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Effect of Doping on Properties of the Hall Effect and Electrical Conductivity for $AgInTe_2$ Thin Films

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Abstract: ***The effect of different doping ratio (0.3, 0.5, and 0.7) with thickness in the range 300nmand annealed at different temp.(Ta=RT, 473, 573, 673) K on the electrical conductivity and hall effect measurements of $AgInTe_2$thin film have and been investigated $AgAl_xIn_{(1-x)}Te_2$ (AAIT) at RT, using thermal evaporation technique all the films were prepared on glass substrates from the alloy of the compound. Electrical conductivity (σ), the activation energies (Ea_1, Ea_2), Hall mobility and the carrier concentration are investigated as a function of doping. All films consist of two types of transport mechanisms for free carriers. The activation energy (Ea) decreased whereas electrical conductivity increases with increased doping. Results of Hall Effect Analysis of (AAIT) films show that the kinds of all films were (n-type) and both the carrier concentration and hall mobility increase with increased the doping of the film.***

Keywords: AAIT, Electrical conductivity, Hall Effect and Thermal Evaporation method.

1. Introduction

The compound ternary semiconductor Silver Aluminum Indium Trillium ($AgAl_xIn_{(1-x)}Te_2$) due to high absorption coefficient (10^5 cm^{-1}) and good thermal its received great attention as photovoltaic absorber material for the fabrication solar cells [1].

I-III-VI2 compounds, chiefly Ag-chalcopyrite thin films have played a main role in thin films technology of photovoltaic. Typical Ag-chalcopyrite-based absorber materials are $AgInGSe_2$, $AgALInSe_2$, $AgInGTe_2$ and their alloys with band gap in the range (1.05-1.5) eV[2].

2. Experimental

Electrical properties

The semiconductor electrical properties are the important properties that recognize them from other materials. These properties are influenced by difference preparation method and conditions [3].

D.C Electrical Conductivity

The most important electrical properties of solids is Electrical conductivity consists of the density electric charge carriers and mobility.

The semiconductor total electrical conductivity represents the total connectivity the negative-positive carriers, the sum of the electron current density (Jn) and holes current density(Jp) is equal to current density(J) as shown in the following equation [4]:

$$J = J_n + J_p \quad \ldots\ldots (5)$$

Where: J_n, J_p electrons holes current density respectively.

Some atomic vibrations in semiconductor have enough energy to broken the bond, that lead the liberated of the electron it would be free to moved inside and around the crystal, it so-called electron of conduction, it leaving behind a hole to take part in the process conduction. The hole is moving in opposite direction to the electrons way and in the same direction of the electric field applied, we have two types of charge carriers will contribute in the process of conduction [5, 6].

For semiconductors, the electrical conductivity (σ) is given in the equation [7]:

$$\sigma = J/E = e\,(n\,\mu_e + p\,\mu_h) \quad \ldots\ldots (6)$$

According Ohm's Law [8]:

$$J = \sigma E \quad \ldots\ldots (7)$$

where: J: electric current density, E: electric applied field intensity, e: electron charge, μ_e: electrons mobility, μ_h: holes mobility, n:electrons concentration, p: holes concentration.

From this equation, we find that the electrical conductivity depends on both the charge carriers concentration and mobility under the applied electric field effect and these depend on temperature, preparing conditions and ratios of doping [9].

The equations (8) showed the electrical conductivity (σ_{dc}) and is equal to the inverted specific electrical resistivity (ρ) [10]:

$$\sigma_{dc} = \frac{1}{\rho}\ (\Omega.cm)^{-1} \quad \ldots\ldots (8)$$

$$\rho = R\frac{A}{L}\ , where: \{ A = b.t \} \quad \ldots\ldots (9)$$

Where: *R*: electrical resistance (Ω), L: distance between the poles of aluminum (cm), *A*: cross-sectional area the electrons move within, *b*: Pole width (cm), t: the thickness of film (nm) it converts to (cm)

The semiconductor electrical conductivity continuous depends both on the temperatures and activation energies. The electrical conductivity at high temperatures achieved by thermal excitation of charge carriers, while the electrical conductivity at low temperatures is achieved by hopping process [11].

Hall Effect

This phenomenon is studied the electrical properties of semiconductors. So from this study, we can know the type and charge carriers (n, p) concentration and be finding carriers mobility (μ_{nh}).Hall for the (n-type) semiconductors have a negative sign and for the (p-type) semiconductors have a positive sign is given in the following equations [12, 13]:

R_H = [+ *1* / nq]... for p-type……..……..….(10)

R_H = [-*1* / nq]... for n-type………………….(11)

We can found Hall mobility by the following equations (12) and (13) respectively [14]:

$V_H=R_H$[B.I/t]……………….(12)

$\mu_n=\sigma.|R_H|$ ………………..(13)

Where: B: magnetic field (Tesla), t: film thickness (nm).

