# Electrical properties of aluminium antimonide thin films deposited by vacuum evaporation technique

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Thin films having different thickness of AlSb were deposited by thermal evaporation techniques, onto precleaned amorphous glass substrate. The structural properties of films were evaluated by XRD, SEM, EDAX, Transmission Electron Microscopy (TEM) and optical microscopy. The Photo Luminescence (PL) study of the films are also studied and it is observed that the peaks are obtained at 488.04, 517.29 and 574.8nm shows that zero phonon transition of donor - acceptor pair recombination. The electrical transport properties of annealed thin films have been evaluated. Resistivity (9.2-13.35 X$10^{-5}$ohm - cm), activation energy (0.0122 – 0.0251 eV), carrier concentration (1.0746 X $10^{18}$/cm$^3$), mobility (0.6348 X $10^5$) has been estimated. The X-ray diffraction analysis confirms that films are polycrystalline having cubic structure cell. The average grain size is found to be 8.65 – 10.75 nm.

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*Keywords*: AlSb, Thin films, Vacuum evaporation

## 1. Introduction

The III–V semiconductors have importance due to their applications in various electro optic devices [1]. Such P–N junction diodes, transistors, high efficiency solar cells, infrared detectors, photon detectors, computers etc. The AlSb is a suitable semiconducting material for high temperature applications especially for transistors and P–N junction diodes because of large band gap [2, 3]. The AlSb has rapidly growing interest in opto-electronics [4]. Several worker worked on, the electrical, optical and structural properties of Aluminium Antimonide [5- 8]. From the study of literature review, it can be seen that no attempt has been made to study the variation of electrical properties by change in thickness of thin films.

In present work, the effect of film thickness of thin AlSb films over the thickness range of thickness 200 – 2000 Å has been investigated. An attempt has been made to evaluate the electrical parameters such as bulk resistivity, mean free path of charge carriers as a function of thickness. Using bulk resistivity and mean free path, carrier concentration has also been evaluated.

## 2. Experimental

Polycrystalline AlSb films of different thicknesses have been deposited by physical evaporation technique under vacuum of about $10^{-5}$ torr. The two materials taken in two sources were deposited simultaneously. The plots of ρ against 1/d and ρd against d which represent straight line graph following Sondheimer relations.

$$\rho d = \rho_0\left[d + \frac{3\lambda}{8}(1-p)\right]$$

$$\rho = \rho_0\left[1 + \frac{3\lambda}{8d}(1-p)\right]$$

Where $\rho_0$ and p are respectively the bulk resistivity and specular reflection coefficient at the surface of thin film. Above relations indicate the plots of ρd against d and ρ against 1/d should be straight line. Surface scattering assumed entirely non specular so that P = 0, the mean free path $\lambda_0$ and bulk resistivity $\rho_0$ may be computed from the observed slope and intercept. The values of $\rho_0$ and $\lambda_0$ so obtained may be used to calculate the electron density from the relation (Chopra 1966).

$$\frac{1}{\rho_0\lambda} = \left(\frac{8\pi}{3}\right)^{1/3}\left(\frac{e^2}{h}\right)n^{2/3}$$

Where e and h are respectively the electronic charge and Planck's constant. Adjusting the rate of evaporation, the stoichiometric of the compound is controlled in the deposition. The substrate to source distance was kept 20 cm. The samples of different thicknesses at room temperature were deposited under similar conditions. The films were annealed at reduced pressure of about $10^{-5}$ torr and at temperature 523 K for the period of three hours. The thickness of films was controlled by using quartz crystal thickness monitor model no. DTM – 101 provided by Hind High Vac. The deposition rate was maintained 10-20 Å/sec throughout sample preparation.

The X-ray Diffractogram (Rigaku, Miniflex, Japan) were obtained of these samples to find out structural information and to identify the film structure qualitatively. The scanning angle (2θ) range was from $20^0$ - $80^0$ (CuKα line). The X-rays shows that all the films prepared were polycrystalline with cubic structure. The resistivity of samples was measured by four probe technique using model no. DEP – 02, "Scientific Equipments, Roorkee", as a function of thickness and temperature. The thermo electric power of samples was measured by TEP set up using model no. DMV – 001, "Scientific Equipments, Roorkee", as a function of thickness and temperature.

