

## Structural and Electrical Properties of InSb Films Prepared By Flash Evaporation Technique

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### Abstract

Indium antimony (InSb) alloy were prepared successfully. The InSb films were prepared by flash thermal evaporation technique on glass and Si p-type substrate at various substrate temperatures ( $T_s = 423, 448, 473$ , and  $498$  K).

The compounds concentrations for prepared alloy were examined by using Atomic Absorption Spectroscopy (AAS) and X-ray fluorescence (XRF). The structure of prepared InSb alloy and films deposited at various  $T_s$  were examined by X-ray diffraction (XRD). It was found that all prepared InSb alloy and films were polycrystalline with (111) preferential direction .

The electrical properties of the films are studied with the varying  $T_s$ . It is found that the electrical conductivity of the films increased with the increase of  $T_s$ , while the activation energies decreased. The Hall Effect measurements showed that the type of all prepared films was n-type .The charge carrier concentration decreased with the increase  $T_s$  whereas, the carriers mobility increased. The drift velocity, mean free path and life time of the deposited films for all the range of  $T_s$  have been determined. From the measurements of the four point probe methods, the sheet conductivity increased with the increase of  $T_s$ .

**Key words:** InSb thin films, D.C conductivity, Hall Effect.

## Introduction

In recent years, searches have been made on various semiconductors to supplement silicon and germanium for use in electric applications. Among many elements appear particularly useful, interest has been focused on compounds formed from group III and V of the periodic Table, such as GaAs, GaP, InSb, etc. [1].

These compounds, such as, InSb has highest electron mobility and smallest band gap with large lattice constant[2], due to these characteristic, it is well established material system for mid- thermal imaging middle wavelength infrared (MWIR) applications, including IR thermal imaging obtained from InSb focal plan array (FPA) on Si, in the (3-5) $\mu\text{m}$  wavelength ranges, military infrared systems, environmental gas monitoring [3], photocell[1], fast automatic recording instruments, infrared photonic detectors ,Hall generator, transport device ,such as magneto resistors ,magnetic sensor[4],glavanomagnetic device[5],high speed electronic devices operating at low temperature, free space communications[6], antenna-coupled infrared detectors, photo-electronic and magnet-electric conversion devices[7,8].

Thin films of InSb may be deposited by different methods like r.f. sputtering, molecular beam epitaxy (MBE), chemical vapor deposition (CVD), flash evaporation and vacuum evaporation[9].InSb films are very attractive for using in application as Hall Effect, magnetoresistance devices, and for tuning in infrared laser and detectors [10].

This paper investigates the effect of substrate temperatures on the structural and electrical properties of prepared InSb films by flash evaporation technique from its prepared alloy.

## Experimental procedure

The compound is prepared as ingots by melting the components together (In and Sb) in stoichiometric proportion. The starting materials used were indium and antimony of high purity (99.9999%). The quartz tube was cleaned, then the appropriate weight of In and Sb were placed in quartz tube which was attached to the evacuated system, then sealed under ( $2 \times 10^{-5}$ ) mbar vacuum [11]. The melting processes were done in an electric furnace type Heraeus. The temperature arises gradually to 1023 K. The furnace still about 12 h to complete the reaction. The temperature then was lowered slowly. The prepared ingots were of size 5.4 cm long and 0.6 cm diameter as shown in Fig.(1).

The flash evaporation technique chosen in the present investigation, because, it ensures stoichiometry in deposited films even at low substrate temperatures [12].The InSb films of 1.0 $\mu\text{m}$  thickness were prepared under pressure  $2 \times 10^{-5}$  Torr. By using Balzer's coating unit model (BAE 370) on corning glass substrates. All the samples were prepared under constant conditions (pressure, rate of deposition and thickness), the main parameters that control the nature of the film structure, is the substrate temperatures, which varied within the range (423-498) K under vacuum of  $2 \times 10^{-5}$  Torr.

The elemental composition of InSb alloy has been measured using Atomic Absorption Spectroscopy (AAS) and X-ray fluorescence (XRF) techniques.

