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Research Article

Dependence of Conductivity and Carrier Mobility on Thickness and Annealing Temperature of a- Ge:Sb Films

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Abstract

Ge weight doping percentage by 1% antimony (Ge:Sb) films have been deposited by thermal evaporation technique on glass substrate at room temperature under vacuum of 10^{-5} *mbar with rate of deposition near to 10Å/sec. These films of different thickness (0.25, 0.5, 0.75, 1.0) µm have been annealed at different temperatures* T_a *(373, 473)K, to study the effect of thickness and annealing temperature on the electrical properties. These properties include the (DC, AC) conductivity from which the transport mechanism of the charge carriers can be estimated, and also the Hall Effect which gives information about the type, density and mobility of carriers.*

Keywords: *Thin film, electrical properties, Hall mobility, annealing temperature, Ge:Sb thin films*

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1. Introduction

Germanium (Ge) has been one of the most materials of studied as its properties benefit many pplications. The researchers showed that wide ranging control of the electronic properties of amorphous Ge could be an achieved by substitutional doping, thus leading to the development of amorphous emiconductors devices.

The characteristic of a-Ge thin film depend sensitively on the many deposition parameters (deposition method, nature and kind of substrate, substrate temperature, rate of deposition, impurities in the starting material, etc.) and post deposition by annealing treatments (Spear W.E. *et al*, 1975; M. Jamet *et al*, (2006).G.M. Beensh-Marchwicka *et al*.(2001) observed that pulse magnetron sputtered antimony (Sb)-doped Ge films deposited at low temperature showed n-type behavior with high resistivity, but when deposited at high temperature showed p-type of lower resistivity.

H. Watakabe *et al*, (2006) studied the electrical properties of 0.05µm thick polycrystalline germanium films formed on quartz substrate by method of plasma sputtering. They observed that the density of defect states at grain boundaries in the poly-Ge films was a low of 1.1 × 10^{12} cm^{-2}.Izzat M. AL-Essa *et al.* (2009) studied the electrical properties of a-Ge on glass substrate evaporated by thermal technical. They found that the electrical conductivity of a-Ge films increases with increase film thickness but the activation energy gap decreased. Abdul F.K. *et al*.(2010) deposited Ge thin films with a thickness of about 110 nm by electron beam evaporation of pure Ge powder and annealed in air at 100–500 C for 2 h. A. A.Shehab *et al*.(2011) studied the effect of annealing temperature on the structure of a-Ge films doped with Sb and the electrical properties of a-Ge:Sb/c-Si heterojunction fabricated by deposition of a-Ge:Sb film on c-Si by using thermal evaporation. They found thatThe variation of built-in potential (Vbi) from(0.589 to 0.893) Volt when annealing temperatures changes from RT to 473 K. V.F. Mitin *et al.* (2012) studied a profound effect of film growth rate on the electrical properties and surface morphology of thin Ge films grown on GaAs(100) were prepared by thermal evaporation technical at 500°C. All the Ge films under investigation were single-crystalline and epitaxially-grown on the GaAs(100) substrates. The transport phenomena in Ge films grown at low and high deposition rate differed drastically. Those obtained at low deposition rate were *p*-type and high resistant.

In this paper we investigated the effect of thickness and annealing temperature on the electrical properties.

2. Experimental

Ge:Sb thin films were prepared by thermal evaporation technique in vacuum system supplied by Blazers Model [BL 510]. Thin films of a-Ge:Sb deposited on glass substrate .

All samples were prepared under constant condition (presser, substrate temperature and rat of deposition).

The electrical conductivity has been measured as a function of temperature for Ge:Sb films in the range

