# Effect of Annealing Temperature on The Some Electrical Properties of InSb:Bi Thin Films

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## Abstract:

InSb alloy was prepared then InSb:Bi films have been prepared successfully by thermal evaporation technique on glass substrate at Ts=423K. The variation of activation energies($Ea_1$,$Ea_2$)of d.c conductivity with annealing temperature (303, 373, 423, 473, 523 and 573)K were measured, it is found that its values increases with increasing annealing temperature. To show the type of the films, the Hall and thermoelectric power were measured. The activation energy of the thermoelectric power is much smaller than for d.c conductivity and increases with increasing annealing temperature .The mobility and carrier concentration has been measured also.

**Key words: Thermal evaporation, Activation energy, Thermoelectric power.**

## Introduction:

The recent interest in infrared emitters and detectors operating in the 3-5 μm and 8-12μm atmospheric window range has prompted the search for potentially III-V materials systems. Indeed, considering the present advanced growth and processing technologies associated with III-V compound semiconductors, fabrication of III-V infrared material systems is more appropriate compared to those constructed from II-VI compounds [1, 2].

The interest in doping indium antimonite with bismuth is due to the possibility of decreasing the width of the forbidden band of InSb .It was suggested that the bismuth in InSb not only displaces the antimony, but is also located in interstices which exhibit donor properties and increase the concentration of charge carriers [3].

Upon doping indium antimonite with bismuth a solid solution is formed, in which bismuth both substitutes for antimony and enters into the interstitial positions. The interstitial state of bismuth causes small donor centers to appear[4].

The information about carriers transports and concentration in semiconductor can determined from study d.c conductivity, Hall effect and thermoelectric power.

The results of the work help us to understanding the characteristics of the semiconductor material for using it, in designing electronic devices like, detectors and solar cells.

## Theory:

### 1 . D.C Conductivity:

The d.c conductivity in crystalline semiconductors depends on the presence of free electrons and free positive holes.At 0K the valence band is regarded as filled and the conduction band is empty .As the temperature is raised band are broken and the effect is that free electrons are excited into the conduction band and this leaves behind holes in valence band [5] .

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In amorphous semiconductors the band structures which exhibit the existence of narrow tails of localized states at the extremities of the valence and conduction bands.

Indeed there are two different mechanisms for conduction [6]

**I.** Extended state conduction

**II.** Conduction in localized states

The conductivity for any crystalline or amorphous semiconductors is amenable to the following expression

$$\sigma_{d.cext} = \sigma_{O} \exp\left[-\left(\frac{E_c - E_F}{K_B T}\right)\right] \text{---- (1)}$$

Where:

$\sigma_{d.c\ ext}$: is d.c conductivity in extended states , $\sigma_o$ : is minimum electrical conductivity, $E_c$ : is conduction band energy, $E_F$ : is Fermi energy, $K_B$ : is Boltsmann constant and T : is the absolute temperature.

Conduction in localized states can only occurs by thermal activated hopping to transport the electron from one localized state to another, so that the hopping conductivity($\sigma_{hop}$) is:

$$\sigma_{hop} = \sigma_{Ohop} \exp\left[\frac{-(E_c - E_F) + W_h}{K_B T}\right] \text{--- (2)}$$

Where $W_h$ :is hopping energy and $\sigma_{ohop}$ : is minimum electrical conductivity in localized states.

## 2.Hall Measurement:

The Hall measurement is the most common characterization method used to study the electrical properties such as carrier mobility and impurity concentration, Hall data also provide information on the electrically active impurities in a semiconductor .The Hall mobility is determined by the relation

$$\mu_H = \left|R_H\right| . \sigma_{R.T} \text{---- (3)}$$

where $\sigma_{R.T}$ is the conductivity of the material at the room temperature and $R_H$ is the Hall coefficient ,While the carrier concentration can be determined by the relation

$$n = \frac{1}{\left|R_H\right| . e} \text{---- (4)}$$

where (e): is the electron charge[7].

## 3.Thermoelectric Power:

In studying the conductivity mechanism, it is necessary to know whether the electrons or holes predominant the transport mechanism. The transport subjects to the following relation [8,9]

$$S_{ext} = \pm \frac{k_B}{e}\left[\left(\frac{Ec - E_F}{k_B T}\right) + A\right] \text{…... (5)}$$

Where $S_{ext}$: is Seebeck coefficient in extended states and A is a constant.

This relation represent the conduction in extended states from the other said conduction in localized states (near the mobility edge) will be given by

$$S_{hop} = \pm \frac{k_B}{e}\left[\left(\frac{E_A - E_F}{k_B T}\right) + A'\right] \text{…… (6)}$$

Where $S_{hop}$: is Seebeck coefficient in localized states and $A'$ is a constant.