The structure of the alloy and deposited films has been examined by using Siemens X-ray diffraction (XRD) methods, which records the intensity as a function of Bragg angle. The inter planer distance (d) for a different plane (hkl) was measured by Bragg's law [13]:

$$2d \sin \theta = n \lambda \quad (1)$$

where n is the reflection order. The lattice constant (a) estimated from the relation:

$$a = d (h^2 + k^2 + l^2)^{1/2} \quad (2)$$

The InSb grain size dimension (D) could be calculated from diffraction line broadening using the Scherrer equation [13]:

$$D = K_1 \lambda / \beta_1 \cos \theta \quad (3)$$

where  $\theta$  is the diffraction angle,  $K_1$  is the shape factor, which takes value about 0.9;  $\beta_1$  is the line, The D.C conductivity for the films deposited on the glass substrate with Al electrode could be calculated by measuring the electrical voltage and current by using Keithley 616 digital electrometer as a function of temperature range (303-513) K. Also the resistivity of the films deposited at Si p-type substrate has measured by four-point probe techniques by using, Veeco, Fpp-5000, instruments, Inc.

The concentration, type carrier and mobility of InSb films deposited on glass can be obtained using Hall Effect experiment. We calculated the mobility, drift velocity, free mean path and carrier lifetime from the mobility [11].

## Results and Discussion

Table (1) illustrates the theoretical and experimental values of In and Sb concentration in alloy examined by the two techniques XRD and XRF. We can notice that theoretical value was close to that examined by XRF technique.

From the X-ray diffraction pattern of InSb alloy powder we can find that this alloy had polycrystalline structure in nature and it had zinc blend structure and the preferential orientation was in the (111) direction, as shown in Fig.(2). We can observe that values of lattice constant (a) and the grain sizes (D) and  $2\theta$  for InSb alloy nearly similar to that in the ASTM cards as shown in the Table (2) .

The XRD pattern of deposited InSb films of different  $T_s$  is illustrated in Fig. (3). This figure showed the films had two phases amorphous and polycrystalline structure of all samples. This result is in agreement with Senthilkumar et.al.[14] . XRD pattern for film deposited at  $T_s=423$  K appeared no specified orientation. The same behavior noticed for the other substrates temperatures equal to (448,473 and 489) K as shown in part b, c, d of the figure except in the 448 K there is a peak in the (311) direction of small intensity but it disappear in other cases.

We can deduce from Fig. (3), that in general the intensity of peak, (220) is decreased as  $T_s$  is increased with no indication of separate phase during the process of prepared alloys. This implies the compositions of the prepared alloys are stoichiometry and no re-evaporation was occurred from the growing layer of these alloys.

The variation of various structural parameters of the prepared alloys with various  $T_s$  using XRD technique is showed in Table (3). We could explain the variation of grain size (D) with  $T_s$  in according to preferred direction (111) peaks. It decreased with the increase of  $T_s$  from 423 K to 448 K, whereas it increased with increasing the substrate temperature from 448 K to 498 K. This result goes in line with outcomes of other researchers [14-16]. Just opposite to above trade occurred for the peak intensity (111) of the prepared alloys as shown in Fig.( 4) , that is , the peaks intensity is increased with the increase of the substrate temperatures during the range 423 -448 K while its decreased when the substrate temperature increased from 448 K up to 498 K. Same kind of behaviors were nearly found by Rao et.al.[17].

The plots of  $\ln \sigma$  versus  $10^3/T$  at different  $T_s$  (423,448,473, and 498) K for InSb films are shown in Fig.(5).The electrical conductivity is increased with the increase  $T_s$  for all deposited films .It was elevated about two times of magnitude. Other noticeable behavior one can be drawn from Figure 6, there are two values of activation energy in the range of temperature (303-383) K and (393-493) K. Accordingly one can deduce that there are two mechanisms of transport, one at higher temperature range (383-493) K the conduction mechanism of this stage is due to carriers excited into extended states beyond the mobility edge [18] and the second one lies with the range of temperature (303-383) K, this conduction mechanism might be due to carriers excited into the localized states at the edge of the band and hopping [19].