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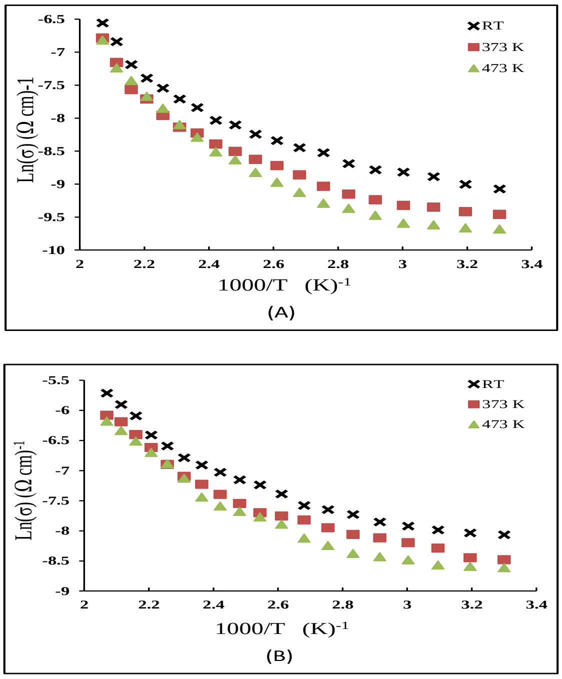
(303 – 483)K by using the electrical circuit. The measurements have been done using sensitive digital electrometer type keithley (616) and electrical oven. For ac- measurement, HP-R2C unit model (4275 A) multi frequency LCR meter has been used to measure the capacitance (C) and resistance (R) with frequency range between 100Hz-100kHz, with an accuracy of 0.1% . AC instrument is shielded by the copper sheet to avoid the distortion signal, and to prohibit the connectors among the experimental portion from becoming a source of noise by using coaxial cables and BNC connectors were used. Hall Effect measurements have been done by Van der Pauw (Ecopia HMS-3000)

3. Results and discussion

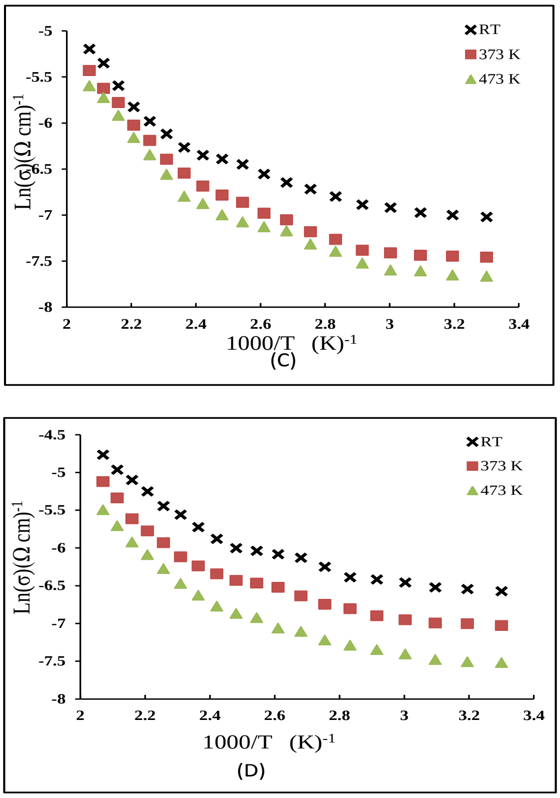
It is known that the study of the temperature dependence of the electrical conductivity of thin films may offer much information about the correlation between the structure and the electrical properties of the films.

The (d.c) conductivity for a-Ge:Sb thin films has been studied as a function of temperature with the range of (303-483) K for different thicknesses(0.25, 0.5, 0.75, 1.0)µm and annealing temperatures (RT, 373, 473)K. Fig.(1) show the relationship of the logarithm of the D.C conductivity (ln σ_{dc}) as a function of 1000/T for Ge:Sb thin film. It is found from this Fig. there are three mechanism of activation energy (E_{a1}, E_{a2} and E_{a3}), the first one at lower temperature range (303-363)K this mechanism due to electronic hopping between the localize state inside the extended state ,the second mechanism at(363-433)K due to carrier excited into localized states at the edge of the band and the third mechanism at higher temperature range (433-483)K this conduction mechanism is due to carrier excited into the extended states beyond the mobility edge.



(A)

(B)



(C)

(D)

Figure (1): Ln σ versus 1000/T for a-Ge:Sb films with different thicknesses (A): 0.25µm, (B): 0.5µm, (C): 0.75µm, (D): 1.0µm and annealing temperatures (RT, 373, 473)K

In Fig. (2) we show the relation between the $\sigma_{R.T}$ and film thickness with difference annealing temperature. From this figure we observe that the d.c conductivity increases with increasing thickness due to the concentration of vacancies defect in amorphous film is increased with increases thickness. The vacancies defect that lead to generate carriers in the films. The degree of localization of electrons increases with the increase in cation concentration there by increasing the number of donor centers. A large concentration of donor centers, effectively increase the electrical conductivity in thicker samples.

