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Electrical and structural properties of flash evaporation InSb thin films

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Abstract

Indium antimonide (InSb) thin films were prepared on glass substrates by flash evaporation technique of a stoichiometric bulk of InSb at different substrate temperatures Ts= (300,320,350)˚C. Films thickness were in the range of t= (0.2 -0.6) μm. X-ray diffraction patterns of InSb powder and thin films were given. The patterns showed that all films were stoichiometric and the crystallinity degree was improved with increasing of the substrate temperature and film thickness.The Hall effect measurements at room temperature showed that all films have n-type conductivity except the film of 0.2 μm thickness prepared at Ts=350 ˚C was p-type conductivity. The electrical conductivity was studied in temperature range (25-200) ˚C and it was decreased with increased the substrate temperature for all samples. The carrier's mobility at room temperature was found to be increased with film thickness and substrate temperature.

Keywords: InSb thin films, Flash evaporation, X-ray diffraction, Hall Effect, Electrical conductivity.

1. Introduction

III-V semiconductors and structures based on them conventionally play a major role in scientific research and application in elbow room of electronics. Among III-V binaries semiconductors compounds, indium antimonide (InSb) which possess many interesting properties such as high electron mobility ~ 40 000 cm^2 /Vs, for 1.5 μm thick of film grown on GaAs substrate at room temperature with very small effective electron mass [1,2] . Thus, InSb is widely used in high speed sensitive sensors, Hall sensors and magneto resistors , millimeter wave devices and magnetic sensors [3-6].

InSb has small band gap (~0.17 eV at 300 K) that corresponds to IR cut-off wavelength (6.2 μm). Therefore InSb is suitable as infrared detectors and filters [7].

InSb films are grown on different substrates such GaAs , InP, Si , Mn-Zn ferrite , by employing a large number of growth techniques like molecular beam epitaxy (MBE) , meta-

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lorganig chemical vapor deposition (MOCVD) , liquid phase epitaxy (LPE) , plasma assisted epitaxial growth (PAEG) and co-evaporation [8-13].

Among all growing methods were used to prepare InSb films; vacuum thermal evaporation is the very simple and inexpensive technique which can be used for large area deposition , but the problem is that of non-stoichiometry also In rich because of loss of antimony which has higher vapor pressure than indium [13,14]. (Please re-write this sentence)
To avoid non-stoichiometry problem a flash evaporation technique is used in the present work to prepare InSb thin films. The effect of thin film's thicknesses and substrate temperatures on the structural and electrical properties of these films were being considered and investigated.

2. Experimental Details

Bulk InSb ingot was prepared by mixing pure In and Sb (99.999%) provided from Fluke company in dividing elements in stoichiometric proportion in a sealed quartz ampoule evacuated to 1×10^{-5} torr pressure.

The sealed ampoule was placed in furnace type Linberg 304 Hart ST at temperature of 1000 K and rotated mechanically for 10 hours. It was slowly cooled to room temperature.
The prepared InSb powder was used to syntheses thin films by flash evaporation technique. Figure 1 show the schematic diagram of the system that has been used.
Cleaned optically flat corning glass substrates at substrates temperature were varied in values (300,320,350) ˚C by temperature control type (ATX3000) joint with substrates holder by nickel-chrome thermocouple .A vacuum of the order of 1×10^{-5} torr was maintained in the chamber of system type Varian 3117 throughout the deposition process and molybdenum boat was used in present work. The dimensions of the films are 25x 75mm. X-ray diffraction (XRD) analysis from Philips X-ray diffractometer PW1253 employing CuKά radiation source was used to obtain information about the films structures.

The electrical characterization was carried out in a conductivity set up coupled with a rotary pump to pump down to 10^{-3} torr. Samples with dimension 5x30 mm were used for study. The variation of current with temperature at constant voltage was studied using silver paste as an ohmic contact.