## Materials and Methods:

Polycrystalline InSb alloy was prepared by mixing of In and Sb high purity (99.999% ) in evacuated quartz tube at pressure of ($10^{-5}$mbar).The tub was sealed and heated in a furnace at (600) K. Thermally evaporated InSb:Bi films when used two tungsten boats for both of InSb and Bi, were prepared. The InSb:Bi films were deposited on glass substrate with (0.3 cm) distance between two electrodes and (0.2 cm ) width of electrodes . To study influence of the temperature on the electrical conductivity we used digital electrometer keithley (616) for resistance measurement. We can calculate the activation energy Ea from the equation [10].

$$\sigma = \sigma_o \exp\left(-E_a / k_B T\right) \text{ ---- (7)}$$

The charge carrier concentration (n) was determined by using equation (4) and Hall mobility $(\mu_H)$ at room temperature by equation (3). The Seebeck coefficient (S) was calculated from the relation :

$$\mathbf{S} = \frac{\Delta \mathbf{V}}{\Delta \mathbf{T}} \text{ ---- (8)}$$

where V: is the voltage and T is a temperature.

## Results and Discussion:

### 1. D.C. Conductivity

The activation energies ($Ea_1$&$Ea_2$) have been studied as a function of different $T_a$ for films prepared by thermal evaporation at $T_s$= 423 K from the variation of lnσ vs. 1000/T as shown in figure(1), different mechanisms of conduction can be seen and that is familiar in amorphous materials and have been discussed in detail by Mott and Davis[11]. The activation energies increases with increasing annealing temperature as shown in figures (2&3). This behavior could be explained as follows ,the annealing processes makes reduction to the density of dangling bonds, which leads to increase optical energy gap and activation energy ,whereas the carrier concentration decreases, this caused a decrease in the $\sigma_{R.T}$[11].

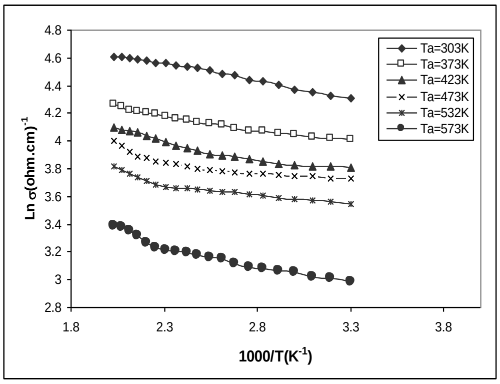


**Fig.(1) The variation of Lnσ vs. 1000/T**

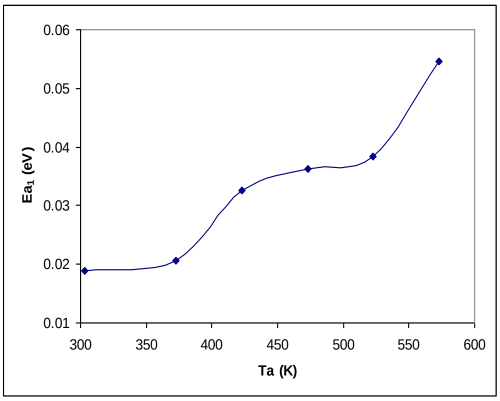


**Fig. (2) The variation of $Ea_1$ vs. annealing temperature.**

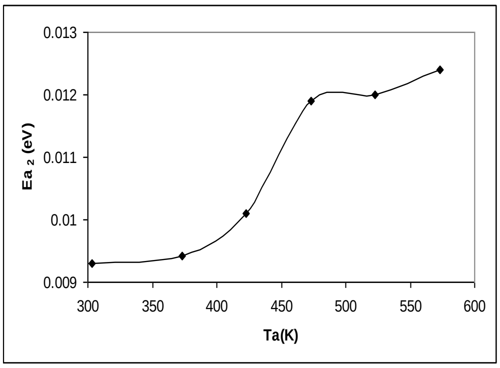


**Fig. (3) The variation of $Ea_2$ vs. annealing temperature.**

## 2. Thermoelectric Power

Figure (4) shows the variation of thermoelectric power with temperature for films at the same conductions. We can see that the values of S are negative for all films which indicate that electrons are the majority charge carriers. We also observe the values of S are a stable for decrease and increase with increasing Ta. By drawing the activation energy of the thermoelectric power $E_s$ with annealing temperature we can see that the increase $E_s$ with increasing Ta as shown in figure (5) this behavior is resulting from decreasing in the density of the localized states and improvement the structure of the films [12].