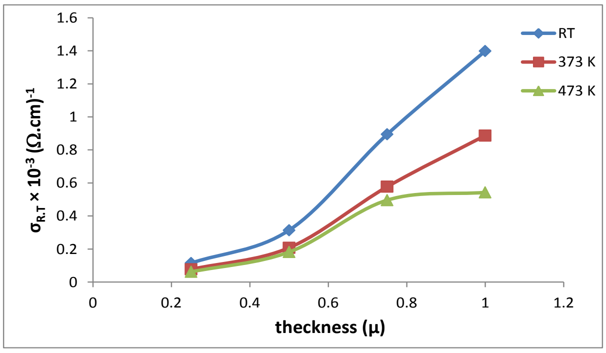


Figure (2): Variation of $\sigma_{R.T}$ versus thickness for a-Ge:Sb films at different annealing temperatures

Table (1): D.C conductivity parameters for a-Ge:Sb films at different thicknesses and annealing temperatures

Thickness (μm)	T_a (K)	(303 – 363)K	(363 – 433)K	(403 – 483)K	$\sigma_{R.T} \times 10^{-3}$ $(\Omega.cm)^{-1}$
		E_{a1} (eV)	E_{a2} (eV)	E_{a3}(eV)	
0.25	R.T	0.069	0.159	0.346	0.115
	373	0.075	0.179	0.376	0.077
	473	0.089	0.215	0.411	0.062
0.5	R.T	0.055	0.143	0.335	0.314
	373	0.064	0.161	0.361	0. 208
	473	0.0755	0.172	0.386	0.182
0.75	RT	0.0466	0.1	0.321	0.894
	373	0.061	0.125	0.332	0.577
	473	0.067	0.132	0.358	0.496
1.0	RT	0.042	0.084	0.276	1.398
	373	0.05	0.1039	0.317	0.887
	473	0.064	0.124	0.341	0.543

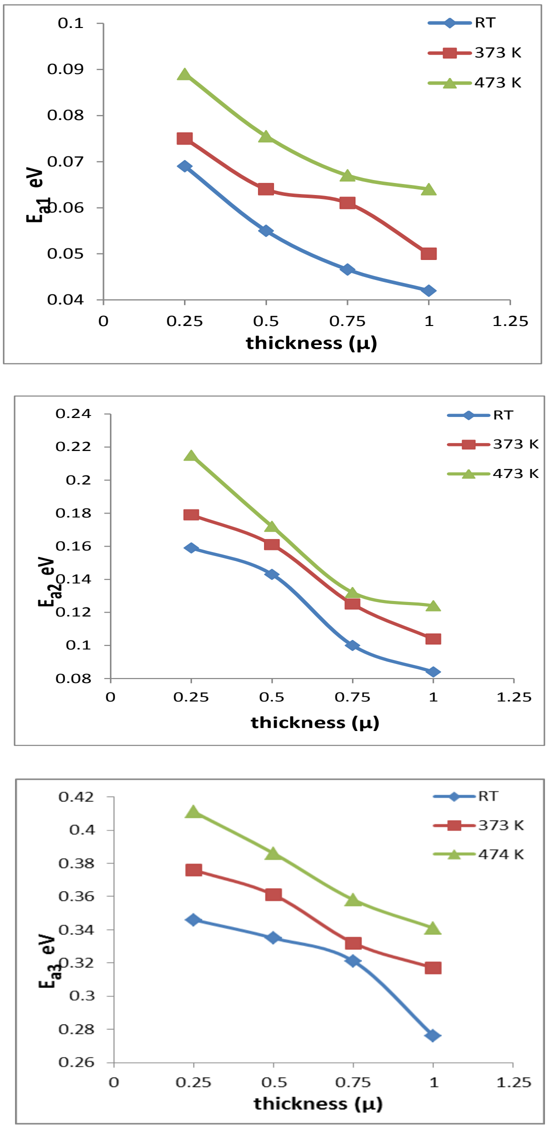
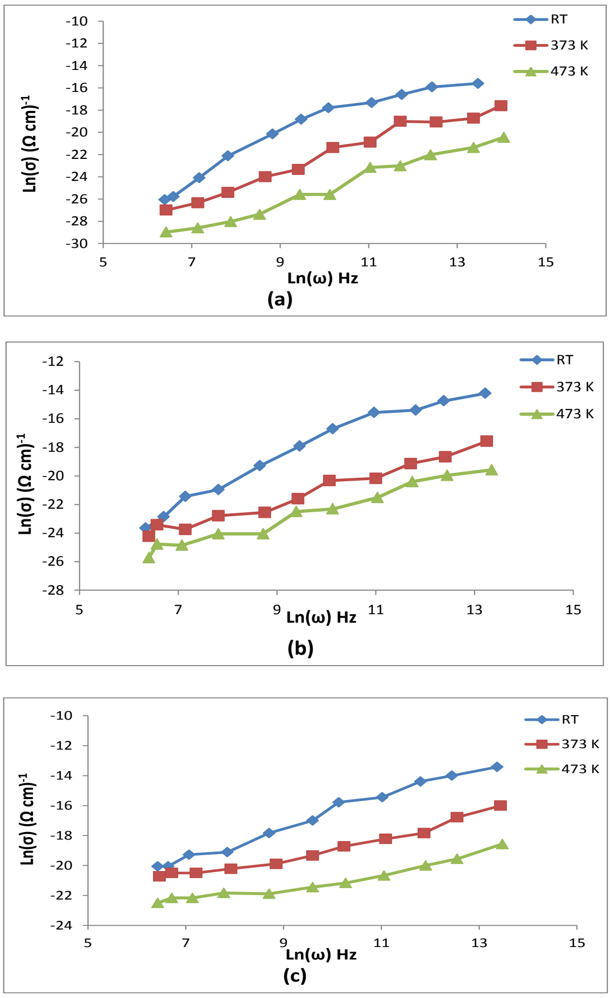


