

## Energy Gap and Electrical Conductivity of Doped Amorphous Silicon (a- Si)with Sb

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### الخلاصه

لقد حضر غشاء السليكون العشوائي المطعم بالانتيمون بطريقه التبخير الحراري تحت ضغط الفراغ العالي ( $10^{-6}$  torr). تم دراسته تأثير التطعيم بالانتيمون وبنسب مئوية مختلفه ضمن المدى % (0-3.5) على التوصيليه الكهربائيه، ( $\sigma_{RT}$ )، تركيز الحوامل (n) وفجوة الطاقه الضوئيه ( $E_g$ ). من خلال اعتماده التوصيليه الكهربائيه على درجة الحراره لاغشية السليكون العشوائي النقي والمطعم بالانتيمون ضمن مدى درجة الحراره (303-503)k ظهرت منطقتين للتوصيل ضمن المدى (303-393)k و (393-503)k. من خلال طيف الامتصاص والقياسات الكهربائيه وجد ان فجوة الطاقه الضوئيه او البصريه تقل من (1.22eV) الى (0.92 eV) عندما زادت النسبه المئوية للتطعيم بالانتيمون % (0-3) في حين عند النسبه % (3.5) زادت الى (0.96 eV) اما التوصيليه الكهربائيه ( $\sigma_{RT}$ ) و تركيز الحوامل (n) فقد زادت من  $(0.898 \times 10^{-4}) (\Omega \text{cm})^{-1}$  الى  $(2.95 \times 10^{-3}) (\Omega \text{cm})^{-1}$  و  $(0.602 \times 10^{21}) \text{m}^{-3}$  الى  $(16.53 \times 10^{21}) \text{m}^{-3}$  على التوالي. بينما عند النسبه % (3.5) من التطعيم بالانتيمون قلت التوصيليه الكهربائيه الى  $(\Omega \text{cm})^{-1}$   $(1.99 \times 10^{-3})$  وتركيز الحوامل (n) الى  $(13.52 \times 10^{21}) \text{m}^{-3}$  على التوالي.

### ABSTRACT

Energy gap and electric conductivity of Sb doped samples was investigated. Thin films of amorphous silicon (a-Si) were prepared and doped by thermal evaporation under high vacuum condition ( $10^{-6}$  torr). The influence of doping with (Sb) of various percentages within the range (0-3.5)% on the electrical conductivity ( $\sigma_{RT}$ ), carriers concentration and optical energy gap ( $E_g$ ) were studied.

The temperature dependence conductivity for pure and various percentage doping with (Sb) of (a-Si) recorded within the range (303-503)K consist of two conduction regions within the temperature range (303-393)K and (393-503)K.

From the absorbance spectrum and electrical measurements. It is found that ( $E_g$ ) decreases from 1.22eV to 0.92eV when the percentages doping with Sb increases from (0 -3)% but it increases to 0.96eV at 3.5% Sb while the electrical conductivity ( $\sigma_{RT}$ ) and carriers concentration (n) increases from  $0.898 \times 10^{-4} (\Omega \cdot \text{cm})^{-1}$  to  $2.95 \times 10^{-3} (\Omega \cdot \text{cm})^{-1}$  but it decreases to  $1.99 \times 10^{-3} (\Omega \cdot \text{cm})^{-1}$  at 3.5% Sb, and (n) increases from  $0.602 \times 10^{21} \text{m}^{-3}$  to  $16.53 \times 10^{21} \text{m}^{-3}$  but it decreases to  $13.52 \times 10^{21} \text{m}^{-3}$  with 3.5% Sb respectively.

### INTRODUCTION

There is no doubt that the control of the electrical properties of crystalline semiconductor achieved by substitutional doping has been one of most significant factors in the development of semiconductor physics and of solid state electronics. evidently a similar systematic control of properties of amorphous semiconductors would be invaluable for electrical investigation of these materials and could also open up important new fields of applications[1]. There are many similarities between properties of amorphous and crystalline semiconductors [2].