One can draw from the data shown in Table (4) that the activation energies decrease with the increase of  $T_s$  about one and half times, this is might be due to the increase of the density of states in the gap or saturate the dangling bond .Similar behavior was found by Sharma and Reddy [15].

Also the data shown in Table (4) indicated that the activation energy became less than the band gap of the material (0.18eV) with the increase of substrate temperature .This behavior leads to conclusion that the transformation is due to impurity levels which is located within the band gap of InSb films, to valence band. This outcome result is emphasized by M Singh and Y K Vijay [7].

Table (4) moreover illustrates the variation of conductivity at room temperature ( $\sigma_{R,T}$ ) for InSb films as a function of  $T_s$ . These data show that  $\sigma_{R,T}$  of films increased about one order of magnitude with varying  $T_s$  from 423 K to 498 K . It was clear from this Table that  $\sigma_{R,T}$  increased monotonically with the increase of  $T_s$ . This behavior could be attributed to the improvement in the films structure with the increase of  $T_s$ , and this might be due to reduce of dangling bonds, voids and defects. This result is in agreement with Sharma and Reddy[15] .

Hall measurements are carried out to investigate the type of charge carriers, concentration( $n_H$ ) , Hall mobility ( $\mu_H$ ) ,drift velocity ( $v_d$ ) ,lifetime( $\tau$ ) ,and mean free path ( $l$ ) of charge carriers for deposited InSb films at different  $T_s$  .The result of such measurement and calculation is illustrated in Table (5).

We can notice from this Table that the all deposited films at various  $T_s$  have n-type charge carriers. The mobility will the increase of with the increase of  $T_s$  because the coalescence of InSb islands and in turn is producing larger grains with temperature elevation and this leads to increase the Hall mobility of these preparing films The carrier concentration will decrease with the increase of  $T_s$  .This might be due to the increase of the carrier mobility. This result is in agreement with outcomes of results published by Burvenich[20].

A four point prop method was used to measure the sheet resistivity ( $R'$ ), resistivity ( $\rho$ ) and conductivity ( $\sigma$ ) of InSb films deposited on Si p-type wafer at different  $T_s$  . The result of this measurement is shown in Table (6). We can notice from data of this table that the sheet resistivity of the films was decreased with the increase of  $T_s$ , while the conductivity was increased. This might be due to the increase in the density of states as well as the high lattice mismatch and thermal expansion coefficient. This result is in agreement with outcomes of other researcher [20]. Another noticeable remark, shown in Table (6), is that the electrical conductivity ( $\sigma$ ) increased with the increase of the temperature.

## Conclusions

We prepared successfully InSb alloy and then films were prepared by flash evaporation technique. The effect of substrate temperature on structural and electrical properties for prepared InSb films were studied .The outcome of this investigation can be summarized as follows:

- The structure of InSb film was polycrystalline at various  $T_s$  and the preferential orientation was in (111) direction.
- All the samples were prepared at various  $T_s$  were n-type.
- DC conductivity is increased with the increase of  $T_s$ .
- There were two activation energies and they were decreased with the increase of  $T_s$ .
- The carrier concentration of films decreased with the increase of  $T_s$ , while the mobility increased.
- The sheet resistivity of the films was decreased with the increase of  $T_s$ .

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**Table No. (1) Illustrates the composition of InSb alloys by AAS and XRF techniques**

	Theoretical concentration of element%	Experimental concentration of element% by AAS	Experimental concentration of element% by XRF
<b>Sb</b>	50	47.57	50
<b>In</b>	50	52.43	50
<b>Total%</b>	100	100	100

**Table No. (2) The X-ray diffraction parameters of InSb alloys**

2θ	(hkl)	I/I <sub>o</sub> stand.	d stand. (Å)	d exp. (Å)	I/I <sub>o</sub>	a (Å)	D (nm)
23.65	111	100	3.740	3.735	100	6.469	20.278
39.40	220	80	2.290	2.271	77.27	6.424	21.079
46.50	311	55	1.953	1.952	36.36	6.474	21,599
56.82	400	16	1.620	1.619	18.18	6.476	18,056
62.60	331	20	1.486	1.483	7.58	6.463	23.257