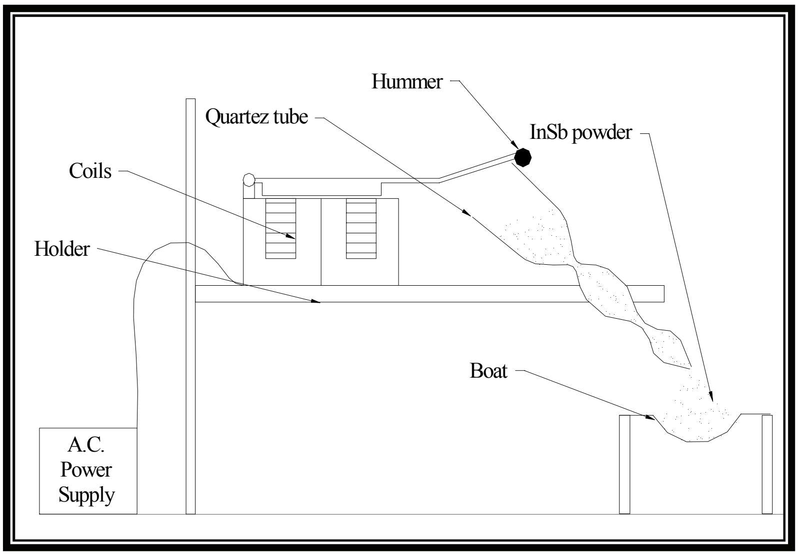

Fig. 1: flash evaporation system.

3. Results and discussion

3.1 Structural properties

Figure 2 shows the X-ray diffraction pattern of InSb powder. Figure 3 shows the X-ray diffraction pattern of some InSb thin films were prepared at different substrate temperatures (300,350) ˚C and different films thicknesses (0.2,0.4,0.6) µm.

We notice that all the films are stoichiometric and all the peaks (planes) are belong InSb phase where the result showed agreement with ASTM data [15]. It has been found from the X-ray diffraction patterns that the powder and thin films are zinc-blend structure (a=b=c).Neither In nor Sb peaks have been noticed in XRD spectrum.

Also we note that increasing of the substrate temperature and film's thickness leads to increasing of peaks intensity and sharpness, indicating that the crystalline structure is improved it could be due to decrease in strain and the dislocation density. By using thermal evaporation technique Senthilkumar et al.[14] notice that the prepared thin films were non-stoichiometric where X-Ray diffraction pattern report Sb and In peaks but the crystallinity of the films also improved with increasing substrates temperatures.

The inter-planer spacing d_{hkl} was calculated and tabulated in Table (1) for (111) plane from the Bragg's relation [16].Mangal and Vijay[17] reported d_{111} value 3.739 Å for vacuum annealed In-Sb thin film which is in a good agreement with our samples (Table 1).

For cubic geometry, the lattice constant (a) is also calculated [16]and listed in Table (1) along with that of ASTM[15]. From Table 1 it is noted that both the lattice constant (a) and $d_{111}$of the films at Ts =300 ˚C are increased with increasing films thickness but at Ts =350˚C these constants are higher for 0.2 µm sample.

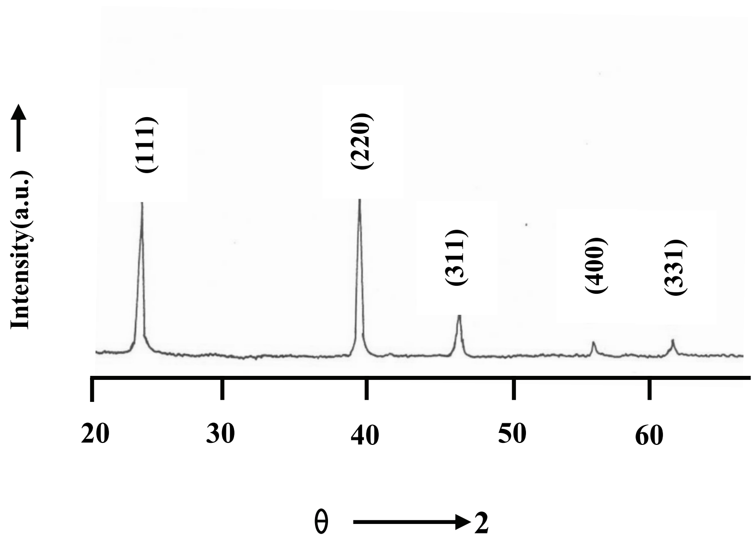

Fig. 2 : X-Ray diffraction pattern of InSb powder.

