Structural, optical and electrical properties of nanocrystalline AlSb thin films

Yogesh Chandra Sharma
Department of Physics
Vivekananda Global University, Jaipur (Rajasthan)- 303 012.

Amol Purohit
Department of Electronics and Communication Engineering
Vivekananda Global University, Jaipur (Rajasthan)- 303 012.

Yogesh Kumar Vijay
Department of Physics
Vivekananda Global University, Jaipur (Rajasthan)- 303 012.

Abstract: Thin films of Aluminum antimonide (AlSb) were prepared using vacuum evaporation technique. Bilayers of the elemental powders were deposited on the glass substrate. The effect of substrate temperature variation was monitored in terms of variation in the band gap of resultant thin films of AlSb. Structural, optical and electrical properties of the films were investigated using X-ray diffraction (XRD), Scanning electron microscopy (SEM), I-V characteristics and optical transmittance studies. As substrate temperature increased, measurements indicate formation of good quality nano dimensional thin films of AlSb having band gap within the range reported in the literature.

Keywords: thin-film antimonides, AlSb, band gap, XRD, SEM

I. INTRODUCTION

Development of environmental friendly solar cell material is the need of the present era. This requires use of material available in abundance which will lead to low cost of the solar cells. Simultaneously systematic improvements in the material quality are necessary to achieve economic viability of use of solar energy (1). AlSb is an indirect band gap material having band gap 1.62eV at room temperature. At room temperature, the reported mobility for AlSb is rather high, 1100 $cm^2/(V.s)$ for electrons and 700 $cm^2/(V.s)$ for holes (2). Among the elemental constituents of AlSb, aluminum (Al) is abundantly available in the crust of the earth while antimony (Sb) is also richly available; moreover both of them are non toxic. The photoelectric conversion efficiency of AlSb predicted by theoretical models is 27%. This makes AlSb a highly promising material for the use in solar cells. AlSb also has potential applications as a radiation detector and as a material in high-mobility heterostructures (3).

Use of thin films is superior over bulk material which further betters with the development of nanocrystalline thin films (4). A number of methods have been tried for the development of the thin films of AlSb like co-evaporation (5), liquid phase epitaxy (LPE) (6) and laser annealing (7), single crystal evaporation (8), hot wall epitaxy (9), multilayer films (10), co-sputtering (11) and doped AlSb thin films (12-17). Use of antimony and tellurium based materials in solar cells has become very vital (18). Vacuum evaporation technique is the most cost effective among all the techniques referred above. With the development of good quality temperature and thickness sensors nowadays it possible to control the thickness and stoichiometry of the thin films very precisely. It is much easier to deposit the elemental constituents using thermal evaporation.

This work reports fabrication of nano dimensional thin films of AlSb employing vacuum evaporation technique and their characterization using XRD, SEM, I-V characteristics and optical measurements.

II. EXPERIMENT

The nanocrystalline AlSb thin films were deposited by vacuum evaporation technique. Thin films of thickness 80±2 nm were grown on glass substrate kept intentionally on different temperatures, i.e. at Room temperature (300K), 400K and 500K. For this high purity (99.99%) aluminum (Al) and antimony (Sb) targets were used. The thickness of the layer of a single element was kept 50±1% in the bilayer structure i.e. 40±1 nm. For cleaning the glass substrate it was ultrasonically cleaned in acetone and then with deionized water. Before the start of the deposition the chamber was pre-pumped down to a base pressure of 10^{-5} mbar. The films grown at RT were annealed for 15 min. at 500K to compare the effect of substrate temperature while preparing the films.

The XRD spectra was acquired with a diffractometer using Cu K_{α} radiation (λ =1.5405 Å) at RRCAT, Indore. Optical transmission was measured in the 200 to 900 nm range by using an UV/VIS/NIR spectrometer (Lambda 950 by PerkinElmer, USA) at INUP, IITB, Mumbai. The surface morphologies of samples were observed by scanning electron microscope (SEM) (EVO 18 SEM from Carl Zeiss, Germany) at INUP, IITB, Mumbai. The I/V measurements were done by using Keithley 4200-SCS set up at INUP, IITB, Mumbai.

