

# Effect of Annealing Temperature on the Electrical Conductivity of Amorphous InAs Thin Films

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## Abstract

In this research the electrical conductivity measurements were made on the amorphous InAs films prepared by thermal evaporation method in thickness 450 nm and annealed in different temperatures in the range (303- 573) K.

The electrical conductivity ( $\sigma$ ) showed a decreasing trend with the increasing annealing temperature, while the activation energies ( $E_{a1}$ ,  $E_{a2}$ ) showed an opposite trend, where the activation energies are increased with the annealing temperature.

## Introduction

In recent years, metal or semiconductor thin films were the topic of an extensive research to reveal the effects of their disordered structure on their physical properties. In particular, the analysis of the electrical characteristics has in some cases shown a typical behaviour of an amorphous structure for both metallic and semiconducting films. [1-3]

The III-V semiconducting compounds, such as InSb and InAs, appear to be the most suitable materials for this type of study because of the characteristics of their energy bands and charge carriers. [4-8]

It would be of interest to study the electrical conductivity of InAs and correlate the data with other properties so that a coherent picture of the physical nature of the material may be obtained. We have already reported [9,10] on the A.C.conductivity and Hall effect measurements on a-InAs films obtained at different deposition parameters like film thickness and annealing temperature.

Different authors have used different techniques to obtain InAs films, viz.sputtering [4], electro deposition [11], chemical deposition and heating with a vacuum deposited [12], flash evaporation [13] etc, but the studies on the properties of vacuum evaporated InAs films are very limited because of the tendency of the material to dissociate at its melting point, which makes it difficult to obtain stoichiometric films.

In this paper, thermal evaporation technique was chosen to obtain a-InAs films as it ensures stoichiometry, and studied the electrical conductivity behaviour of these films as a function of annealing temperatures.

## Experimental

Thin InAs films in the thickness 450 nm were obtained on glass substrates from InAs alloy which is prepared by fusing the mixture of the appropriate quantities of the elements of high purity (99.999 %) in evacuated fused quartz ampoules at 1273 K. The ampoules were kept at this temperature for [5-6] hours from the optimum temperature, then the ampoules quenched rapidly in cold water.

These films were prepared by thermal evaporation in a high vacuum system of ( $3 \times 10^{-6}$ ) torr by using Edward coating unit model E 306 A from molybdenum boat heated to 1273 K.

The source to substrate distance was maintained at 15 cm to obtain uniformly thick films. The rate of deposition was about 1 nm/sec.

Annealing processes were carried out on these films at different temperatures of (373, 423, 473, 523, and 573) K for one hour.

Electrical conductivity measurements for all samples prepared (before and after heat treatment) includes studying the variation of resistivity with temperature range (303-503) K by using Keithly model 616. The resistivity ( $\rho$ ) of the films is calculated by using the following equation [14]:-

$$\rho = R.A/L \dots\dots\dots (1)$$

- Where, R: is the resistance.
- A: is the area of the film (W.t).
- W: is the width of the electrode.
- t: is the films thickness.
- L: is the distance between the electrodes.

Then the conductivity of the films was determined by using the equation:-

$$\sigma = 1/\rho \dots\dots\dots (2)$$

The activation energy ( $E_a$ ) could be calculated using the formula (14): -

$$\sigma = \sigma_0 \exp (-E_a / k_B T) \dots\dots\dots (3)$$

- Where  $\sigma_0$ : is constant, but change slowly with temperature.
- $k_B$ : is Boltzman's constant.
- T: is absolute temperature in kelvin.

**Results and Discussion**

The electrical resistance (R) of a- InAs films deposited at and around room temperature (~303 K) were found ( $67.2 \cdot 10^6$ ) ohm, this result is in agreement with A.Mavrokefalos et al. [15]

**a-Electrical conductivity and annealing behaviour**

Fig.1 shows the electrical conductivity of a- InAs films with thickness 450 nm, as a function of temperature for different films with variable annealing temperature ( $T_a$ ). This figure appears to separate two temperature ranges characterized by different conductivity slopes.