The (a-Si) has been the subject of many investigations on disorder system over the past 15 years (a-Si). Film generated made by different techniques contain a large density of states in the dangling bond and resulting large density of states in the energy gap makes it very difficult to move the Fermi level [3,4]. The density of localized states which is known play very important part in the conduction processes of these materials at room temperature and influence in the electrical and optical characteristic of these material [5]. Spear and Le Comber [4] have observed that glow discharged produce (a-Si) possessed a relatively low density of gap state as compared to sputtered or evaporated film . It's now clear that these films are actually a amorphouse silicon alloy and currently refered to as hydrogenated amorphouse silicon . The density of states in the energy gap of (a – Si :H) is relatively low density of state , and thus the Fermi level can be removed with respect to the band edge by adding a small quantities of certain dopant such as boron , phosphor , arsenic ,erbium and antimony (Sb) [4,6,7].

Therefore the properties of (a-Si :H)are not a unique but depend on the preparation conditions as well as on the impurities [6]. This means that the presence of hydrogen is of key importance for the doping of (a-Si) and (a-Ge) [8]. To characterized semiconductor materials knowledge of the type and concentration carriers is necessary in device materials , usually the doping agent and therefore the carrier type is known . Different doping elements have different influence on the mobility and carrier concentration, specially in the case of heavy dopent,[9].

The electrical conductivity of thin film ( $\sigma$ ) varies with temperature according to the Arrhenius realtion[10][11]:

$$\sigma = \sigma_o \exp\left(\frac{-\Delta E}{KT}\right) \quad (1)$$

Where  $\sigma_o$  is a parameter depend on the semiconductor nature , K is boltzman constant and  $\Delta E$  is the thermal activation energy .

The carrier density (n) calculated from the relation [12]:

$$n = \frac{r}{Re} \quad (2)$$

Where the scattering factor r is close to the unity and R is Hall coeffiecien combine with measurement of conductivity and e is the electric charge .This yields the well – known equation for the Hall mobility ( $\mu_H$ ) [12]:

$$\mu_H = R\sigma \quad (3)$$

In the high obsorption region from which the optical band gap is determined .the obsorption is characterized by Tauc relation [13][11]:

$$\alpha h\nu = B(h\nu - E_g^{optical})^n \quad (4)$$

Where  $h\nu$ ,  $E_g^{optical}$  and B denoted the photon energy, the optical energy gap and band tailing parameter respectively

$n = 1/2$  for a direct allowed transition,  $n = 3/2$  for a direct forbidden transition,  $n=2$  for an indirect allowed transition and  $n=3$  for an indirect forbidden transition [13].

In the present work we have studied the effect of doping with (Sb) on the electrical conductivity , carrier concentration and optical energy gap ( $E_g$ ) of (a- Si) prepared by thermal evaporation.

## MATERIALS AND METHODS

Amorphous silicon(a-si) films were prepared by evaporation of silicon material(from Balzer company with high purity) from tungsten boat at room temperature substrate , while the doping were performed also by evaporation of antimony (Sb) from second boat. Diffusion process with a temperature (473-500)K for one hour, the time required for diffused the (Sb) atoms inside the amorphous silicon films.

Deposition was carried by vacuum system (type Edwards, E 306Å ) at  $(4-2) \times 10^{-6}$  torr .Thickness of (a-si) Films ( $4000 \pm 200$  )Å were measured by using a multiple beam interferometer method. The films prepared under deposition rate ( $5 \text{ \AA}/\text{sec}$ ) . Electrical measurement were made on film deposited on a glass substrates at various temperature with aluminum electrodes prepared by evaporation. Electrical connection were attached with silver paste and then the sample were mounted in oven.

We used power supply PE 1540 Dc 40-3 A , Keithly 616 digital electrometer, Digital thermometer (273-737)K and electrical oven for DC conductivity measurement .