III. RESULTS AND DISCUSSION

(a) XRD diffraction analysis

The XRD diffraction analysis (Fig. 1) shows that the diffraction patterns of the three films [grown at different temperatures, RT (300K), 400K and 500K] of AlSb. The plot (a) shows the pattern for bilayer film grown at 300K while the plot (c) is for the films annealed at 500K for 15 min. Plots (b) and (d) shows the XRD pattern for the films grown at substrate temperatures 400K and 500K, respectively. From plots b-d it is seen that the (111) peak is more prominent. The sharpness of the peak increases with the substrate temperature having sharpest peak in the film grown at highest substrate temperature i.e. at 500K. The value of the lattice constant obtained for this sample is very close to the standard value (shown in table 1).

The lattice constants of the films were calculated using the Bragg's formula:

$$2d_{hkl} \sin\theta = \lambda \qquad ....(1)$$

$$d_{hkl} = \frac{a}{\sqrt{h^2+k^2+l^2}} \qquad ....(2)$$

where d denotes the crystal face space, λ is the wavelength of XRD ray, θ is the diffraction angle, h, k, l represent the crystal face index and a is the lattice constant.

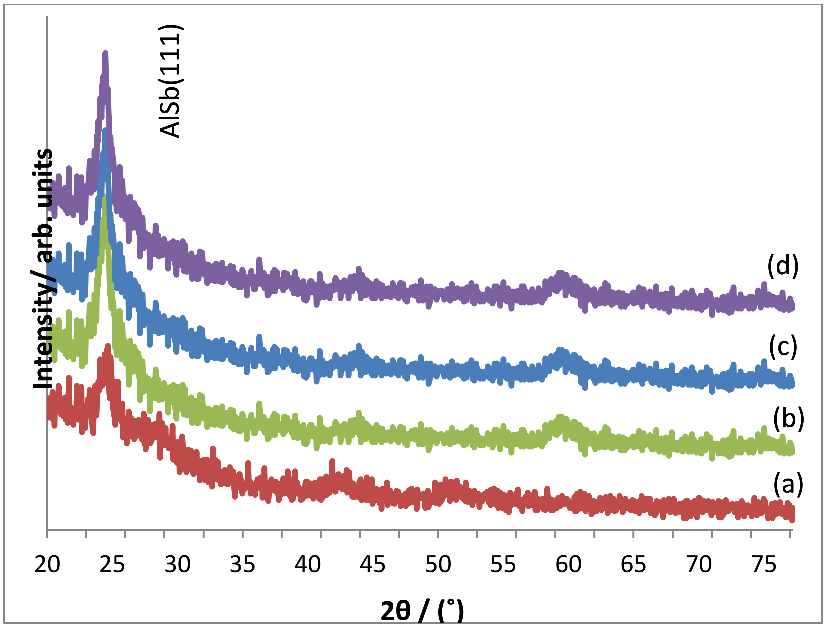


Fig. 1. XRD patterns of nano crystalline thin films of AlSb. (a) for substrate temperature 300K; (b) for substrate temperature 400K; (c) sample 'a' annealed for 15 min at 500K; and (d) for substrate temperature 500K.

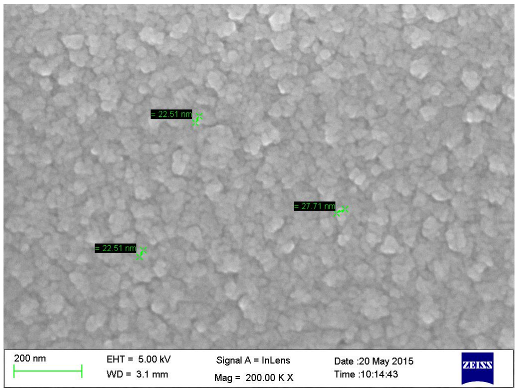
Table 1. Lattice constants of nano crystalline thin films of AlSb

Sample	Description	Lattice constant (in nm)
b	for substrate temperature 400K	0.59445
c	sample 'a' annealed for 15 min at 500K	0.60409
d	substrate temperature 500K	0.60547

