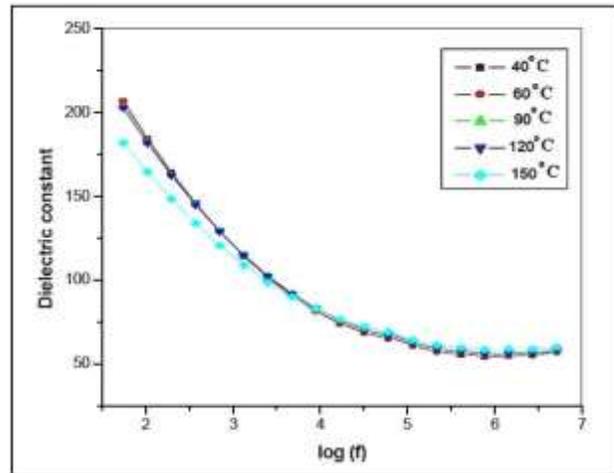
Fig. 5. Dielectric constant of PbSe thin film.
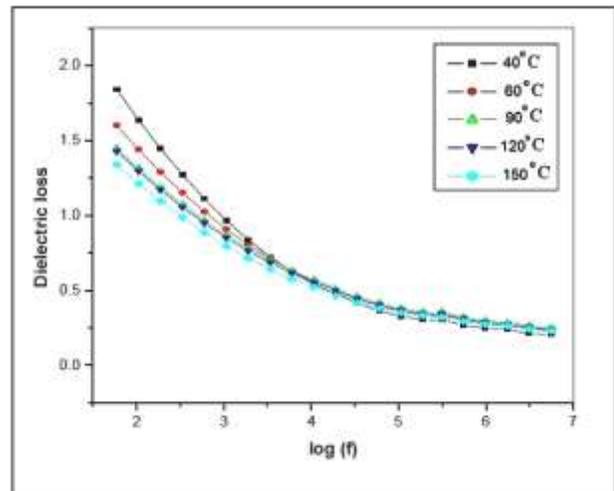
Fig. 6. Dielectric loss of PbSe thin film.

AC electrical conductivity studies

Fig. 7 shows the deviation of ac conductivity with differing frequencies and temperatures. It is observed that the value of ac conductivity rises with rise in the frequency. The electronic switching of the number of ions in the PbSe thin films provides local dislocation of electrons in the direction of the applied field, which consecutively raises polarization [14]. The activation energy required for the conduction process of the charge carriers as well as that of the PbSe thin films was found to be 0.056 eV.

Photoconductivity studies

Fig. 8 the function of the applied voltage plotted for the photo current and the dark current. Both the photo and the dark current of PbSe thin films increase linearly with the applied voltage, and it is noticed from the figure that the photo current is always higher than the dark current. Thus by the absorption of photon heading to positive photo conductivity the production of mobile charge carriers motivated which and the photocurrent is more than the dark current [15]. This leads to the indication of positive photoconductivity nature which is accepted by the stated outcome [16].
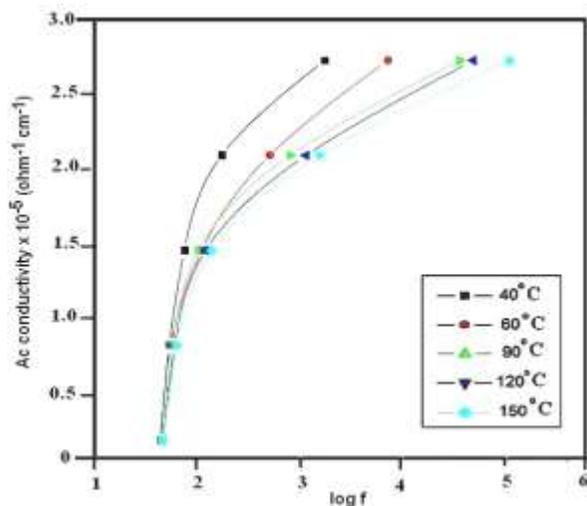
Fig. 7. Variation of conductivity with log frequency.
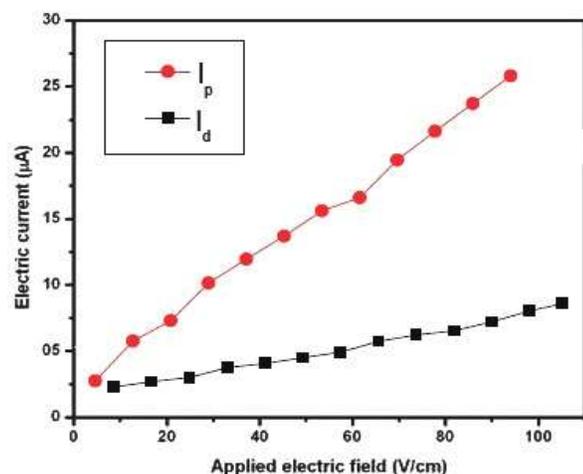
Fig. 8. Photoconductivity study of PbSe thin films.

Conclusion

Using chemical bath deposition (CBD) technique, on the glass substrate Lead selenide (PbSe) thin film was deposited. The structural and the morphological properties were investigated by XRD and SEM methods of the PbSe thin films. The excellent transmission of UV-Visible absorbance spectrum was exhibited in the entire visible region. The electrical properties such as dielectric constant, the dielectric loss and AC conductivity of the PbSe thin films were measured. The photoconductivity analysis ascertained the positive photoconductivity character of the PbSe thin films.

Reference

1. Plante, I. Jen-La.; Zeid, Tahani W.; Yang, P.; Mokari, T. *J. Mater. Chem.* **2010**, *20*, 6612.
2. Zhu, J.; Liao, X.; Wang, J.; Chen, H.Y. *Mater. Res. Bull.* **2001**, *36*, 1169.
3. Ozin, G. A. *Adv. Mater*. **1992**, *4*, 612.
4. Alivisatos, A. P. *J. Phys. Chem*. **1996**, *100*, 13226.
5. Enue Barrios-Salgado, Nair, M. T. S.; Nair, P. K.; Zingaro, R. A. *Thin Solid Films*. **2011**, *519*, 7432.
6. Qiu, X.; Zhao, Y.; Steward, I. M.; Dyck, J. S.; Burd, C.; Dalton Trans. **2010**, *39*, 1095.
7. Schmidt, *Chem. Rev.* **1992**, *92*, 1709.
8. Das, V. D.; Bhat, K. S.; *J. Mater. Sci.* **1990**, *7*, 169.
9. Saloniemi, H.; Kanniainen, T.; Ritala, M.; Lesketa, M.; Lppalinen, R. *J. Mater. Res. Bull.* **1998**, *8*, 651.
10. Zhu, J. J.; Palchik, O.; Chen, S. G.; Gedanken, A. *J. Phys. Chem.* **2000**, *104*, 7344.
11. Sagadevan, S.; Sundaram, S. *Chalcogenide Lett* **2014**, *11*,159.
12. Suresh, S. *Journal of Non-Oxide Glasses* **2014**, *6*, 47.
13. Sagadevan, S.; Murugasen, P. *Int. J. Chem. Tech. Res* **2014**, *6*, 5608.
14. Thirumavalavan, S.; Mani, K.; Sagadevan, S. *Journal of Ovonic Research* **2015**, *11*, 123.
15. Thirumavalavan, S.; Mani, K.; Sagadevan, S. *Chalcogenide Lett*. **2015,** *12*, 237.
16. Thirumavalavan, S.; Mani, K.; Sagadevan, S. *Scientific Research and Essays* **2015,** *10*, 378.