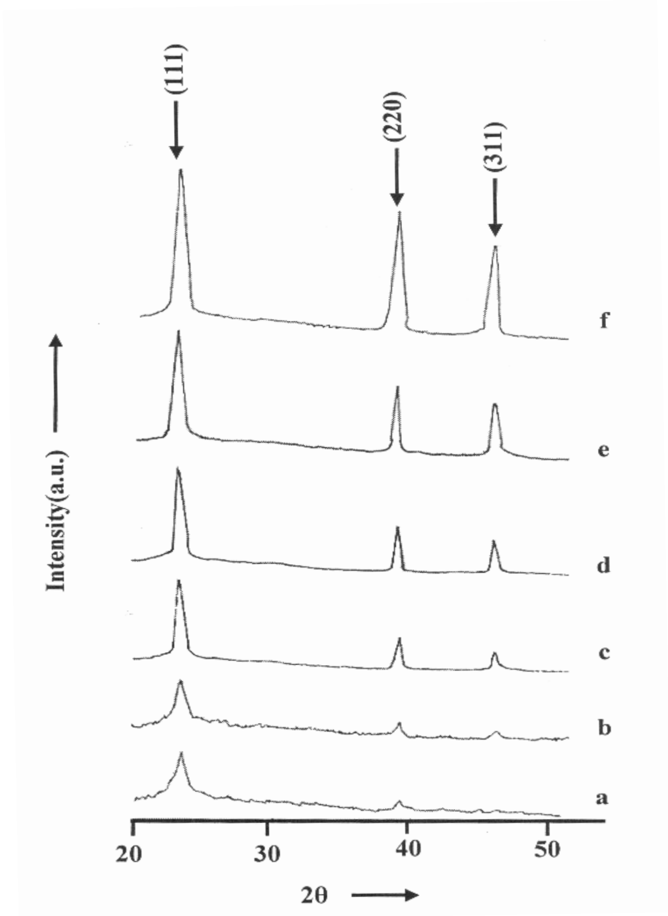

Fig. 3:X-Ray diffraction patterns of InSb thin films : (a) t=0.2µm,T_s=300 ^{0}C, (b) t=0.2µm,T_s=350 ^{0}C, :(c) t=0.4µm,T_s=300 ^{0}C, (d) t=0.4µm,T_s=350 ^{0}C, (e) t=0.6µm,T_s=300 ^{0}C, (f) t=0.6µm,T_s=360 ^{0}C

Films thickness µm	Substrate tem. ^{0}C	Inter-planer spacing d_{111} A^0	lattice constant (a) A^0	Lattice constant (a) of powder A^0	lattice constant (a) standard A^0
0.2	300 350	3.71 3.76	6.42 6.51	6.478	6.479
0.4	300 350	3.73 3.72	6.46 6.44		
0.6	300 350	3.77 3.72	6.53 6.44		

Table 1: structure parameters of films.

3.2 Electrical properties

3.2.1 Hall effect measurements

The Hall Effect of all samples at room temperature was studied to determine the carrier's type as well as their concentration. The Hall coefficient (R_H) for thin films were calculated [18] at intensity of magnetic field (B_Z = 0.2 Tesla).

The Hall coefficient of InSb thin films were negative, so all films were n-type except that of 0.2 µm thickness was p-type at T_S =350 ˚C as shown in figure (4).

The reason of changing in carriers type of this film is may be due to the diffused impurities from the glass substrate inside films such as (Si , Mg , K, Na, Ca, Ba, Al,O) atoms, some of these atoms due to accepters levels in the film's gap[19].

Isia [19] used co-evaporation technique to deposit InSb thin films. Using secondary ion mass spectroscopy he noticed that increasing in substrate temperature to 450˚C led to change in conductivity carrier's type from n-type to p-type.

Also, Senthilkumar et al [14] noted that all films which prepared by thermal evaporation at different T_S =(303, 373, 743) K were p-type because of increasing antimony (Sb) ratio than indium (In) in films (non-stoichiometry thin films).

Flash evaporation method which is used gives good stoichiometry InSb thin films so all films were n-type in agreement with a conductivity carrier type of bulk InSb. We noticed that Hall coefficient R_H was increased with increased T_S, this result also agreed with that obtained by Senthilkumar et al. [14].From figure 5 the carriers concentration **n** decrease – except for 0.2 µm film thickness at Ts=350˚C with an increasing in substrate temperature and films thickness. These results also agree with the results obtained by Senthilkumar et al results [14].