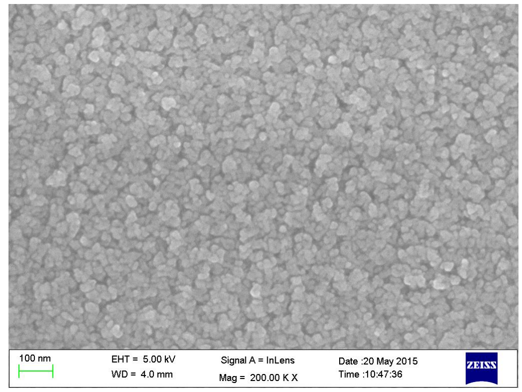
It can be seen that the lattice constant of thin films of AlSb grown at higher temperature is larger than that of grown at 400K. This verifies that the higher temperature of the substrate helps in development of good quality nanocrystalline thin films of AlSb. In the XRD pattern of the films the (111) peaks are the most intense peaks which imply that the crystals grow up preferentially along the <111> direction. Other peaks are very weak in the films. No diffraction peak corresponding to metallic Al, Sb or other compounds was observed in the AlSb thin films.

(b) Surface morphology

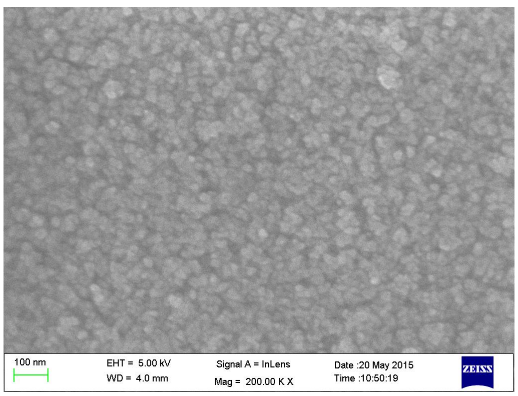
The SEM measurements are carried out to determine the surface morphology of AlSb films. From the SEM measurements in Fig. 2 (a-d) it can be seen that films are continuous, homogeneous with high compactness. The grain size of sample 'd' is a little larger than samples 'b and c' which is in agreement with the XRD results.



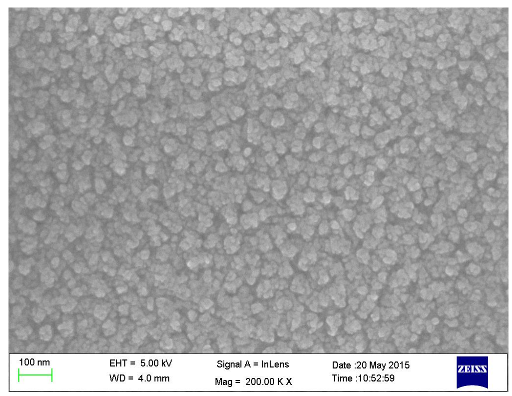
(a)



(b)



(c)



(d)

Fig. 2 Morphology of nano crystalline thin films of AlSb. (a) for substrate temperature 300K; (b) for substrate temperature 400K; (c) sample 'a' annealed for 15 min at 500K; and (d) for substrate temperature 500K

(c) Optical properties

Figure 3 show the transmission (%) vs wavelength spectra for various thin films of AlSb. According to the theory of optical interband transitions (direct or indirect) in solids, near the absorption edge, the absorption coefficient varies with the photon energy 'hυ'. Optical band gap of the films were calculated with the help of Tauc (1974) relation[15]

$$\alpha h\nu = A\left(h\nu - E_g\right)^n \quad \ldots(3)$$

where α is the absorption coefficient, Eg the optical band gap, A is a constant. The exponent 'n' depends on the type of transition and it may have values 1/2, 2, 3/2 and 3 corresponding to the allowed direct, allowed indirect, forbidden direct and forbidden indirect transitions, respectively.

The extrapolation of straight line to $(\alpha h\nu)^{1/2}=0$ axis gives value of the band gap. The value of the optical band gap Eg was taken as the intercept of $(\alpha h\nu)^{1/2}=0$ vs. $(h\nu)$ at $(\alpha h\nu)^{1/2}=0$. The optical band gap derived for the films are 1.58, 1.595 and 1.61 eV, for samples b, c and d, respectively. These values are in a good agreement with the theoretical value of 1.62 eV [4] this fact indicates that the AlSb thin films prepared with optimized deposition parameters using vacuum evaporation technique in the present work have good optical properties.