At low temperature range (303-383) K, the conduction mechanism due to carriers excited into the localized states at the edge of the band by hopping and at other range of temperature (383-503) K the conduction mechanism due to carriers excited into extended states beyond the mobility edge by thermal excitation. [16]

Fig.2 and table (1) shows the electrical conductivity ( $\sigma$ ) of a-InAs (450 nm thick) as a function of annealing temperature ( $T_a$ ). The noticeable remark is that the electrical conductivity decreases with increasing the  $T_a$ . It is decreased from ( $6.61 \cdot 10^{-4}$ )  $\text{ohm}^{-1} \cdot \text{cm}^{-1}$  at  $T_a=303$  K to ( $8.67 \cdot 10^{-5}$ )  $\text{ohm}^{-1} \cdot \text{cm}^{-1}$  at ( $T_a=573$  K). We can notice that the decreasing trend in ( $\sigma$ ) upon increasing  $T_a$ , is in agreement with our result on Hall effect measurements (10). The Hall mobility and carriers concentration showed an decreasing trend with annealing temperature.

This behavior can be attributed to the improvement in the films structure with increasing  $T_a$ , due to reducing of dangling bonds, and defects like vacancy sites.

**b-Activation energies**

Activation energies ( $E_{a1}$ ,  $E_{a2}$ ) were calculated from  $\ln\sigma$  vs  $1/T$  plots for a-InAs films in the temperature range (303 – 503) K.

Fig.3 shows the behaviour for a 450 nm thickness film formed at different annealing temperature ( $T_a$ ). It is clear from this figure that the activation energies for a film treated at a higher annealing temperature were higher than those treated at lower annealing temperature.

The increasing trend in  $E_a$  upon increasing annealing temperature is due to the decreasing voids, dangling bonds, and localized states through energy gap which seems larger after heat treatment.

## Conclusions

In conclusion, we studied in detail the influence of annealing temperature on the electrical conductivity of a-InAs thin films.

The experimental results obtained in this work indicate that the electrical conductivity decreasing with increasing annealing temperature, while activation energies shows as increasing behaviour with increasing annealing temperature .

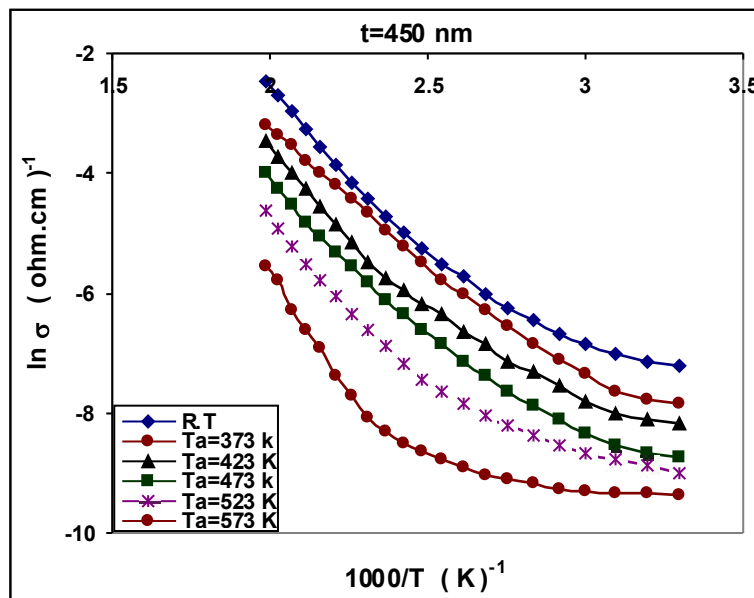
Finally, we should mention that the behavior of the electrical conductivity as a function of temperature is a result of the community between two mechanism of transport, hopping charge transport between localized gap states near Fermi level and charge transport to extended state beyond the mobility gap.