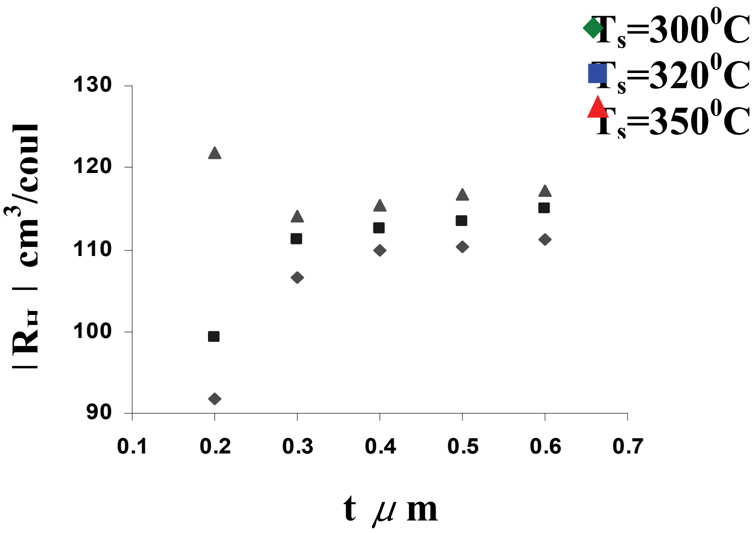

Fig. 4: Hall coefficient Vs. films thickness at different substrates temperature.

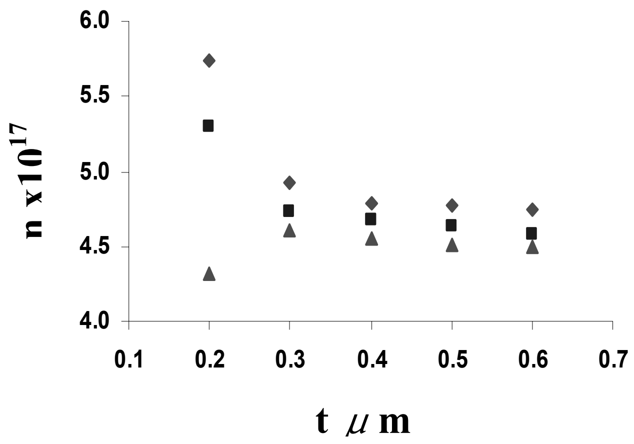

Fig. 5: Variation of concentration with substrate temperature of films at varies films thickness.

3.2.2 Electrical conductivity

The electrical resistivity (ρ) of samples has been determined following the method described by Ref. 20, in the temperature range (25-200) ˚C. Also the electrical conductivity (σ) of the films was obtained as a function of film's thickness at different substrates temperatures.

From figures (6-8) we noticed that the electrical conductivity was decreased with increased the Ts, which leads to increase in the values of the activation energy (Ea), as expected where the films become more crystalline. This is in accordance with the above structural results. That means decreasing in crystal defects due to less localizes levels in film's energy gap. Also activations energy of all samples prepared at different Ts are calculated and tabulated in Table 2. It is also noted that σ_{DC} for n-type film (0.2 μm) is higher than its counter p-type.

The carrier mobility μe of the films is also obtained and found in room temperature from the relation:

$$\mu e = R_H \sigma \quad (1)$$

Carrier mobility depends on predominate scattering mechanism. In bulk semi conductors two scattering mechanisms are dominant; the scattering of carriers by crystal lattice and scattering by a ionized impurities. The carrier mobility due to the lattice vibration can be expressed by:

$$\mu_L = A_L m_{ef}^{-5/3} T^{3/2} \quad (2)$$

and charged ionized centers effect mobility as follows:

$$\mu_I = A_I m_{ef}^{-1/2} T^{3/2} \quad (3)$$

where A_L , A_I ,are the characteristic, m_{ef} denoted to scalar effective mass of charge carriers and T is absolute temperature.

In polycrystalline thin films, free carriers are scattered by the crystallite boundary surface in addition to the scattering mechanisms observed in respective bulk materials [20].