3. Results and Discussion

The activation energy of the electrical conduction was determined and showed in Table (1) for undoped sample, Table (2) from doped and figure(4) which present a plot of lnσ of AIAT versus 10^3/T for different doped. The electrical conductivity increases with increasing the doped because increasing the number of the available carriers transport. From table No.(2) and figure (2), we can observe that all (AIT) films have two mechanisms for electrical conductivity that means there is two mechanism of transport free carriers and which have two activation energy(Ea1, Ea2) values of each one in different temperature ranges. At the temperature range, (300-405) K carriers excited into the localized states at the edge of the band and hopping and at the higher temperature range(405-490) K the transport of free carriers in extended states beyond the mobility edge [15].We also note from the Table(1) and (2) present the values of the activation energy, that increasing the value of the addition and the reason for reduce of some of the defects crystalline when the entry of aluminum atoms in the vacant space, which caused the occurrence of crystalline defects and the least value of activation energies at the ratio of x = 0.7 This is due to an improvement in crystalline structure and increase the number of carriers.

Table 1: The electrical conductivity and activation energies of AIT films at different thickness and various Ta (473-573-673) K

Thickness (nm)	T(K)		$\sigma_{d.c.}(\Omega.cm)^{-1}$	E_{a1}(eV)	Temp. range(K)	E_{a2}(eV)	Temp. range(K)
150	RT		11.62	0.0471	300-405	0.289	405-490
	Ta	473	13.27	0.0446	300-405	0.227	405-490
		573	16.92	0.0441	300-405	0.197	405-490
		673	20.15	0.0424	300-405	0.143	405-490
300	RT		12.62	0.0443	300-405	0.213	405-490
	Ta	473	15.44	0.0402	300-405	0.196	405-490
		573	16.74	0.0357	300-405	0.128	405-490
		673	20.35	0.0321	300-405	0.111	405-490
450	RT		11.67	0.0401	300-405	0.210	405-490
	Ta	473	16.32	0.0364	300-405	0.186	405-490
		573	21.18	0.0321	300-405	0.129	405-490
		673	22.08	0.0295	300-405	0.122	405-490

Table 2: The electrical conductivity and activation energies of AIT films at different doped at Ta=673K

X=Al content	E_{a1}(eV)	Temp.range(K)	E_{a2}(eV)	Temp.range(K)
0.3	0.0127	300-405	0.0946	405-490
0.5	0.0114	300-405	0.0871	405-490
0.7	0.0121	300-405	0.0831	405-490

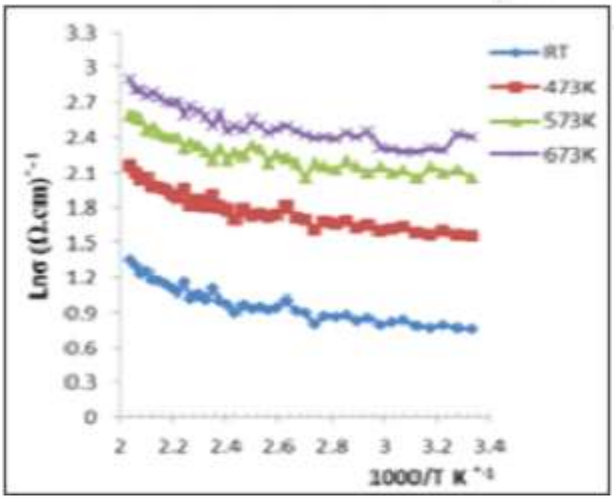

Figure 1: Plots lnσ as a function of 103 /T(K-1) at (150) nm thickness and Ta=(RT, 473-573-673) K

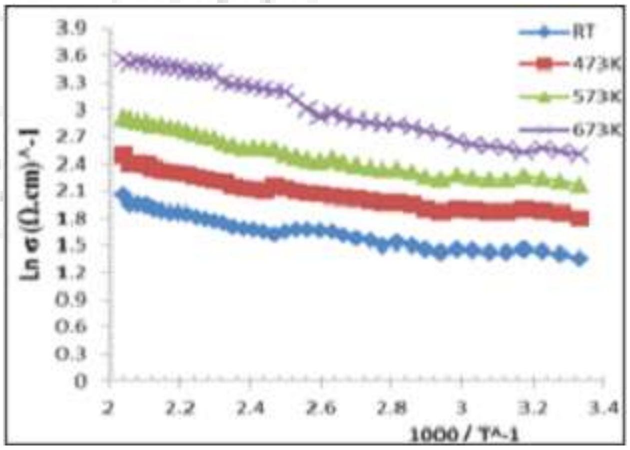

Figure 2: Plots lnσ as a function of 103 /T(K-1) at (300) nm thickness and Ta=(RT, 473, 573, 673) K