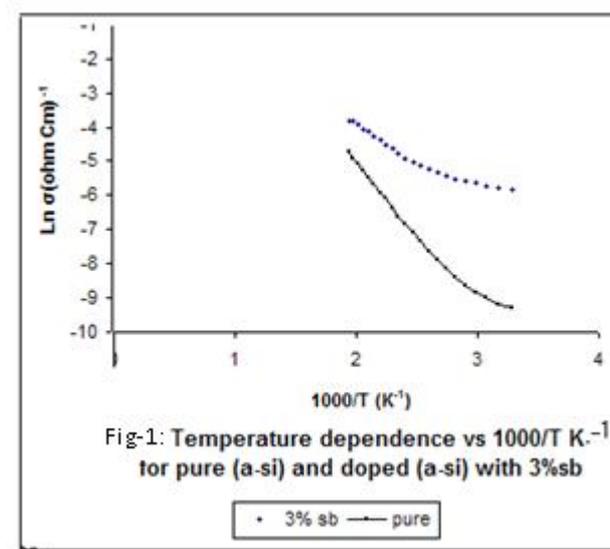
Measurement of temperature dependence were carried out in the temperature range (303-503) K. from the slope of  $\ln(\sigma)$  vs.  $1000/T$  dependence the values of  $\Delta E$  were calculated using equation (1). From Hall effect measurement we know the type of the film (P or n type) ,and calculate the carrier concentration(n) and Hall mobility( $\mu$ ) by applying equation(2),(3).

For optical measurement we used the device type Perkin- Elmer Lambda Uv/Vis/NIR spectrometer for obtain the change in the absorbance (A) of films as a function of wavelength . The optical energy gap obtain by using equation (4)(from plotting between  $(\alpha h\nu)^{1/2}$  against  $h\nu$ , (the optical energy gap ( $E_g$ ) determined by the intercept of the extrapolation with the photon energy axes( $(\alpha h\nu)^{1/2} \rightarrow 0$ )).

## RESULTS AND DISCUSSION

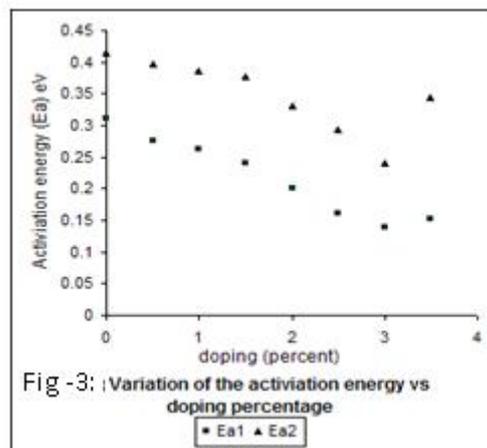
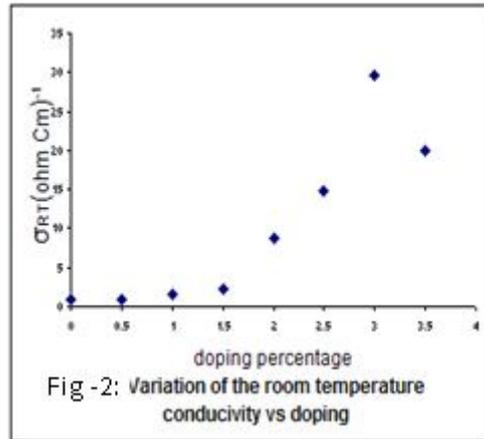
Results of our measurements of electrical conductivity and optical energy gap at room temperature as a function of doping percentages are summarized in the figures(1,2,3,4,5,6,7) and table 1.

In fig.1 the temperature dependence of electrical conductivity for pure (a-Si) and doped with 3% Sb in a temperature range (303-503)K. Fig.1 shows two regions in the temperature range (303-393)K and (393-503)K. the curve are shifted to higher value of conductivity with increasing the percentages of doping with 3%Sb(see table1). In the temperature range (393-503)K the conductivity is due to the transmission of carriers in the extended states above the mobility edge while in the range (303-393)K the conductivity is due to the excitation of carriers to the extended states near the bands edge.