It is found that the carriers mobility μe at room temperature are increased as the film thickness and substrate temperature are increased (figures 8-10) because of increasing in grain size due to less carrier scattering by crystallite boundaries as well as increasing σ_{DC}.

The mobility values obtained here for InSb thin films prepared by flash evaporation technique are greater than (8×10^3 cm²/V.S) [21] and (7.74×10^3 cm²/V.S) [14]. Dixit et al[22] find μe =3.96×10^4 cm²/V.S for n-type InSb films prepared by LPE which is comparable with our value at T_S=350 ˚C .

Motsumoto et al.[22] reached 6500 cm^2/V.S carrier mobility at room temperature for 1 μm InSb films deposited on sapphire (0001) substrate by MOCVD technique and this feature plays an essential role when rapid response to external signal is needed. They also noted that carrier mobility increased as films thickness and temperature are increased.

Indeed, recent studies demonstrated that InSb is one of the thermoelectric materials for practical use [23], as a candidate channel material for future nanoscale FET devices [24]. Using principle of exclusion/ extraction to design InSb MOSFET operating at room temperature [25], undoped InSb Schottky detector for gamma- ray measurements [26] and high-sensitivity InSb thin film micro-Hall sensor arrays for simultaneous multiple detection of magnetic beads for biomedical application [27].

The results obtained above indicate that the films are of high quality, optimized parameters and high mobility. Hence the flash evaporation may be considered as an inexpensive and viable alternative to those obtained from MBE and MOCVD techniques for industrial growth of InSb films and related heterostructures which are important for IR detectors and magnetic sensors.

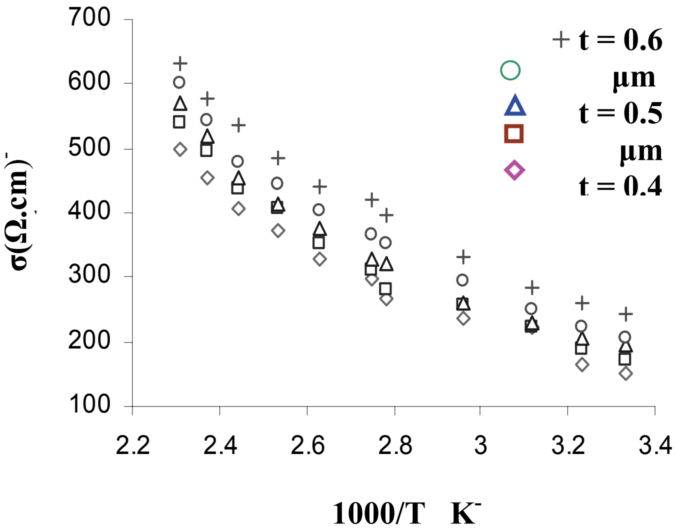

Fig. 5: Variation of conductivity (σ) with temperature of films , Ts =300 ^{o}C.

