



# Structural, Electrical, Thermo-electrical and Optical Properties of Indium doped Lead Selenide Thin Films Deposited By Physical Evaporation Technique

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## ABSTRACT

Thin films having different thickness 1000- 3000 Å of  $Pb_{1-x}In_xSe$  (X=0.2) were deposited by thermal evaporation techniques, onto precleaned amorphous glass substrate. The optical microscopy and XRD were used to detect the structural properties of the films. The electrical, thermoelectric and optical properties of annealed thin films have been evaluated. From electrical properties bulk resistivity, mean free path, charge carrier concentration, mobility were calculated. The calculated value of bulk resistivity is  $1.6647 \times 10^{-4} \Omega\text{-cm}$ , mean free path is  $2.348 \text{ Å}$ , charge carrier concentration is  $5.8941 \times 10^{21} \text{ cm}^{-3}$  and mobility is  $0.0113 \times 10^3 \text{ cm}^2/\text{volt-sec}$ . Thermoelectric Properties shows a positive sign exhibiting p- type nature of films. Fermi energy and scattering parameter were determined. The calculated values of Fermi energy and scattering parameter are 0.02 to 0.16 eV and 0.26 to 0.143 respectively. The evaluated absorption coefficient and extinction coefficient were  $(1- 4) \times 10^5$  and  $(2.5 - 9.07) \times 10^{-3}$  respectively. The evaluated direct and indirect optical band gaps are 1.71 to 1.75 eV and 0.816 to 0.819 eV respectively

**Keywords:** XRD, Optical Microscopy, EDAX, electrical, thermoelectric and optical properties.

## INTRODUCTION

In the recent years a fair amount of research has been carried out on lead chalcogenides because of their application in devices such as infrared devices, diodes, lasers, thermo photovoltaic conversions, solar cells, opto electronic devices, etc [1-7]. Physical methods are expensive but give relatively more reliable and reproducible results [8, 9]. Due to its potential applications, thin films of lead chalcogenides have been extensively studied by doping n or p – type, so that they may be used in various solid state devices (10). InSe and PbSe based materials are of considerable technological interest for application to high speed and optoelectronic devices because of their high electron mobility and low effective electron mass [11]. Majority of these compounds have been reported to be grown in the crystalline form.

## MATERIALS AND METHODS

The Indium doped PbSe ingot was prepared from its own constituent elements. Appropriate weight of lead, indium and selenium (purity 99.999%) were mixed together and placed in a quartz ampoule which was heated in furnace at temperature  $1120^{\circ}\text{C}$  for 24 hours, then cooled by melt quench method. Thin films of  $\text{Pb}_{1-x}\text{In}_x\text{Se}$  ( $X=0.2$ ) with varying thickness from  $1000\text{ \AA}$  -  $3000\text{ \AA}$  were obtained on clean glass substrates held at room temperature, by physical evaporation technique at a pressure of  $10^{-5}$  torr by thin film coating unit model no 12A4D. The lateral dimensions of the glass substrates of size  $75\text{mm} \times 25\text{mm} \times 1.35\text{mm}$  were used and the source to substrate distance was kept as 20 cm. Quartz crystals monitor Model No. DTM 101 was used to measure the thickness of the films. Appropriate weight of  $\text{Pb}_{1-x}\text{In}_x\text{Se}$  ( $X=0.2$ ) was taken in the molybdenum boat and evaporated at the rate 5 to  $10\text{ \AA}^0$  per second. The deposition condition were maintained nearly the same during evaporation.

Rigaku Miniflex X-Ray diffractogram was used to obtain for finding out the structural information and qualitative analysis of the grown films. The scanning angle ( $2\theta$ ) with the range of  $20^{\circ}$  -  $80^{\circ}$  ( $\text{CuK}\alpha$  line) was used for the XRD. The optical absorption studies were carried out to estimate the band gap of the semiconductor films. The optical absorption spectra obtained in an UV-VIS-NIR spectrophotometer in the range 200 to 1100 nm at room temperature.