## References

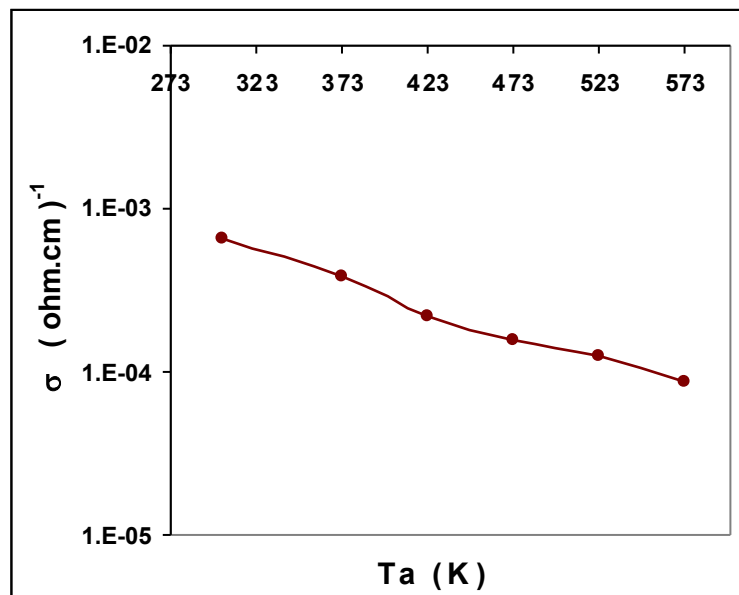
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**Table (1):**Listed the value of  $\sigma$  at a given annealing temperatures  $T_a$  for thermal evaporated a-InAs films.

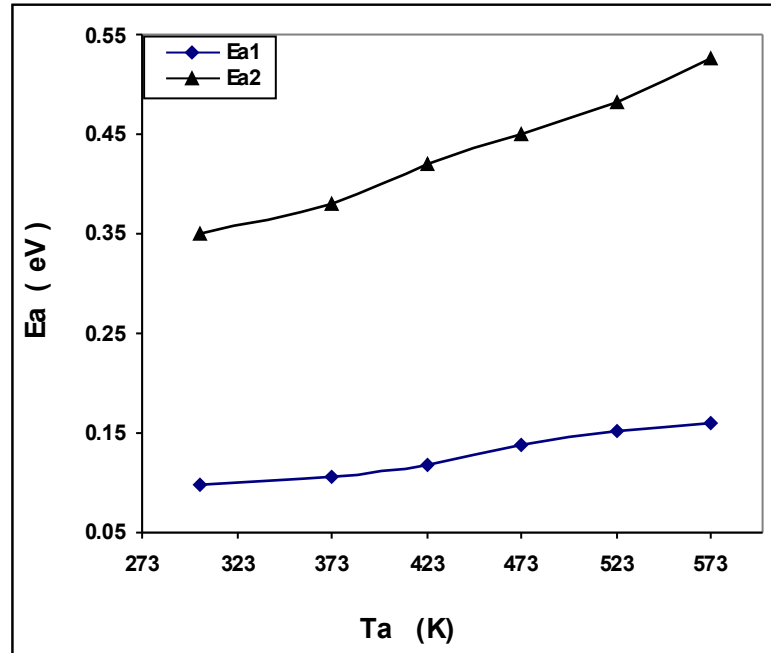
Annealing temperature $T_a$ (K)	$\sigma * 10^{-4}$ $\text{ohm}^{-1}.\text{cm}^{-1}$
303	6.61
373	3.86
423	2.22
473	1.58
523	1.25
573	0.867



**Fig.(1):**Plot of  $\ln \sigma$  versus  $1000/T$  of 450 nm thick InAs films treated at different annealing temperature.



**Fig.(2):**Electrical conductivity as a function of annealing temperature for a 450 nm thick InAs films.



**Fig.(3):** The variation of the activation energies ( $E_{a1}$ ,  $E_{a2}$ ) versus the annealing temperature for a 450 nm thick InAs films.

## InAs تأثير درجة حرارة التلدين في التوصيلية الكهربائية لأغشية العشوائية

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### الخلاصة

في هذا البحث أجريت قياسات التوصيلية الكهربائية لأغشية InAs العشوائية والمحضرة بطريقة التبخير الحراري بسمك 450 nm وعند درجات حرارة تلدين مختلفة (303 – 573) K . وقد لوحظ نقصان التوصيلية الكهربائية مع زيادة درجات حرارة التلدين ، بينما أظهرت طاقات التنشيط سلوكا معاكسا ، إذ ازدادت طاقات التنشيط مع زيادة درجة حرارة التلدين .