## 3. Results and discussion

### 3.1 Structural characterization

The structural composition of the grown films was studied through the XRD analysis, SEM, TEM and optical microscopy.

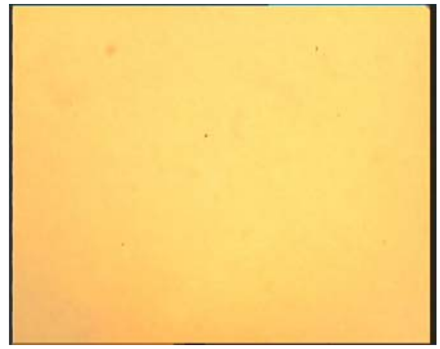

*Fig. 1. Micrograph of AlSb film of thickness 2000 Å.*

Fig. 1 shows the micrograph of AlSb of thickness 2000 Å indicates uniform surface coverage. Further confirmation of the structure of the grown films was carried out using the x-ray diffraction pattern in Fig. 2.

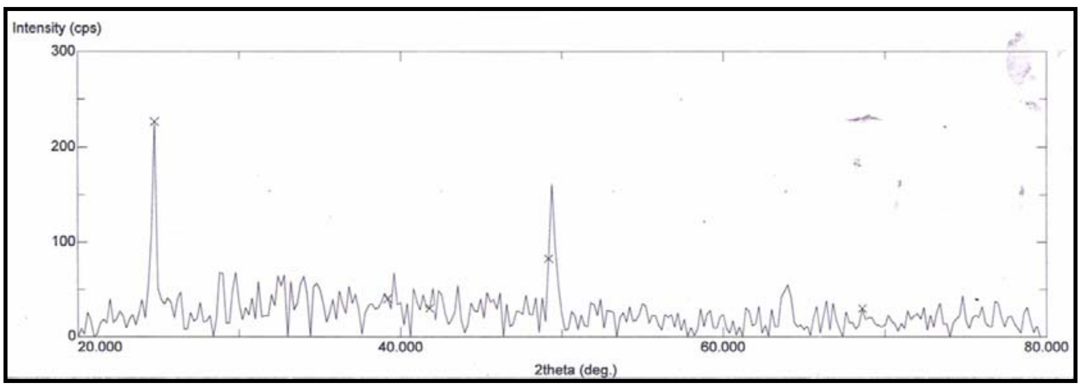


*Fig. 2. (a) XRD of AlSb of thickness 500 Å.*

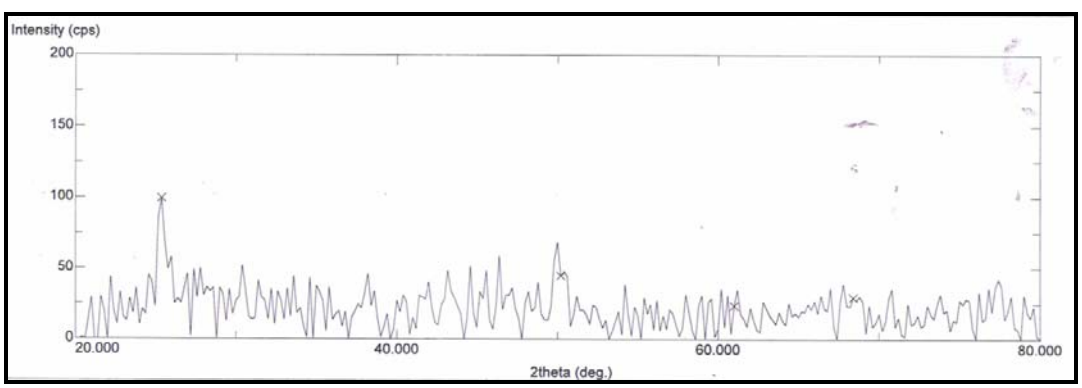


*Fig. 2. (b) XRD of AlSb of thickness 2000 Å.*

Fig. 2 shows the XRD pattern of AlSb thin film prepared at substrate temperature of 303k. The 2θ peaks observed at $24.8^0$, $39.2^0$, $41.8^0$, $49.2^0$ and $68.6^0$ exhibit the formation of the cubic phase of AlSb which correspond to the (111), (220), (311) and (100) planes of reflections. The presence of large number of peaks indicates that the films are polycrystalline in nature [9]. These results are well in agreement with the reported values. The value of the lattice parameters obtained from the analysis of x-ray diffraction pattern is shown in Table 1. The average grain size is found to be 8.65 – 10.75 nm.