## RESULTS AND DISCUSSION

### Structural Characterization

The optical microscopy, XRD analysis, and EDAX were used to study the structural composition of the grown films. Fig.1 shows the micrograph of  $\text{Pb}_{1-x}\text{In}_x\text{Se}$  ( $X=0.2$ ) thin film of thickness  $3000\text{ \AA}$  indicates particles are distributed over the surface uniformly. Fig. 2 shows the diffraction pattern of grown thin film. The large number of peaks shows that the deposited films were polycrystalline in nature [12]. The plane indices are obtained by comparing the intensities and position of the peaks with JCPDS data. The calculated average grain size was  $34.298\text{ nm}$ . The stoichiometry and atomic wt % of  $\text{Pb}_{1-x}\text{In}_x\text{Se}$  ( $X=0.2$ ) thin films was found by EDAX. Fig. 3 shows EDAX spectrum of the as deposited  $\text{Pb}_{1-x}\text{In}_x\text{Se}$  ( $X=0.2$ ) thin film. The actual atomic % for composition Lead, Indium and Selenium is found to be 37.26: 10.94: 51.80.



**Figure 1: Micrograph of  $\text{Pb}_{1-x}\text{In}_x\text{Se}$  ( $X=0.2$ ) Thin film of thickness  $3000\text{ \AA}$**

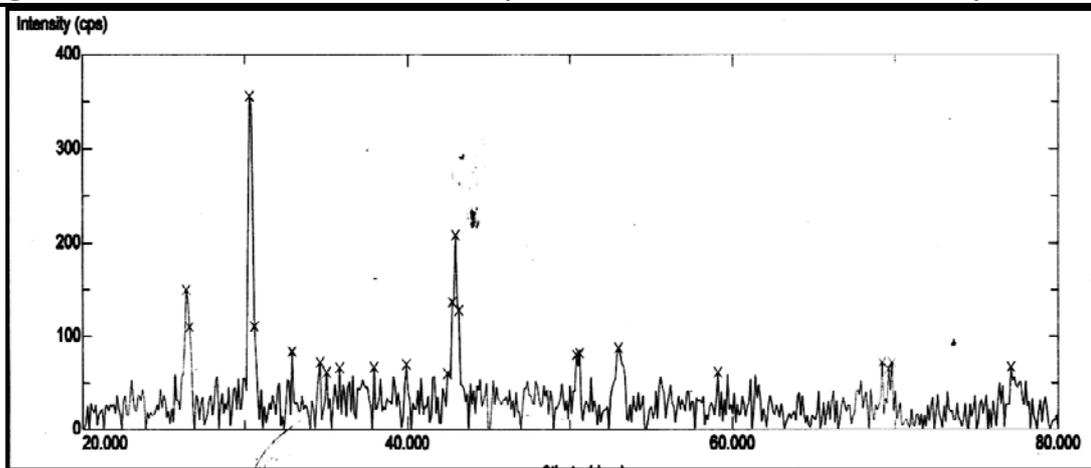


Figure 2: XRD of  $Pb_{1-x}In_xSe$  ( $X=0.2$ ) thin film of thickness  $3000 \text{ \AA}$