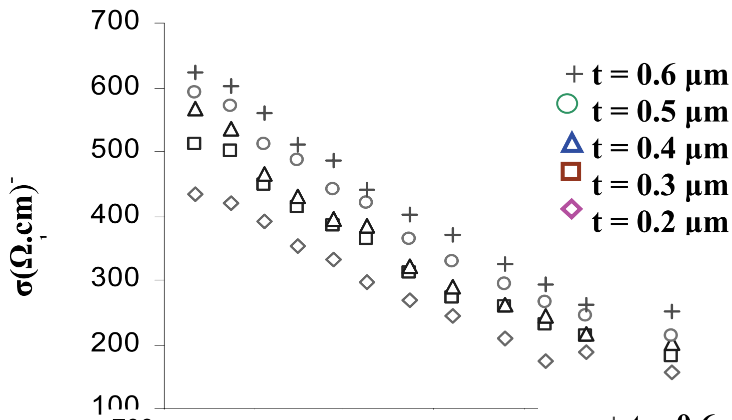

Fig. 6: Variation of cond

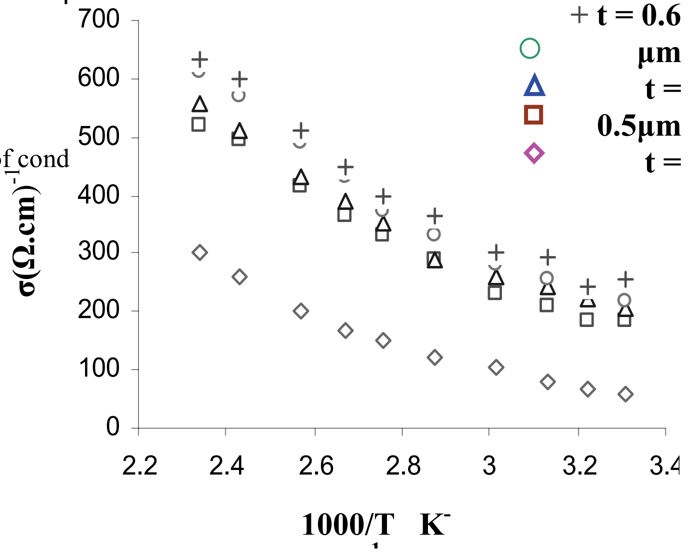

Fig. 7: Variation of conductivity (σ) with temperature of films , Ts =350 °C.

t(µm)	E_a (eV) T_s=300 °C	E_a (eV) T_s=320 °C	E_a (eV) T_s=350 °C
0.2	0.0954	0.099	0.1389
0.3	0.0934	0.0934	0.0967
0.4	0.0878	0.0905	0.0910
0.5	0.0866	0.0874	0.0894
0.6	0.0781	0.0791	0.0802

Table 2: Activation energy of InSb films with different substrates temperature

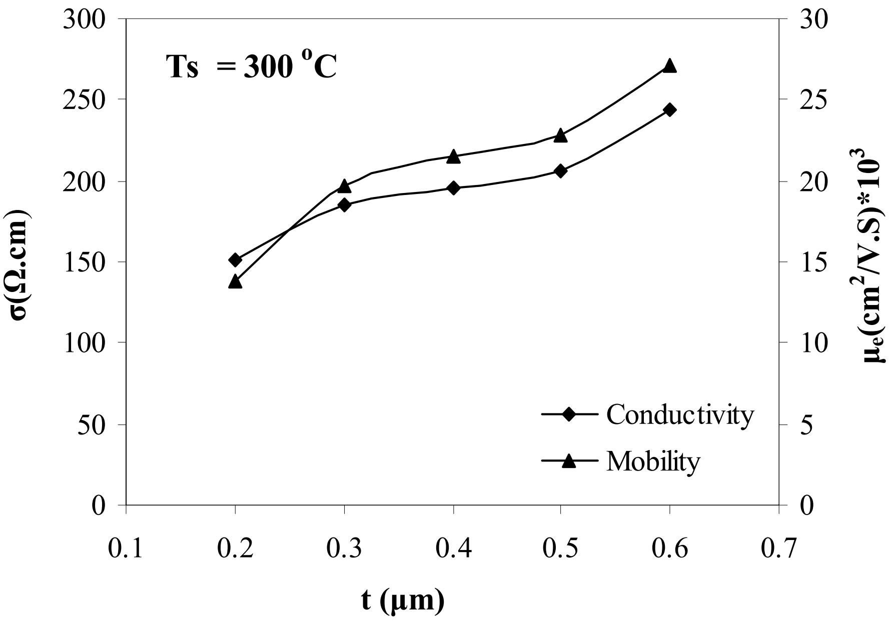

Fig. 8: Electrical conductivity and carrier mobility vs thin films thickness at T_s=300 ^{0}C