**Table No.(3) Parameters form XRD pattern for InSb films versus T<sub>s</sub>.**

T <sub>s</sub> (K)	hkl	I/I <sub>o</sub> stand.	d (Å) stand.	2θ	d(Å) <sub>exp.</sub>	I/I <sub>o</sub>	a(Å)	D(nm)
<b>423</b>	111	100	3.740	23.8	3.734	100	6.467	8.112
	220	40	2.290	44	2.055	60	5.812	25.942
<b>448</b>	111	100	3.740	23.6	3.765	100	6.521	1.308
	220	80	2.290	39.2	2.295	28.57	6.491	14.043
	311	55	1.953	46.2	1.963	19.05	6.511	10.787
<b>473</b>	111	100	3.740	23.8	3.734	100	6.467	1.560
	220	80	2.290	39.3	2.289	53.33	6.474	8.929
<b>498</b>	111	100	3.740	23.7	3.749	100	6.493	1.763
	220	80	2.290	39.4	2.284	30	6.460	8.431

**Table No.(4) The electrical conductivity and E<sub>a</sub> for InSb films versus T<sub>s</sub>**

T <sub>s</sub> (K)	σ <sub>R.T</sub> (Ω.cm) <sup>-1</sup>	E <sub>a1</sub> (eV)	Temp. range (K)	E <sub>a2</sub> (eV)	Temp. range(K)
<b>423</b>	0.0217	0.0916	303-383	0.185	393-493
<b>448</b>	0.0372	0.0671	303-383	0.174	393-493
<b>473</b>	0.0869	0.0594	303-383	0.154	393-493
<b>498</b>	0.1818	0.0576	303-383	0.149	393-493

**Table No. (5) Hall Effect parameters for InSb films versus T<sub>s</sub>**

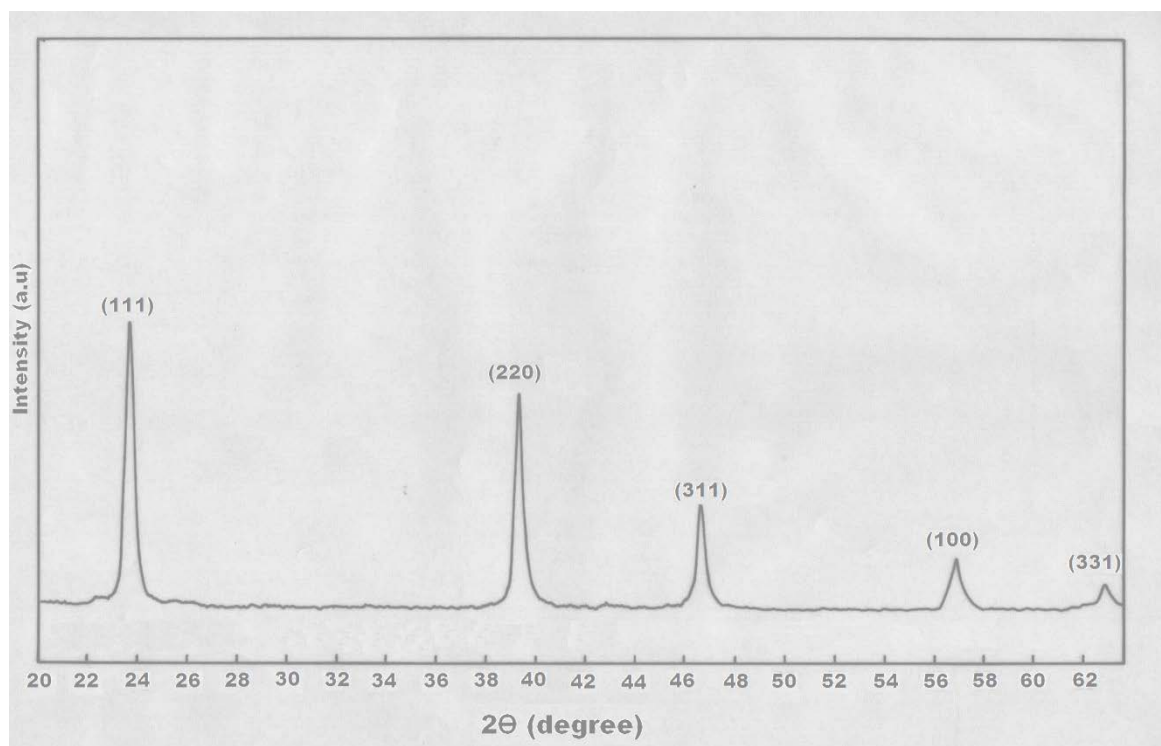
T <sub>s</sub> (K)	n <sub>H</sub> (cm <sup>-3</sup> )	μ <sub>H</sub> x 10 <sup>3</sup> (cm <sup>2</sup> /V.s)	v <sub>d</sub> (cm/s)	τ(s)	l(cm)	type
<b>423</b>	3.210x10 <sup>16</sup>	2.191	483.5	2.0x10 <sup>-9</sup>	9.66x10 <sup>-7</sup>	n
<b>448</b>	1.092x10 <sup>15</sup>	5.176	346.8	3.4x10 <sup>-10</sup>	1.18x10 <sup>-7</sup>	n
<b>473</b>	4.460x10 <sup>14</sup>	25.469	2461.9	1.0x10 <sup>-10</sup>	2.46x10 <sup>-7</sup>	n
<b>489</b>	2.677x10 <sup>14</sup>	53.060	12822.8	3.0x10 <sup>-9</sup>	3.84x10 <sup>-5</sup>	n