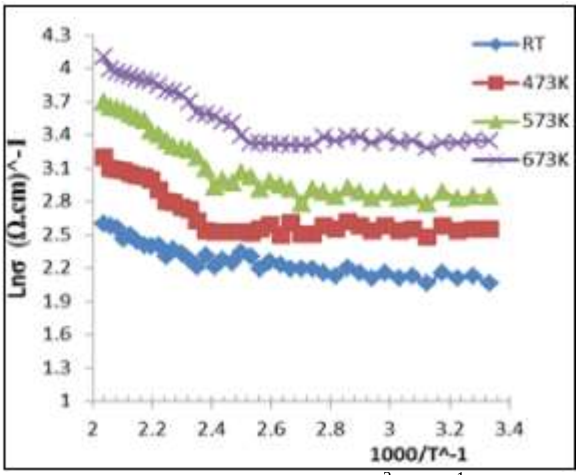

Figure 3: Plots lnσ as a function of 10^3 /T(K^{-1}) at (450) nm thickness and Ta=(RT, 473, 573, 673) K

The values Hall coefficient (RH) were calculated for AIAT films with different doping have positive sign that means the conduction type was p-type, i.e. majority charge carriers are electrons in the process of conduction. The carrier concentration (n) about 10^{17} $cm^{-3}$and is in good result, the carrier mobility's (μ_h) value in contrast is found in the order of 1.047cm^2/V.s.

Table (3) and (4) are shown all these parameters both (np) and (μh) increase as with increasing the doping. This manner can be referred to the decrease the centers of trapping of charge carriers with the increase of doping, this is maybe, because of the grain boundary scattering which limits the mobility in thinner films is decreased and due to reducing native defect centers, grain boundary defects, and improved film structure, therefore, the carrier mobility improves[10].

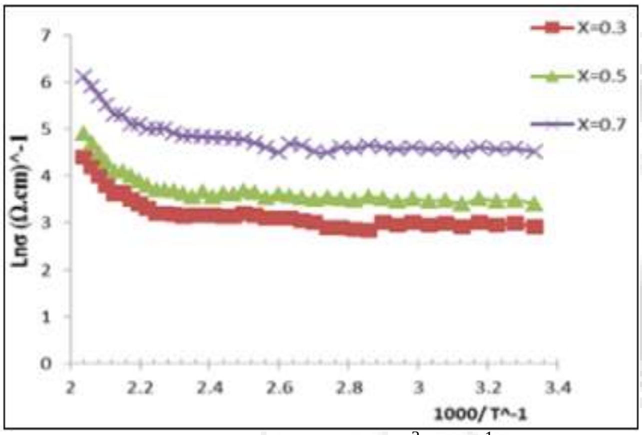

Figure 4: Plots lnσ as a function of 10^3 /T(K^{-1}) for different doping AIAT films with t=300nm at Ta=673K

Thickness (nm)	T(K)		$\sigma_{d.c.}$(Ω.cm) $^{-1}$	R_H(cm^3C^{-1})	μ_H(cm^2/V.s)	N_A (cm^{-3}) *10^{18}
150	RT		11.54	8.686	99.4547	0.71954
	Ta	473	13.46	6.025	81.0965	1.03734
		573	16.58	4.243	70.3489	1.40578
		673	19.83	3.517	69.7421	1.77708
300	RT		11.17	6.067	67.7683	1.0301
	Ta	473	15.53	3.419	53.0970	1.8280
		573	16.41	3.012	49.4269	2.0750
		673	21.08	2.056	43.3404	3.0398
450	RT		11.07	7.413	82.0619	0.8431
	Ta	473	15.12	4.758	71.9409	1.3135
		573	20.47	3.420	70.0074	1.8274
		673	20.03	3.243	64.9572	1.9272

Table 4: Values of carrier concentration, conductivity, carrier mobility and Hall coefficient of AIAT films for different doping at temperature 643K.

X= Al content	$\sigma_{d.c.}$(Ω.cm) $^{-1}$	R_H(cm^3C^{-1})	μ_H(cm^2/V.s)	N (cm^{-3}) *10^{18}
0.3	22.37	1.956	43.7557	3.1952
0.5	23.06	1.632	37.6339	3.8296
0.7	22.71	1.428	32.4298	4.3767

The increase in the ratio of aluminum leads to a decrease in the coefficient of Hall because of the increase in the concentration of carriers, which leads to increase the current passing through the thin films.

4. Conclusion

In research the effect of doping on the electrical properties of AIT through measurements of conductivity and hall effect have been studied in this work, we conclude the following:

1) The electrical conductivity and activation energies of (AIT) films are seen to be dependent on the film doping the electrical conductivity shows as an decrease of behavior with an increase of doping
2) The behavior of the electrical conductivity of AIAT films as a function of doping is a result of the community between two mechanisms of transport, hopping charge transport between localized states at the edge of the band

at low temperature (290-415) K and charge transport to extended state beyond the mobility gap at higher temperature (450-490) K[16].

3) Hall Effect measurements confirmed that electrons were predominating in the conduction process, both the mobility and concentration of the charge carrier's increase with doping.
4) The increase in the ratio of aluminum leads to a decrease in the coefficient of Hall.
5) The undoped improvement in crystalline structure and increase the number of carriers.
6) Finally, from the above properties we concluded that (AIAT) films may be suitable for solar cells application.

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