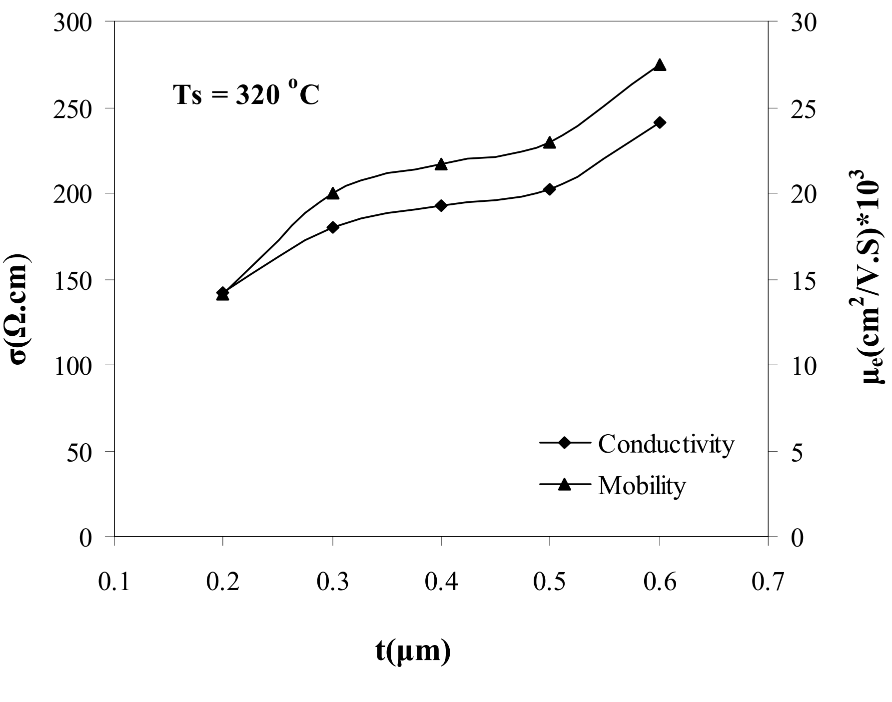

Fig. 9: Electrical conductivity and carrier mobility vs thin films thickness at T_s=320 ^{0}C

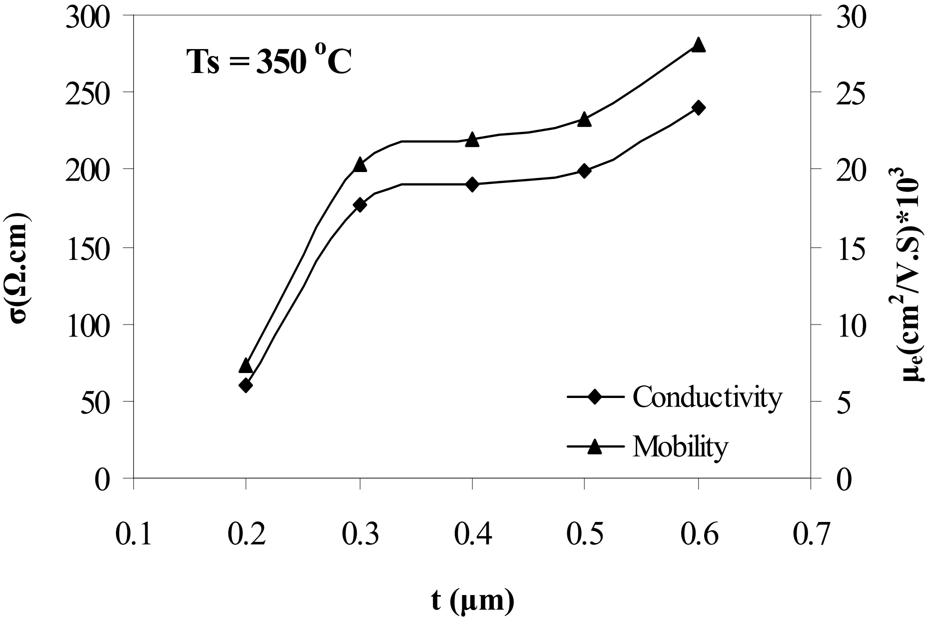

Fig. 10: Electrical conductivity and carrier mobility vs thin films thickness at T_s=350 ^{0}C.

4. Conclusions

InSb thin films were successfully prepared by flash evaporation technique onto well-cleaned glass substrates kept at various substrate temperatures.

The effect of deposition parameters such as substrate temperatures and film's thickness on the film's structure, conductivity type and electrical conductivity were mainly studied and a correlation among them is established.

All films prepared were stoichiometric and the crystallinity improved with increasing substrate temperatures and film's thickness.

The Hall measurements showed that the films exhibit n-type conductivity except the film of 0.2 μm thickness prepared at Ts =350˚C was p-type.

Electrical conductivity was decreased with increasing the substrate temperature for all samples. The carrier's mobility at room temperature was found to increase with increasing both film thickness and substrate temperature.

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