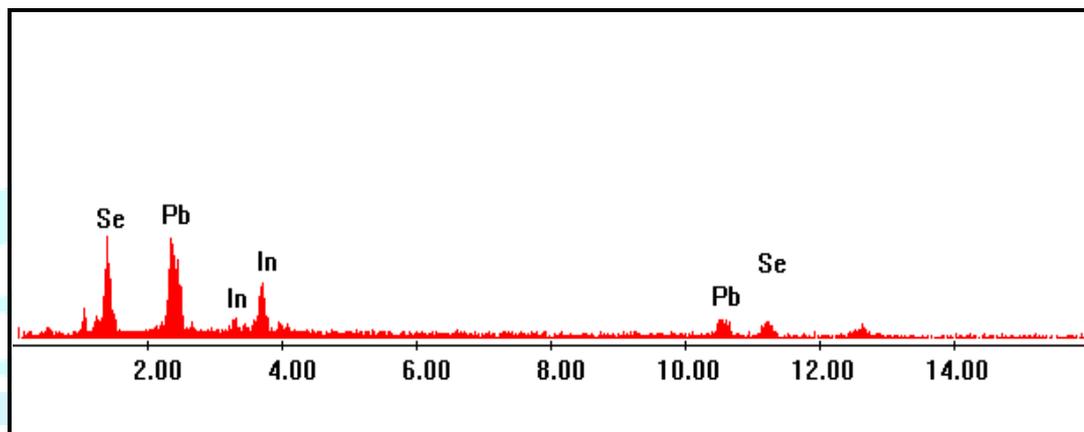


Figure 3: EDAX of  $Pb_{1-x}In_xSe$  ( $X=0.2$ ) thin film

## Electrical properties

### Resistivity measurement

#### a) Room temperature resistivity measurement by Four-probe method

The resistivity of  $Pb_{1-x}In_xSe$  ( $X=0.2$ ) films of different thickness ( $1000 - 3000 \text{ \AA}$ ) was measured by four-probe set up supplied by scientific equipment, Roorkee, Model No DEP 02 resistivity for all samples were measured at room temperature. The graphical representation of probe voltage versus probe current for different thickness is as shown in Fig.4. The plot of resistivity as a function of thickness (Fig.5) indicates that resistivity of film increases as thickness increases, obeying size effect theory and shows the semiconducting nature of the material. This fact is further confirmed from the plot  $\rho$  against  $1/d$  (Fig. 6), and plot of  $\rho d$  against  $d$  (Fig. 7). From these graphs one can calculate bulk resistivity ( $\rho_0$ ), mean free path and charge carrier concentration. The calculated values are as shown in Table 1.