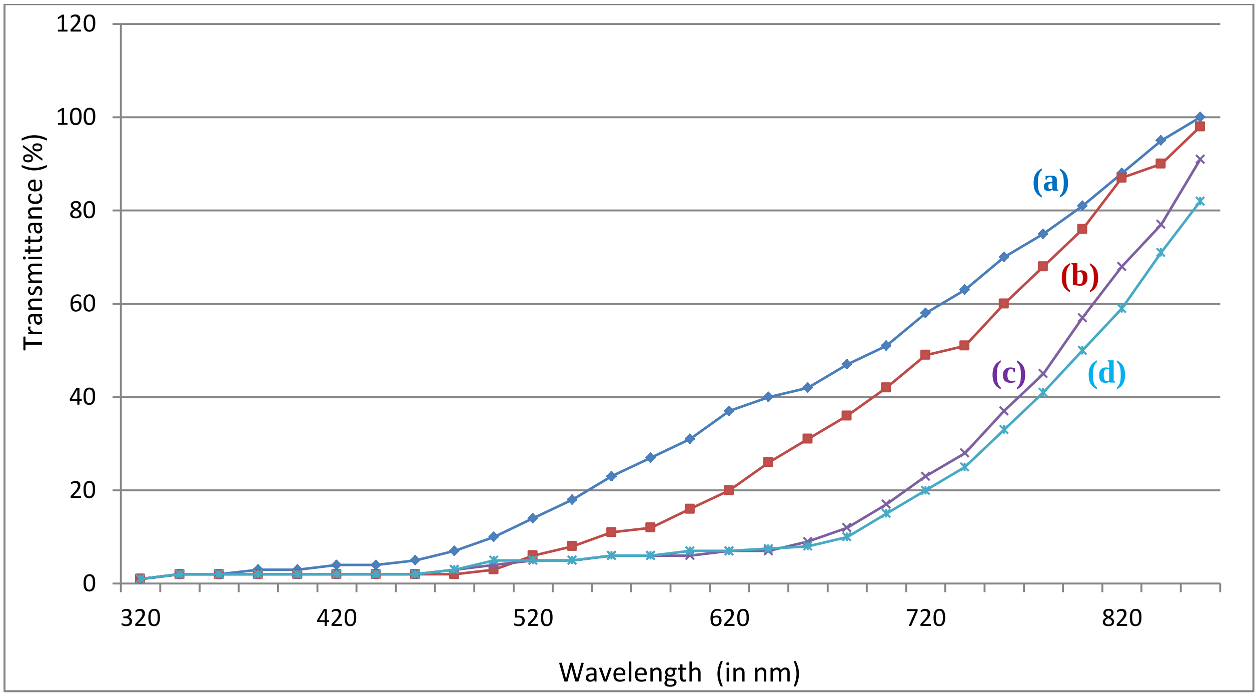


Figure 3 Wavelength v/s transmittance spectrum of the thin films of AlSb

(d) Current voltage (I-V) characteristics

Figure 4 shows graphs plotted for current voltage (I-V) characteristics of the nanocrystalline thin films of AlSb grown at three different temperatures, i.e. at 300K, 400K and 500K, respectively. The plot ‘a’ is for bilayer grown at 300K and ‘c’ is for this bilayer annealed to 500K for 15min, while ‘b and d’ are for films grown at substrate temperatures 400K and 500K, respectively.

It is observed that the films grown at higher substrate temperatures and annealed to 500K (b, c and d films) show low resistance. This is due to the fact that the mixing of bilayer is better it the film is grown at higher substrate temperature.