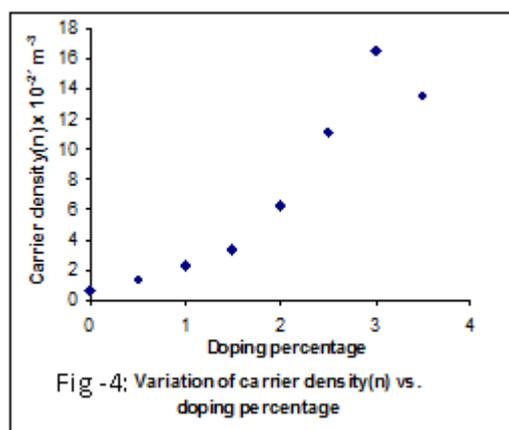


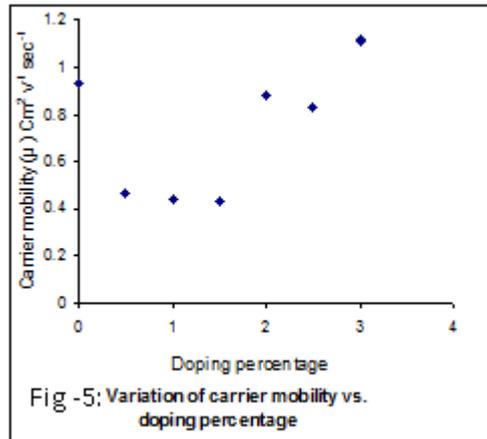
The effect of doping percentage on ( $\sigma_{RT}$ ) and activation energy( $E_a$ ) are summarized in figures 2 and 3. The electrical conductivity ( $\sigma_{RT}$ ) increases from  $0.898 \times 10^{-4} (\Omega \cdot \text{cm})^{-1}$  to  $27.5 \times 10^{-4} (\Omega \cdot \text{cm})^{-1}$  as the doping percentages increases from (0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0)%Sb. But at 3.5% Sb, ( $\sigma_{RT}$ ) decreases to  $19.9 \times 10^{-4} (\Omega \cdot \text{cm})^{-1}$ , all these results are listed in table 1.

From fig.3 we see that the activation energy( $E_{a1}$ ) decreases from 0.31 eV to 0.138eV as the doping percentages increases from (0, 0.5, 1.0, ..., 3.0) % Sb ( $\Delta T = (303-393)\text{K}$ ). but at 3.5% Sb the activation energy increases to 0.152eV while at ( $\Delta T = (393-503)\text{K}$ ) the activation energy( $E_{a2}$ ) decreases from 0.41eV to 0.24 eV for the same percentages of the doping. But at 3.5%Sb the activation energy increases to 0.345eV.

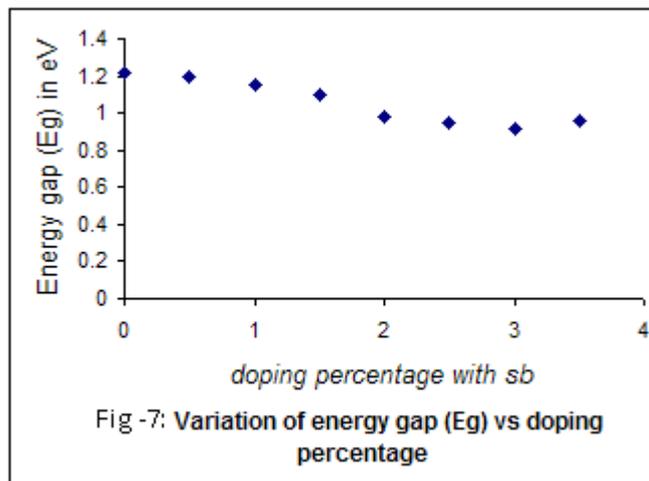
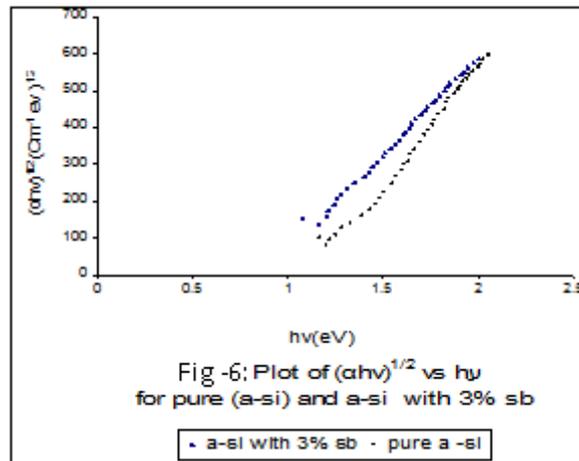