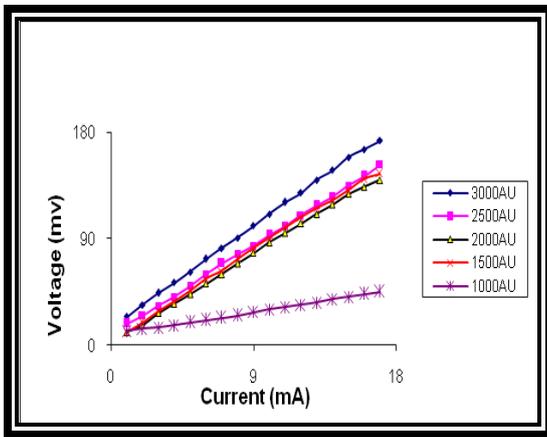


Figure 4: Probe voltage versus probe current

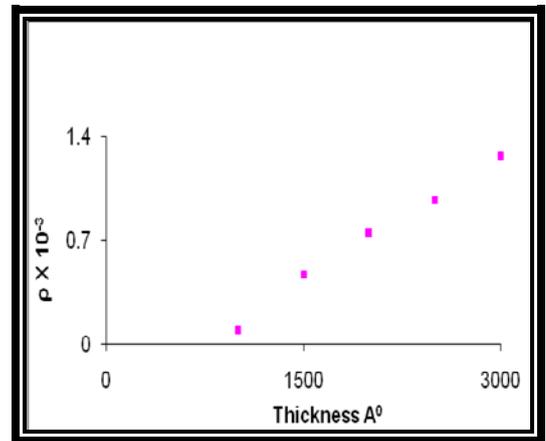


Figure 5: Resistivity versus thickness

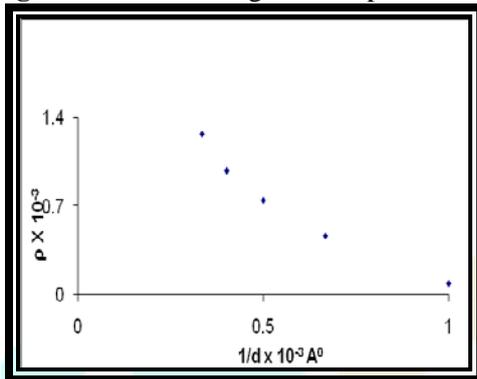


Figure 6: Resistivity versus 1/thickness

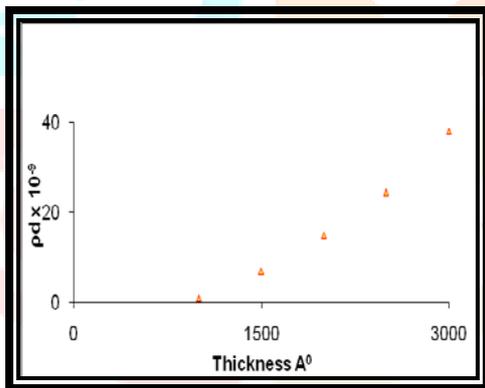


Figure 7: ρd versus thickness

Table No. 1

Sr. No.	Description	Values
1	Mean free path $\lambda_0$	2.348 Å
2	Bulk Resistivity $\rho_0$	$1.6647 \times 10^{-4} \Omega\text{-cm}$
3	Carrier concentration $\eta$	$5.8941 \times 10^{21} \text{ cm}^{-3}$
4	Mobility $\mu$	$0.0113 \times 10^3 \text{ cm}^2/\text{Volt-Sec}$

### b) High Temperature (303 to 453 K) in plane resistivity measurement by four probe method

Using the high temperature Four- probe resistivity set up the resistivity of  $Pb_{1-x}In_xSe$  ( $X=0.2$ ) thin films having different thickness was measured in the temperature range 303 - 453 K. A graphical variation of  $\log \rho$  versus  $1000/T$  is shown in Fig. 8. The curve suggest that resistivity of material is temperature dependent. Graphical representation gives the relation between them as temperature of thin film is increases the resistivity decreases it suggest the semiconducting nature of material. The calculated activation energy of  $Pb_{0.8}In_{0.2}Se$  thin film are as shown in Table 2, whose values are varied between 0.054 to 0.099[12 – 13]

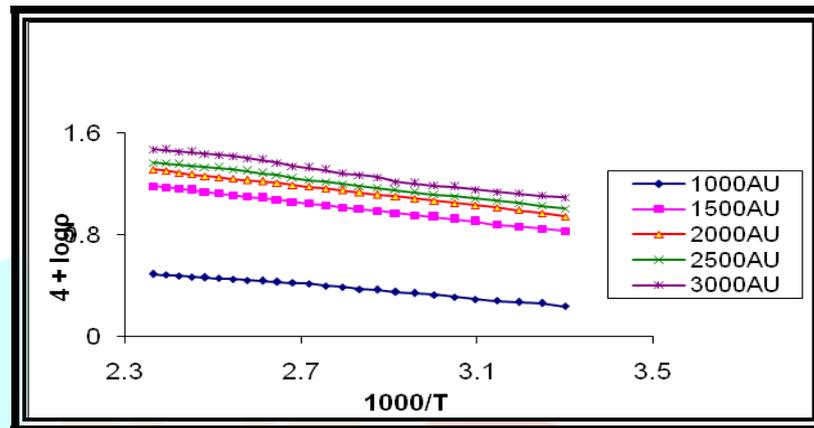


Figure 8:  $4 + \log \rho$  versus  $1000/T$

Table 2

Thickness $A^0$	$\Delta E$ eV
1000	0.054
1500	0.0757
2000	0.0779
2500	0.0839
3000	0.099