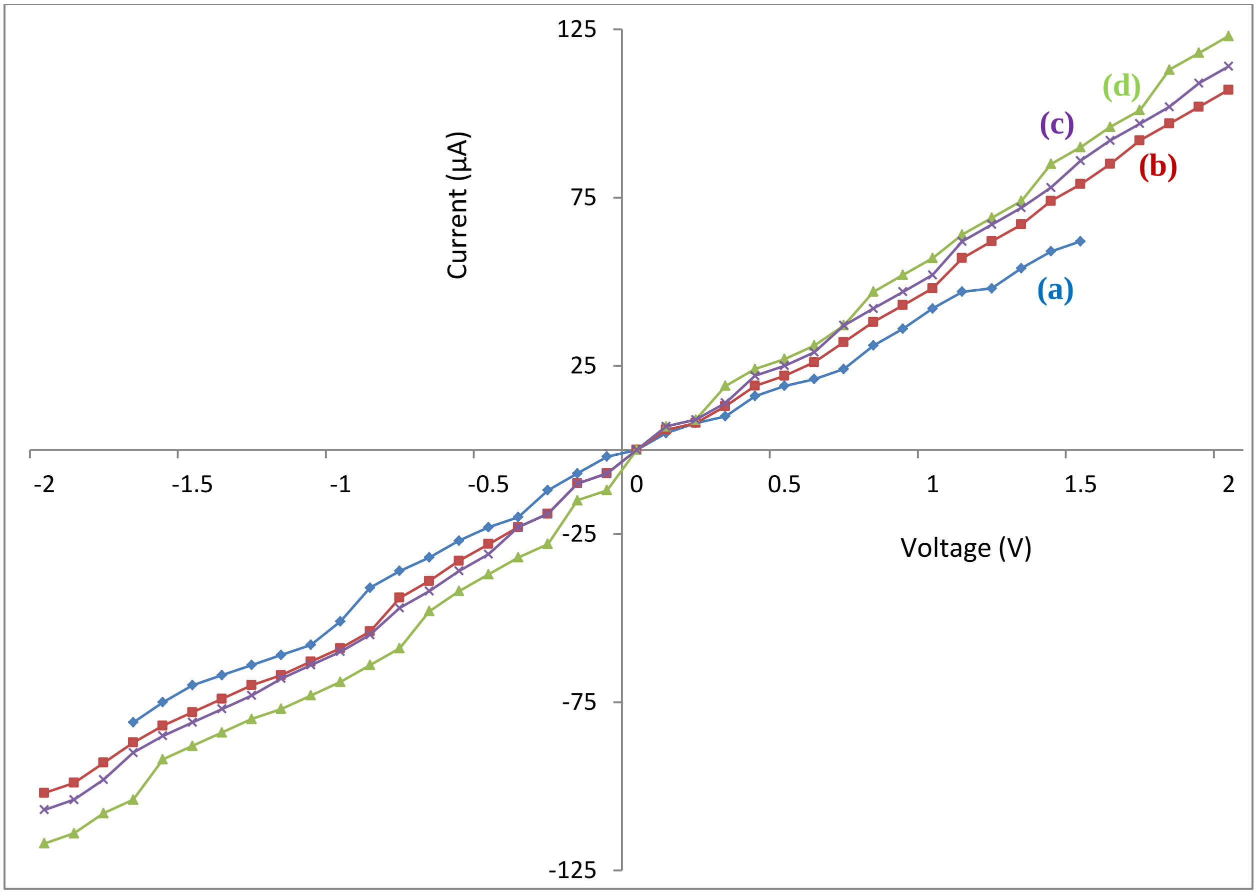


Figure 4 I-V characteristics of nanocrystalline thin films of AlSb.

IV. CONCLUSIONS

The nanocrystalline thin films of AlSb were obtained by vacuum evaporation technique. The films were compared in terms of the variation in structural characteristics and electrical properties. The films which were deposited at higher substrate temperature were having better crystalline nature having most of the crystals oriented along <111> direction. The results indicate that if the films are deposited at higher substrate temperature better quality nano dimensional thin films of AlSb are obtained. The increase in the substrate temperature increased the lattice constant of the films. The lattice constant of the film at higher substrate temperature was found in close accordance to the value reported in the literature. This shows that substrate temperature has a significant role in the preparation of the nanocrystalline thin films of AlSb which is in accordance with the reported work.

ACKNOWLEDGEMENTS

Authors are thankful to The management, Vivekananda Global University, Jaipur; Director, RRCAT and PI, INUP, IITB for extending their research facilities. We are especially thankful to Dr. K. Nageshwari, INUP, IITB and Dr. M. K. Tiwari, RRCAT, Indore.