Figure (3): E_{a1} , E_{a2} and E_{a3} as a function of thickness for a-Ge:Sb films at different annealing temperatures

Fig.(3) shows the effect of thickness and annealing temperature on both activation energies E_{a1} , E_{a2} and E_{a3} for a-Ge:Sb films. It is clear that the activation energies decrease with increasing of thickness and increase with increasing of annealing temperatures, these results could be explained as: both tailing of the conduction and the valence band is diminished thus moving the conduction into regions with higher density of states and mobility. Another reason may be the variation of crystallinity of film with increasing of annealing temperature in term partial crystallization. The results we interpret previously set within a Table (1)



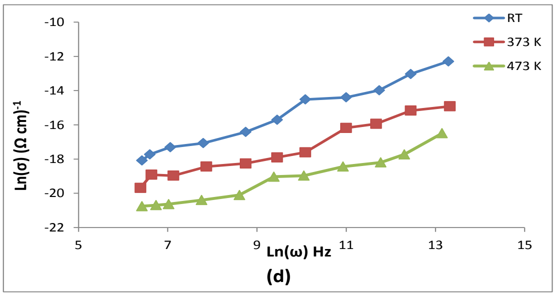


Figure (4): Ln$\sigma_{a.c}$ as a function of Ln(ω) for a-Ge:Sb films at different thickness and annealing temperatures(a): 0.25μm, (b): 0.5 μm, (c):0.75μm, (d): 1μm

The variation of A.C. conductivity with the frequency for a-Ge doped with Sb (Ge:Sb) films for different thicknesses(0.25, 0.5, 0.75, 1.0)μm and annealing temperatures (RT, 373, 473)K have been shown in Fig. (4). The A.C. conductivity increases with the increasing frequency for all samples. $\sigma_{a.c}(\omega)$ is proportional to ω_s which means that $\sigma_{a.c}(\omega)$ dominates at higher frequency, in the range of (10^3 – 10^5)Hz. For lower frequency in the range of (10^2 – 10^3) Hz, $\sigma_{a.c}(\omega)$ becomes independent on the frequency because D.C conductivity dominates in this frequency range.

The values of exponent (s) are estimated from the slope of the curves plotted between Ln$\sigma_{a.c}(\omega)$ versus Ln (ω) listed in Table(1) and found to be less than unity for all prepared films and decreases with the increasing annealing temperature, also the value decreases as the film thickness increases.

The behavior of $\sigma_{a.c}(\omega)$ with frequency can be explained in terms of polarization effect and hopping i.e. polarization effect in low frequency region where polarization is slightly changed and $\sigma_{d.c}$ is dominated, and at higher frequency region the hopping takes place. That means the exponent (s) fits CBH model given by Elliott from which A.C conductivity occurs between two sites over the barrier separating between D^+ and D^- defect centers in the band gap. This leads to greater loss in the dielectric and $\sigma_{a.c}(\omega)$ is dominating.