**Table No. (6) The variation of sheet resistivity, resistivity and conductivity versus T<sub>s</sub>**

T <sub>s</sub> (K)	R'(Ω/□)x10 <sup>4</sup>	ρ(Ω.cm)	σ(Ω.cm) <sup>-1</sup>
<b>423</b>	1.58	0.375	2.666
<b>448</b>	1.23	0.342	2.923
<b>473</b>	1.01	0.328	3.048
<b>498</b>	0.98	0.228	4.385



**Figure No. (1) As grown InSb ingot**



**Figure No.(2) XRD patterns of InSb alloys**

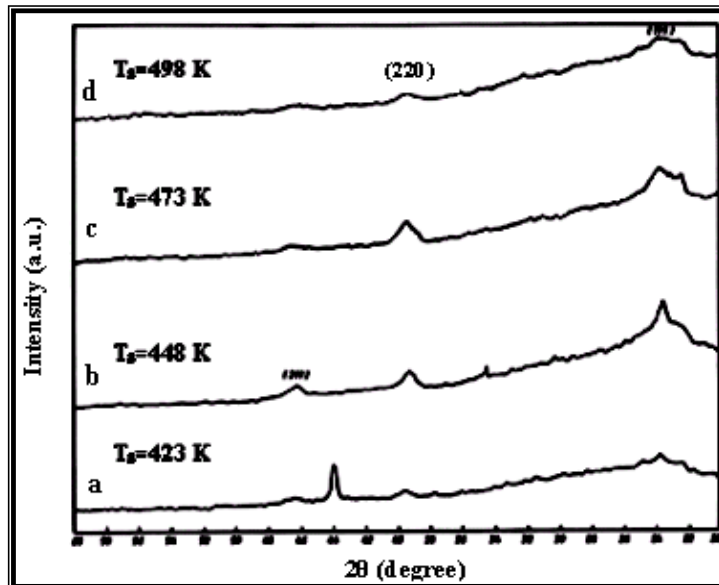


Figure No.(3) XRD patterns of InSb films at different  $T_s$ .