The Hall measurement show that the films p-type before doping and becomes n-type after doping with Sb. Figures 4, and 5 show the effect of doping on the carrier density and carrier mobility respectively. From fig.4 we see that the carrier density ( $n$ ) increase from  $0.602 \times 10^{21} \text{m}^{-3}$  to  $16.53 \times 10^{21} \text{m}^{-3}$  as the doping percentages increase from (0, 0.5, 1.0, 1.5, ...3)% Sb but it decreases to  $13.52 \times 10^{21} \text{m}^{-3}$  at 3.5% Sb. From fig.5 we shows that carriers mobility ( $\mu$ ) are variable between decreasing and increasing at the doping percentages from (0, 0.5, 1.0, 1.5, ...3) %Sb.





For optical measurements, fig. 6 shows that the absorption edge of a pure (a-Si) and doped with 3%Sb, are shifted to the lower energies of incident radiation with increasing doping percentages ( all the results are given in table 1). The optical energy gap  $E_g$  decreases from 1.22eV to 0.92eV as the doping percentages increases from (0, 0.5, 1.0, 1.5, ..., 3)%Sb while it increase to 0.96eV at 3.5%Sb as shown in fig. 7.



The interpretations of results in table 1 and the figures are: According to Mott and Devis the width of mobility edge depends on the degree of disorder and defects presents in the amorphous structure. In amorphous solids like (a-Si) un saturated bonds are responsible for the formation of these defects. Such defects produce localized states in the forbidden gap. At low percentages of doping the electrical conductivity increases because of the joining of the doping atoms with the original atoms inside the lattice and this leads to the saturation of the dangling bonds and vacancies. consequently the activation energy decreases .the increase of the impurity to 3% Sb make a donor levels located in the forbidden band which leads to an increase in the electrical conductivity ,carrier density(n) and decrease in the activation energy. when we have more than 3%Sb (i.e 3.5% Sb),the electrical conductivity, carrier density decreases, and activation energy increases because a new defects have formed inside the film and this is the cause of new dangling bond through localized state inside the gap fig.(2,3,4)[14,10,15].

For optical measurement fig.(6,7) as well as the addition of Sb in the structure of (a-Si) cause a deeper band tails extended in the gap and thereby leading to decrease in the value of optical band gap fig.(6,7) .the decrease of optical band gap with increasing of Sb percentage to 3%Sb may also be related to the increase number of (Si-Sb) and (Sb-Sb) bonds and decrease of (Si-Si) bond .the strength of(Si-Sb) and (Sb-Sb) bonds is lower as compare to(Si-Si) bonds so the optical absorption edge shifted toward higher values of wavelength with the addition of Sb .Antimony (Sb) enter the structure of (a-Si) and leading to modification of network.furtherthe optical band gap is strongly dependent on the the fractional concentration of Sb atoms .this may be due to the tendency of Sb atoms to create localized states in the forbidden gap leading to lower optical band gap ( $E_g$ )[13,15,16]

Table -1: Summary of calculation of (a-Si) and doped (a-Si) with Sb.

Doping percente gap	$\sigma_{R-T} \times 10^{-4}$	$E_{a1}$ eV	$E_{a2}$ eV	$n_{12} \times 10^{21} m^{-3}$	$\mu \times 10^{-6}$	$E_g$ eV
0	.898	.31	.414	.602	.931	1.22
.5	1.001	.276	.396	1.33	.467	1.2
1	1.61	.262	.386	2.29	.439	1.15
1.5	2.35	.241	.378	3.34	.433	1.1
2	8.797	.201	.33	6.25	.879	.98
2.5	14.8	.161	.293	11.71	.826	.95
3	29.5	.138	.24	16.53	1.11	.92