REFERENCES

[1] G. A. Armantrout and J. H. Yee "AlSb as a potential photovoltaic material", in Proceedings 2nd Photovoltaic Solar Energy Conference, Berlin, West Germany, 960, 1979.

[2] W. Lili, J. Shuo, Z. Guanggen, Z. Jingquan, L. Wei, F. Lianghuan, L. Bing, and W. Wenwu, "Cu doped AlSb polycrystalline thin films", J. Semi., **34(1),** 13003, 2013.

[3] V. Lordi, D. Åberg, P. Erhart, K. Jen Wu, "First principles calculation of point defects and mobility degradation in bulk AlSb for radiation detection application" in Proc. SPIE 6706, Hard X-Ray and Gamma-Ray Detector Physics IX, 67060, 2007.

[4] H. Zheng , W. Li-Li , L. Bing, H. Xia, H. Jian-Xiong, F. Liang-Huan, L. Wei, Z. Jing-Quan, and C. Yap-Ping, "The electrical, optical properties of AlSb polycrystalline thin films deposited by magnetron co-sputtering without annealing", Chin. Phys. B, **19 (12)**, 127204, 2010.

[5] H. Song, J. He, L. Wu, J. Zheng, L. Feng and Z. Lei, "Study on AlSb polycrystalline thin films material", J. Inorg. Mater., **24(3)**, 517, 2009.

[6] R. Linnebach, and K. W. Benz, "Liquid phase epitaxy of aluminum antimonide from antimony solutions", J. Crystal Growth, **55**, 531, 1981.

[7] L. Baufay, R. Andrew, A. Pigeolet and L.D. Laude, "Preparation of AlSb films by laser annealing", Thin Solid Films, **90 (1)**, 69, 1982.

[8] K. Lal, A. K. Srivastava, S. Singh and R. Kishore, "Effect of process conditions on microstructural development during thermal evaporation of AlSb thin films", J. Mater. Sci. Lett., **22 (7)**, 515, 2003.

[9] T. Singh and R. K. Bedi, "Growth and properties of aluminum antimonide films produced by hot wall epitaxy on single-crystal KCl", Thin Solid Films, **312(1/2)**, 111, 1998.

[10] J. He, L. Wu, L. Feng, J. Zheng, J. Zhang, W. Li, B. Li and Y. Cai, "Structural, electrical and optical properties of annealed Al/Sb multilayer films", Solar Energy Materials & Solar Cells, **95(1)**, 369, 2011.

[11] X. Hao, L. Wu, Z. Huang, J. He, L. Feng, J. Zhang, W. Li, Y. Cai and B. Li, "Study on AlSb films deposited by co-sputtering. Asia-Pacific Power and Energy Engineering Conference (APPEEC), 2010: 28.

[12] W. J. Turner and W. E. Reese, "Infrared absorption in n-type aluminum antimonide", Phys Rev Lett, **117(4)**, 1003, 1960.

[13] P. Hill, N. Weisse-Bernstein, L. R. Dawson, P. Dowd and S. Krishna, "Activation energies for Te and Be in metamorphically grown AlSb and $In_xAl_{1-x}Sb$ layers", Appl Phys Lett, **87(9)**, 092105, 2005.

[14] K. M. Yu, A. J. Moll, N. Chan, W. Walukiewicz and P. Becla, "Substitutionality of Ge atoms in ion implanted AlSb", Appl Phys Lett, **66(18)**, 2406, 1995.

[15] D. Shaw, P. Jones and D. Hazelby, "Zinc diffusion in aluminum antimonide", Proceedings of Physical Society, 1962, 80(1): 167.

[16] R. H. Wieber, H. C. Gorton and C. S. Peet, "Diffusion of copper into AlSb", J Appl Phys, **31(3)**, 608, 1960.

[17] G. P. Xia, L. H. Feng, Y. P. Cai, B. Li, J. Q. Zhang, J. G. Zheng and T. C. Lu, "Effect of oxygen on CdS polycrystalline thin films prepared in ambient of Ar and O2 by close spaced sublimation technology", Acta Phys. Sin., **58**, 6465, 2009.

[18] Y. C. Sharma and A. Purohit, "Tellurium based thermoelectric materials: New directions and prospects." Journal of Integrated Science and Technology **4.1**, 29, 2016.