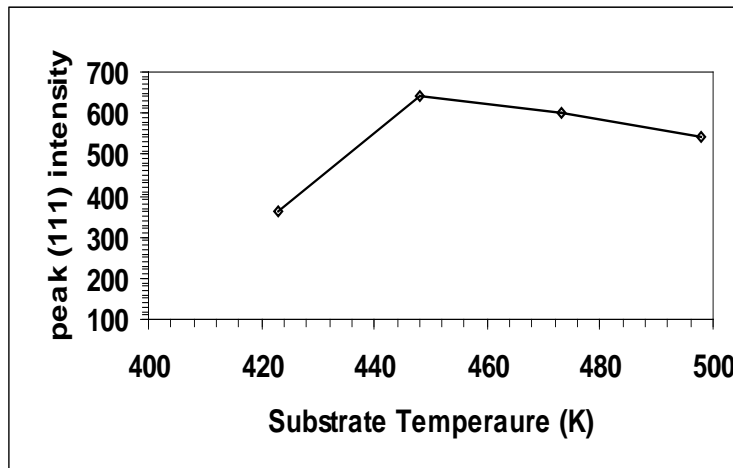


Figure No.(4) The variation of the (111)peak intensity versus  $T_s$ .

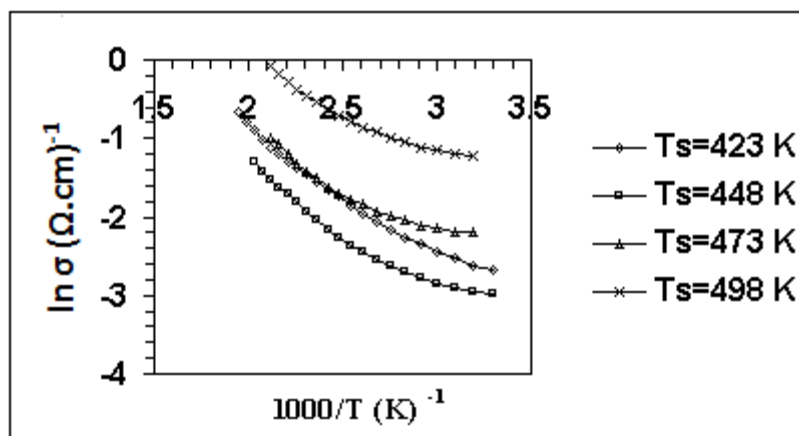


Figure No.(5):  $\ln \sigma$  vs  $10^3/T$  for InSb films versus  $T_s$ .



## الخصائص الكهربائية والتركيبية لأغشية الانديوم انتيمونايد المحضرة بتقنية التبخير الوميضي

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### الخلاصة

حضرت سبيكة الانديوم انتيمونايد بنجاح، وكذلك حضرت اغشية الانديوم انتيمونايد بتقنية التبخير الوميضي على ارضية من الزجاج والسليكون موجب النوع عند درجات حرارة اساس مختلفة (423,448,473,498) كلفن. وحدد تركيز عناصر مركبات السبيكة باستخدام مطياف الامتصاص الذري، وفلورة الاشعة السينية. من تحليل حيود الاشعة السينية تبين ان تركيب السبيكة وجميع الاغشية المرسبة عند مختلف درجات حرارة الاساس ذي تركيب متعدد التبلور، والاتجاه المفضل (111).

دراست الخصائص الكهربائية للأغشية عند مختلف درجات حرارة الاساس، وجد ان التوصيلية الكهربائية للأغشية تزداد مع زيادة درجات حرارة الاساس، بينما تقل طاقة التنشيط.

بينت قياسات هول ان الاغشية المحضرة من النوع السالب تقل تراكيز حوامل الشحنة مع زيادة درجات حرارة الاساس، بينما تزداد حركية الحوامل. عينت الانجراف ومعدل المسار الحر للأغشية المحضرة. من قياسات طريقة المجسات الاربعة تبين ان التوصيلية تزداد مع زيادة درجات حرارة الاساس.

**الكلمات المفتاحية:** اغشية الانديوم انتيمونايد الرقيقة، التوصيلية المستمرة، تأثير هول.