### Conclusions

- optical transmission is used to calculate the energy gap of (a-Si) as a function of doping percentage
- it is found that the electrical conductivity ,activation energy and optical energy gap of (a-Si) film depend on Sb doping percentage.
- The higher value of electrical conductivity and the lower values of the activation energy and optical energy gap of (a-Si) are obtained at 3% Sb doping
- The (a-Si) film is p-type before doping with Sb and becomes n-type after doping

### REFERENCES

- 1- W.E.Spear and P.G.Lecomber , " electronic properties of substitutionally doped amorphous Si and Ge" , "philosophical magazine" vol 33, No.6, pp 935-945 (1976).
- 2- I.B. Ortenburger and D.Henderson " Effect of pressure on the electronic and optical properties of a polymorph of Germanium and of a morphous Germanium" , "physical review letters", vol30 , No.21 , pp 1047-1050 (1973).
- 3- K.L. Bhatia ,M.V.Hamuder and S.Hunklinger , "Study of defect in a-Ge and a-Ge Hx using surface acoustic wave technique", "Journal DE Physique" Colloque C4 ,supplement au n10,Tome42,pp c4-365 to c4-368 (1981).
- 4- Gwo-Jen Jan Ying-Sherg Hunang "optical properties of hydrogenated amorphous silicon", "Chines journal of physics", vol 24 ,No.1 pp 19-27 (1986).
- 5- A.K. Malhotra and G.W. Neudeck , " effect of hydrogen contamination on the localized states in amorphous silicon", "Applied physics letter", vol 28 ,No.1, pp 47-49 (1976)
- 6- Mun-Jun Kim ,Mcbratu G.Kallo and Jung H. Shin , " Effect of Erbium concentration on the band tail states of Er-doped hydrogenated amorphous silicon", "journal of the Korean physical society " ,vol39 , pp s333-s336 (2001).
- 7- G.M.Beensh –Marchw ,E.Prociow ,W.Mielcarek , "structural of Ge-based film exhibiting thermoelectric effect", "crystal Res.Technol. vol36,No(8-10), pp 1035-1043 (2001).
- 8- C.J.Fang ,K.J.Gruntz,L.Ley and M Cardons,F.J.Demond ,G.Muller ,and S.Kalbitzer,"the hydrogen content of a-Ge:H and a-Si:H has determined by I.R. spectroscopy,gas evaluation and nuclear reaction technique , "journal of non- crystalline solids",35 and 36pp 255-260 (1980).
- 9- F.Mousty,P.Ostojca,L.Passaril,"relation ship between resistivity and phosphore concentration in silicon", "journal of applied physics", vol45,No.10 ,pp 4576-4580 (1974).

- 10- Nicolae Tigua, "structural and electrical properties of  $Sb_2O_3$  thin films", "Rom.Jou.phy." vol.53, No.12, pp 203-208 (2008).
- 11- Tayyar Gungor and Hiiseyin Tolunay, "sffect of substrate temperature on properties of a-  $SiN_x:H$  films ,Turk journal phys.,26, pp 269-275 (2002).
- 12- J.W. Orton, B.J. Goldsmith, J.A. Chapman and M.J. powel, "The mechanism of photo conductivity in polycrystalline cadmium sulphide layers" , "Jou.appl.physics" vol 35, No.3 , pp1602-1614 (1982).
- 13- Pankj Shrma, S.C. Katyle "influence of replacing Se in  $Ge_{10} Se_{90}$  glassy alloy by 50 at % Te on the optical parameters" , "Jou. of Ovanic research" , vol. 2 No.6, pp 105-110 (2006).
- 14- Talib saloom hamadi, Ph.D. thesis "study of the optical and electrical transport in doped (a  $Ge :H$ ) ", physics dept. , college of science , Baghdad university, pp 147-150 (1999)
- 15- P. Sharma an V. Sharma , S.C. Katyal , "Variation of optical constant in  $Ge_{10} Se_{60} Te_{30}$  thin film ", cahalcogenide letters, Vol.3, N
- 16- Ishu Sharma, S.K. Tripathi, P.B. Barman "effect of Bi addition on the optical behaviour of a  $Ge-Se-In-Bi$  thin films, Applied surface science 255pp 2791-2795 (2008).