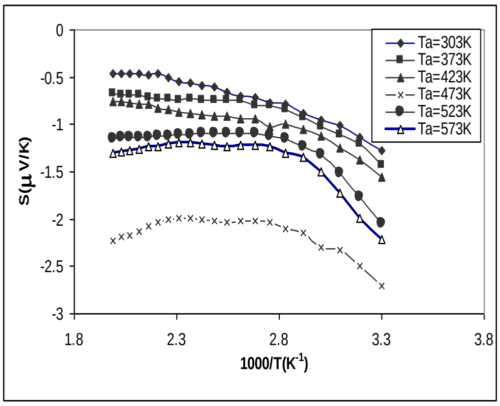


**Fig.(4) The variation of S vs. 1000/T**

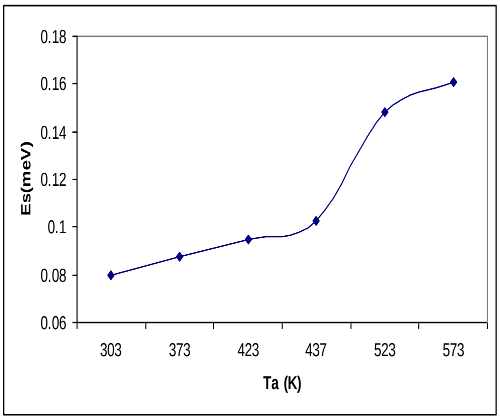


**Fig. (5) The variation of Es vs. annealing temperature**

## 3. Hall Effect:

Hall measurements for all films an n-type has been conductivity observed by the incorporation of Bi which is believed to substitute for Sb in the InSb lattice [6].

Figure(6) shows the increase of mobility from ( 3284.8 up to 28081.8 ) $cm^2/Vs$ as the Ta increases. The electron concentration decrease from $2.98\times10^{17}$ down to $7.53\times10^{16}/ cm^3$ with the increasing of Ta from R.T. to 573K as shown in figure (7).

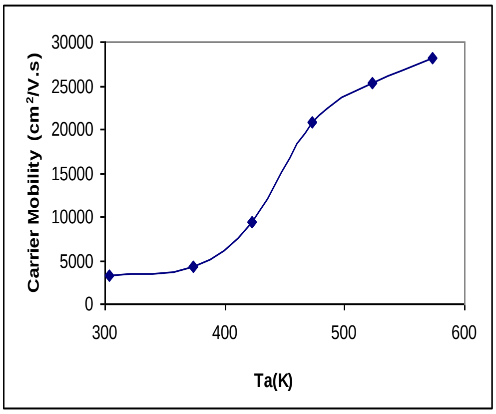


**Fig. (6) The variation of mobility vs. Ta .**

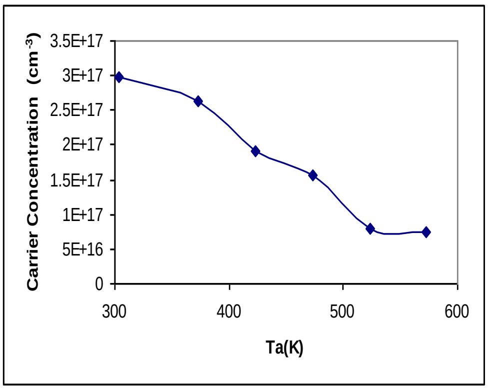


**Fig. (7) The variation of carrier concentration vs. Ta**

## Conclusion:

1-InSb:Bi thin films were prepared by thermal evaporation method.
2-All the films were n-type.
3- The concentration of charge carriers, behavior of the mobility and the activation energies were changed after annealing.

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# تأثيردرجة حرارة التلدين في بعض الخصائص الكهربائية لأغشيةInSb:Bi

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**الخلاصة:**

تم في هذا البحث تحضير سبيكة InSb ثم حضرت أغشية InSb:Bi بنجاح باستعمال طريقةالتبخير الحراري على ارضية من الزجاج وبدرجة حرارة Ts= 423K وتم حساب طاقات التنشيط للتوصيلية المستمرة ($Ea_1,Ea_2$) للاغشية المحضرة عند درجات حرارة تلدين K (573,523,473,423,373,303) بينت النتائج ازدياد طاقات التنشيط مع زيادة درجة حرارة التلدين. أجريت قياسات هول والقدرة الكهروحرارية لمعرفة نوع الاغشية وكذلك تم حساب طاقة التنشيط للقدرة الكهروحرارية ووجد أنها اقل بكثير مما للتوصيلية المستمرة (d.c) كما أنها تزداد بزيادة درجة حرارة التلدين وكما تم حساب تحركية وتركيز حاملات الشحنة.