*Table 1.Experimental values of interplaner spacing and the corresponding data of the AlSb thin films.*

| **Observed Data** | | | | | | | | **Standard Data** | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **500Å** | | **600Å** | | **1500Å** | | **2000Å** | | | | |
| **dA** | **$I/I_1$** | **dA** | **$I/I_1$** | **dA** | **$I/I_1$** | **dA** | **$I/I_1$** | **dA** | **$I/I_1$** | **hkl** |
| --- | -- | -- | -- | 3.0153 | 65 | -- | -- | 3.06 | 35 | 200 |
| -- | -- | -- | -- | -- | -- | 3.587 | 23 | 3.54 | 100 | 111 |
| 2.1994 | 100 | 2.1994 | 100 | 2.1994 | 100 | 2.1994 | 100 | 2.169 | 75 | 220 |
| -- | -- | -- | -- | 1.8503 | 66 | 1.8433 | 25 | 1.85 | 30 | 311 |
| 1.7476 | 15 | 1.7384 | 22 | 1.7384 | 68 | -- | -- | 1.771 | 6 | 222 |

Fig. 3 shows SEM images of AlSb thin film of thickness 2000 Ǻ. The surface of AlSb deposits are covered with spherical and rough crystals, although there are differences in crystal sizes that are in the range of 10 - 40 nm i.e. the surface roughness is seem to be improved [10].

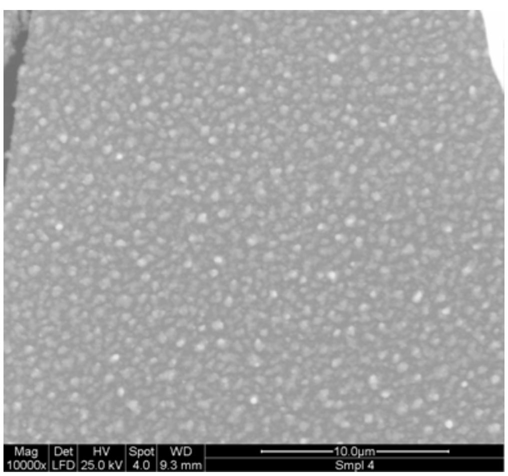


*Fig. 3. SEM image of annealed AlSb thin film of 2000 Ǻ.*

EDAX analysis confirms that the stoichiometry of the synthesized AlSb with Al : Sb ratio is 52.9 : 47.1 (at %). TEM micrograph gives the morphology of the nanocrystallites. Fig. 4(a) shows the TEM micrograph of as-prepared AlSb nanoparticles. The particles were homogeneous and spherical. The sample was agglomerated slightly, but a few separated particles still could clearly be observed in the image. The particle size ranged from 8.95 - 17 nm. This result was in good agreement with XRD result. The selected area electron diffraction (SAED) pattern in Fig. 4(b) furthermore indicated that the nanocrystalline AlSb had a polycrystalline in nature.