### Thermoelectric power measurement

The thermoelectric power ( $\alpha$ ) is measured by integral method [14, 15]. In integral method one end of the sample is heated while the other end is held at constant temperature. The temperature difference ( $\Delta T$ ) between two ends of sample causes the emf generation. "Pushpa Scientific" Hyderabad provided the experimental set up used for the measurement of thermal emf. Maximum temperature gradient obtainable is  $150^\circ C$  in this set up. The graphical representation of thermo emf versus change in temperature for different thickness of  $Pb_{1-x}In_xSe$  ( $X=0.2$ ) thin films are shown in Fig. 9 and the graphical representation of seebeck coefficient versus  $1000/\Delta T$  for different thickness is as shown in Fig 10 From this graph the Fermi energy and scattering parameter are calculated and represented in Table 3. The Fermi energy of  $Pb_{1-x}In_xSe$  ( $X=0.2$ ) thin films is thickness dependant. From TEP measurement, the deposited films are P- type semiconducting in nature [16].

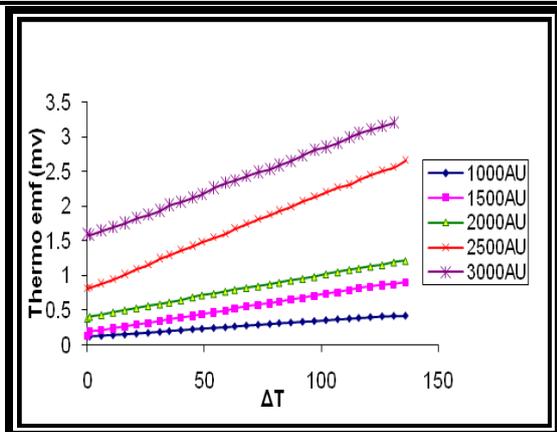


Figure 9 Thermo emf versus ΔT

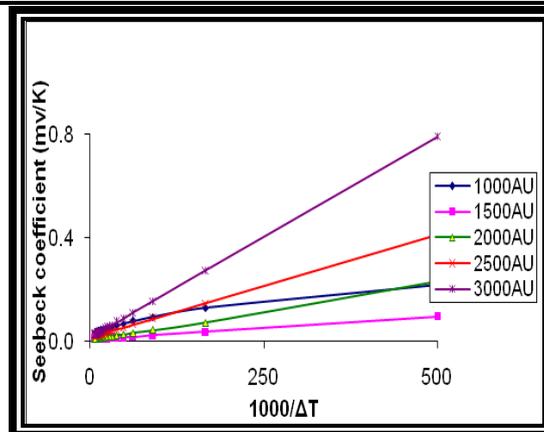


Figure 10 Seebeck coefficient versus 1000/ΔT

Table 3

Thickness Å	Fermi Energy (eV)	Scattering parameter
1000	0.02	0.26
1500	0.02	0.061
2000	0.04	0.07
2500	0.08	0.15
3000	0.16	0.143

**Optical properties**

The optical absorption spectra of  $Pb_{1-x}In_xSe$  ( $X=0.2$ ) thin films for thickness 1000-3000 Å was obtained in an UV-VIS –NIR spectrophotometer in the range 200- 1100nm. Fig. 11 shows the plot of %T versus  $h\nu$ . Fig. 12 shows the plot of  $\alpha$  versus  $h\nu$  the evaluated absorption coefficient and extinction coefficient are  $(1- 4) \times 10^5$  and  $(2.5 - 9.07) \times 10^{-3}$  respectively. Fig. 13 shows the plot of  $(\alpha h\nu)^2$  versus  $h\nu$ , from this graph the value of direct optical band gap was obtained by extrapolating these curves. Fig. 14 shows the plot of  $(\alpha h\nu)^{1/2}$  versus  $h\nu$ , from this graph the value of indirect optical band gap was obtained by extrapolating these curves, from the Fig. 13 and Fig. 14 the evaluated optical direct band gap and indirect band gap are 1.71 to 1.75eV and 0.816 to 0.819 eV respectively, which is nearly equal to reported value [12, 13].