Table (2): Exponent (s) value of a-Ge:Sb films at different thickness and annealing temperatures. Temperatures

Thickness (μ)	S		
	RT	373	473
0.25	0.943	0.93	0.917
0.5	0.927	0.895	0.8266
0.75	0.903	0.848	0.801
1	0.852	0.83	0.744

Carrier concentration and Hall mobility have been determined from Hall measurements for a-Ge:Sb thin films deposited on glass substrate at R.T with different thicknesses and annealing temperatures.

Hall measurements show that all these films have a negative Hall coefficient (n-type charge carriers).

Figs. (5) & (6) show the variation of carriers concentration and Hall mobility as a function thickness with different annealing temperature. It's observed from these figures that the carrier's concentration decrease with increase of annealing temperature while Hall mobility increase, this behavior due to the re-arrangement process, which leads to the decrease of defects in the film during the film growth , and consequently a decrease of the carriers scattering .For this reason, the mobility increasing. There is increasing in the carrier's concentration and Hall mobility with increases of thickness due to concentration of the defect in the film increasing with increase thickness led to increase the charge carrier.

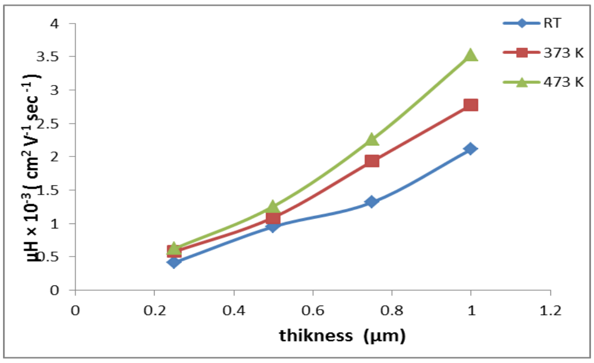


Figure (5): Variation of Hall mobility versus thickness for a-Ge:Sb films at different annealing temperatures

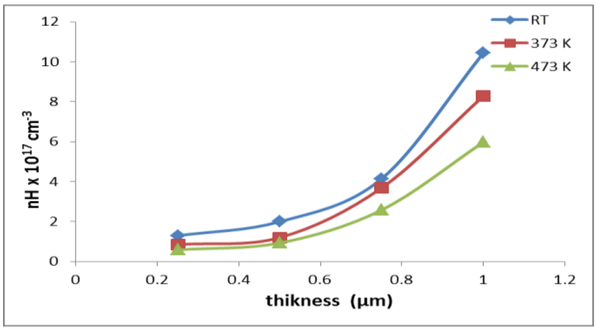


Figure (6): Variation of carriers concentration versus thickness for a-Ge:Sb films at different annealing temperatures

There is direct proportion between the carrier's concentration and the conductivity. Increase of annealing temperature less connectivity and concentration of charge carriers while increase of thickness led to increasing the carrier's concentration and thus increasing conductivity in the thin film.

Table (3): Values of Carrier Concentration and Hall mobility for a-Ge:Sb Thin Films

Thick.(μ)	T_a K	n_H x 10^{17} cm^{-3}	μ_H × 10^{-3} (cm^2 V^{-1} sec $^{-1}$)
0.25	RT	1.297	0.487
	373	0.854	0.578

	473	0.591	0.624
0.5	RT	1.996	0.952
	373	1.203	1.091
	473	0.935	1.257
0.75	RT	4.143	1.318
	373	3.685	1.934
	473	2.582	2.262
1	RT	10.432	2.112
	373	8.284	2.776
	473	7.58	3.527

Conclusions

The outcome foundation of above data is the following:

1. The D.C conductivity for all films increases as the thickness increases and decreases with the increasing annealing temperatures, and there are three activation energies decrease with increasing of thickness and increase with increasing of annealing temperatures.
2. The factor(s) of the A.C conductivity decreases with the increasing of annealing temperatures and thickness. The experimental results for the mechanism of A.C conductivity are consistent with CBH model.
3. Hall measurements show that all the films are n-type. The Hall mobility increases while carrier concentration decreases with increasing of annealing temperatures, but Hall mobility and carrier concentration increase with increasing of thickness.

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