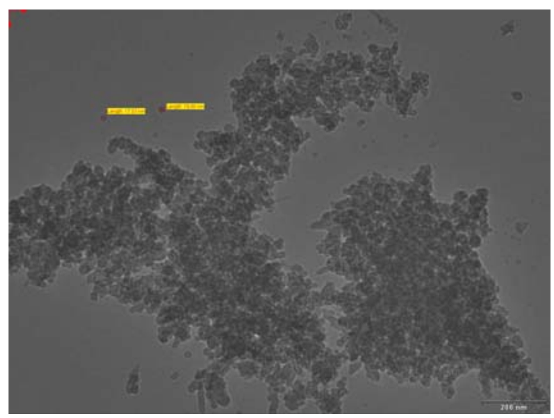

*Fig. 4.(a) TEM Micrograph of AlSb film of thickness 2000 Ǻ.*

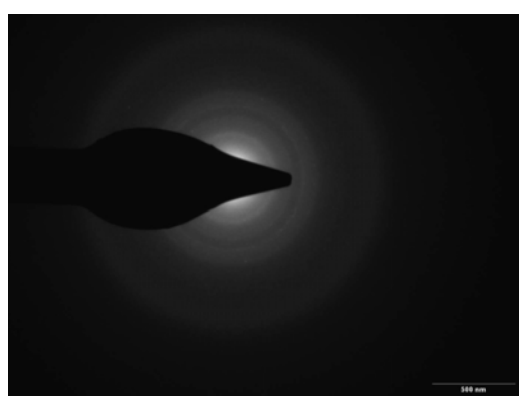

*Fig. 4.(b) SAED patternn of AlSb film of thickness 2000 Ǻ.*

### 3.2. Electrical properties of AlSb thin films

The resistivity of AlSb films of different thicknesses 200–2000 Å was measured for all samples at room temperature. The plot of resistivity as a function of thickness indicates that the resistivity of films decreases as thickness increases and attains constant value beyond 2000 Å, obeying Fuch – Sondheimer size effect theory. This fact is further confirmed from the slopes and intercepts of these plots (Fig. 5 & 6), bulk resistivity ($\rho_0$) and the mean free path of the charge carrier in bulk material are evaluated and $\rho_0 = 8.7571 \times 10^{-5}$ ohm – cm, $\lambda_0 = 291.52$ [11].

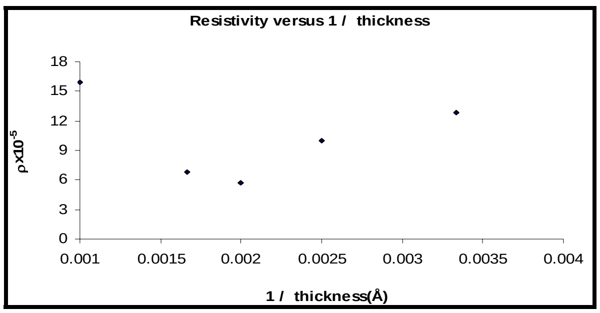


*Fig. 5. Plot of resistivity Vs. reciprocal of thickness.*

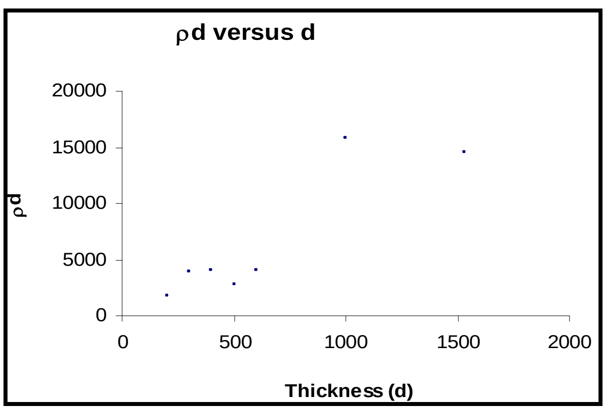


*Fig. 6. Plot of product of resistivity and thickness Vs. thickness.*

Using these values, charge carrier concentration is estimated as $n = 1.0746 \times 10^{18}$ and mobility was found $\mu = 0.6348 \times 10^5$ /cm$^3$ (Table 2).

*Table 2. Estimated parameters.*

| Quantity | Present work |
|---|---|
| Bulk Resistivity ( $\rho_0$ )(ohm-cm) | $8.80 \times 10^{-5}$ |
| Mean free path ( $\lambda_0$ ) | 276.54 |
| Carrier Concentration (n) /cm$^3$ | $1.0451 \times 10^{18}$ |
| Mobility (() | 0.6201 × 105 |

The measurement of temperature dependence of electrical resistivity showed that AlSb films always have positive temperature coefficients [12]. The plots of log ( as a function of reciprocal of absolute temperature (1/T) are represented in Fig. 7.