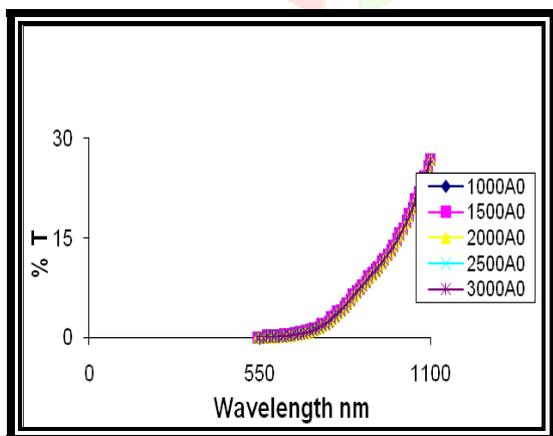


Figure 11 % T versus wavelength

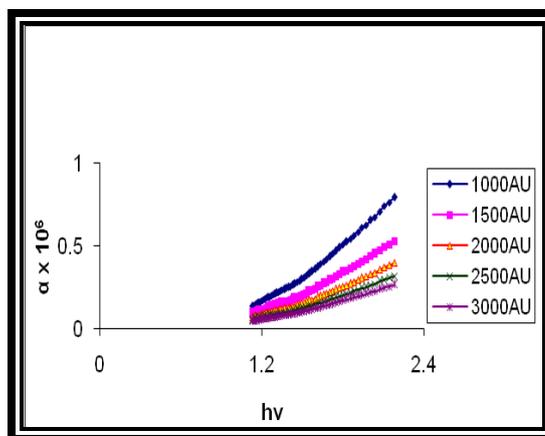


Figure 12  $\alpha \times 10^6$  versus  $h\nu$

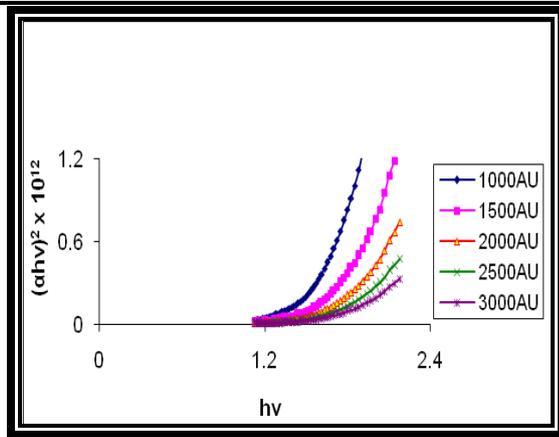


Figure 13  $(\alpha hv)^2$  versus  $h\nu$

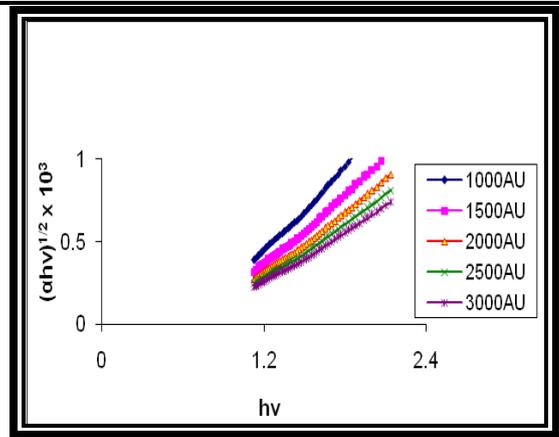


Figure 14  $(\alpha hv)^{1/2}$  versus  $h\nu$

## Conclusion

Thin films of Indium doped lead selenide were deposited successfully. From four probe resistivity measurement the deposited thin films were semiconducting in nature obeying size effect theory. Thermoelectric measurement shows the deposited films were P type in semiconducting in nature. The estimated optical direct band gap was 1.71 to 1.75eV.

The estimated optical direct band gap was 0.816 to 0.819 eV. Optical analysis revealed that prepared films were suitable for photovoltaic applications.

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