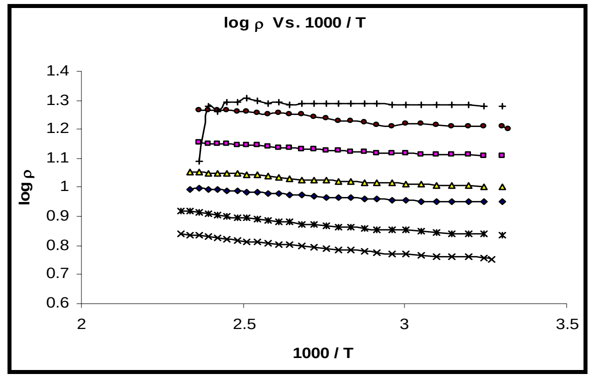


*Fig. 7. Plot of log of resistivity vs. reciprocal of thickness.*

These plots are linear for each thickness. The activation energy is represented in Table 3. The plots follow the relation,

$$\rho = \rho_0 \exp\left(\frac{\Delta E}{KT}\right)$$

*Table 3. Experimental values of activation energy.*

| Thickness (Å) | Activation Energy ( ΔE ) |
|---|---|
| 200 | 0.02515 |
| 300 | 0.02218 |
| 400 | 0.02218 |
| 600 | 0.0305 |
| 1500 | 0.01231 |
| 2000 | 0.01225 |

### 3.3 Photo luminescence study of AlSb films

The PL spectrum consists of several PL bands. The PL band with its maximum at 2.14 eV is the phonon transition of a donor acceptor pair recombination additional band corresponds to replicas of zero phonon DA recombination. The sharp lines are typical for radiative recombination of donor bound electrons with acceptor bound holes at closely spaced DA pairs [13]. Fig. 8 shows the graph of wavelength Vs. Intensity and Fig. 9 shows the Energy vs. Intensity for AlSb films.

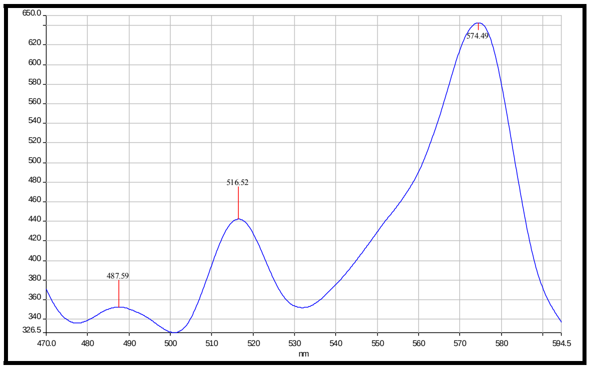


*Fig. 8. Plot of wavelength vs. Intensity.*

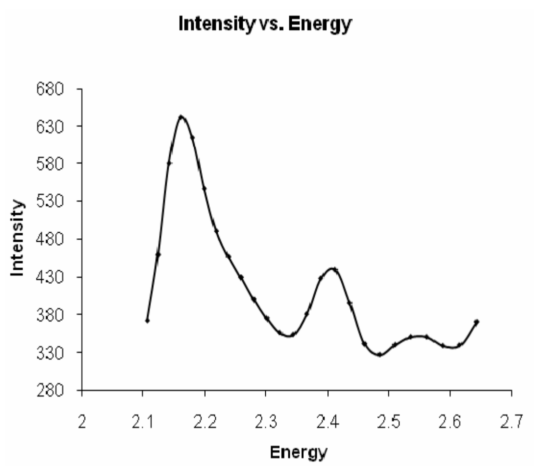


*Fig. 9. Plot of energy vs. intensity.*

## 4. Conclusions

1. The deposited Al-Sb thin films are P type of semi conducting in nature.
2. The films are polycrystalline in nature and having cubic structure.
3. The activation energy is found to be 0.01225 to 0.0305 eV.
4. The PL spectra shows phonon transition of a donor acceptor pair recombination additional band corresponds to replicas of zero phonon DA recombination.

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