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Study of the Electronic Properties and Hall Effect of Amorphous $Si_{1-x}Ge_x$:H Thin Films

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ABSTRACT:

The electronic properties and Hall effect of thin amorphous $Si_{1-x}Ge_x$:H films of thickness (350 nm) have been studied such as dc conductivity, activation energy, Hall coefficient under magnetic field (0.257 Tesla) for measuring carrier density of electrons and holes and Hall mobility as a function of germanium content (x = 0–1), deposition temperature (303-503) K and dopant concentration for Al and As in the range (0-3.5)%. The composition of the alloys and films were determined by using energy dispersive spectroscopy (EDS) and X-ray photoelectron spectroscopy (XPS).

This study showed that dc conductivity of a-$Si_{1-x}Ge_x$:H thin films is found to increase with increasing Ge content and dopant concentration, whereas conductivity activation energy decreases with increasing Ge content and dopant concentration. The carrier density (electrons and holes) of prepared films increases with increasing Ge content, dopant concentration and deposition temperature. The mobility and the mobility activation energy increase with increasing Ge content. The width of localized state is 0.215 eV for a- $Si_{0.5}Ge_{0.5}$:H thin film deposited at 503 K.

دراسة الصفات الالكترونية وتأثير هول لأغشية a-$Si_{1-x}Ge_x$:H الرقيقة

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الخلاصة:

درست الصفات الالكترونية و تأثير هول لأغشية a-$Si_{1-x}Ge_x$:H الرقيقة ذات السمك كالتوصيلية لبمستمرة وطاقة التنشيط ومعامل هول (تحت مجال مغناطيسي 350nm) لقياس كثافة الحاملات كالألمترونات والفجوات وتحر كية هول كدالة لنسب الجرمانيوم (x=0-1) ودرجة الترسيب (303-503)K) وتركيز التطعيم لـ Al و As بمدى (0- 3.5) %.تم تحديد التركيب للسبائك والأغشية بواسطة مطياف التشتت الطاقي (EDS) ومطيافية الإلكترون الضوئي (XPS).

أوضحت هذه الدراسة أن التوصيلة المستمرة لأغشية a-$Si_{1-x}Ge_x$:H تزداد بزيادة نسبة الجرمانيوم والتطعيم بينما تقل طاقة التنشيط للتوصيلية كما تزداد كثافة الحاملات(الالكترونات والفجوات) للاغشية المحضرة مع زيادة نسب الجرمانيوم والتطعيم ودرجة حرارة الترسيب.تزداد التحركية وطاقة التنشيط للتحركية مع زيادة نسب الجرمانيوم كما آت عرض المستويات الموضعية هي 0.215 eV لغشاء a-$Si_{1-0.5}Ge_{0.5}$:H والمرسب عند 503K.

INTRODUCTION:

The physical properties of covalent amorphous semiconductors are currently attracting wide attention, during the few last decade, because of their attractive properties, such as electronic, magnetic and structure properties [1-3]. These properties made them a good candidate for many technological applications [4, 5]. The structure and physical properties of

amorphous $Si_{1-x}Ge_x$:H thin films depend markedly on the preparation conditions (thermal, flash evaporation, quenching from the melt, deposition temperature, dopant concentration, … etc) [6-10]. From the survey of literature it can be seen that almost no attempt has been made to study the effect of preparation conditions on the magnetic and electronic properties of thermally evaporated thin amorphous $Si_{1-x}Ge_x$:H films. Therefore, we have thought that it would be interest to investigate the effect of Ge content (x), deposition temperature (T_d) and dopant concentration of Al and As on dc conductivity, activation energy, Hall coefficient, carrier density and mobility of a-$Si_{1-x}Ge_x$:H thin films prepared by thermal evaporation method.

EXPERIMENTAL:

Silicon-germanium alloys ($Si_{1-x}Ge_x$) have been prepared in an evacuated quartz tube with variable Ge content (x). Amorphous $Si_{1-x}Ge_x$:H thin films have been prepared by thermal evaporation under vacuum 10^{-6} torr at different preparation conditions such as deposition temperature (T_d), Ge content (x) and dopant concentration Al for p-type and As for n-type,the rate of deposition was about 0.9 nm/sec and the film thickness was 350 nm. Hydrogenation took place in situ by exposing the a-$Si_{1-x}Ge_x$:H thin film to hydrogen plasma. The composition of the alloys and films were determined by using energy dispersive spectroscopy (EDS) and X-ray photoelectron spectroscopy (XPS). The confirmation of hydrogenation of a-$Si_{1-x}Ge_x$:H films have been emphasized by using the Fourier-transform infrared unit (FT-IR) and the scanning electron microscope (SEM) analysis and X-ray diffraction (XRD) confirmed the amorphous structure of all prepared films.

The dc conductivity for a-$Si_{1-x}Ge_x$:H thin films was measured as a function of temperature in the range (300-600) K. Hall coefficient was measured by applying a magnetic field (0.257 Tesla) perpendicular to the film surface. The mobility of prepared films was measured as a function of temperature (300-450) K.

RESULTS AND DISCUSSION:

We determined the concentration of the components of the prepared alloy and film by different methods (XPS and EDS). The results of these analyses are tabulated in Table (1).

Table (1): Illustrate the composition of alloys and thin films determined by various methods.

Method	Elements%						Total%	
	Si	Ge	Si	Ge	Si	Ge		
As-made	0.30	0.70	0.50	0.50	0.70	0.30	100	Alloy
Density	0.30	0.70	0.50	0.50	0.70	0.30	100	Alloy
XPS	0.29	0.71	0.51	0.49	0.71	0.29	100	Film
EDS	0.28	0.72	0.53	0.47	0.73	0.27	100	Film
EDS	0.29	0.71	0.53	0.47	0.73	0.27	100	Alloy

The dc conductivity (σ) was measured as a function of temperature and Stuke's equation was applied, [$\sigma=\sigma_o \exp-E_\sigma /K_BT$] [11], where σ_o is the minimum metallic conductivity, E_σ is activation energy for conduction, K_B is Boltzmann constant and T is absolute temperature, to find the activation energy. The observed variation of conductivity with reciprocal (KT) in the temperature range (300-600) K, for various

type of a- $Si_{1-x}Ge_x$:H films i.e. doped with 3.5% Al, 3.5% As and pure deposited at 503 K with different x, is shown in Fig. (1). obviously the conductivity is not single activated in the whole temperature range of investigation.

At higher temperature range (443-570) K the conduction mechanism of this stage is due to carriers excited into the extended states beyond the mobility edge and at intermediate temperature (373-443) K, the conduction mechanism due to carriers excited into the localized states at the edge of the band

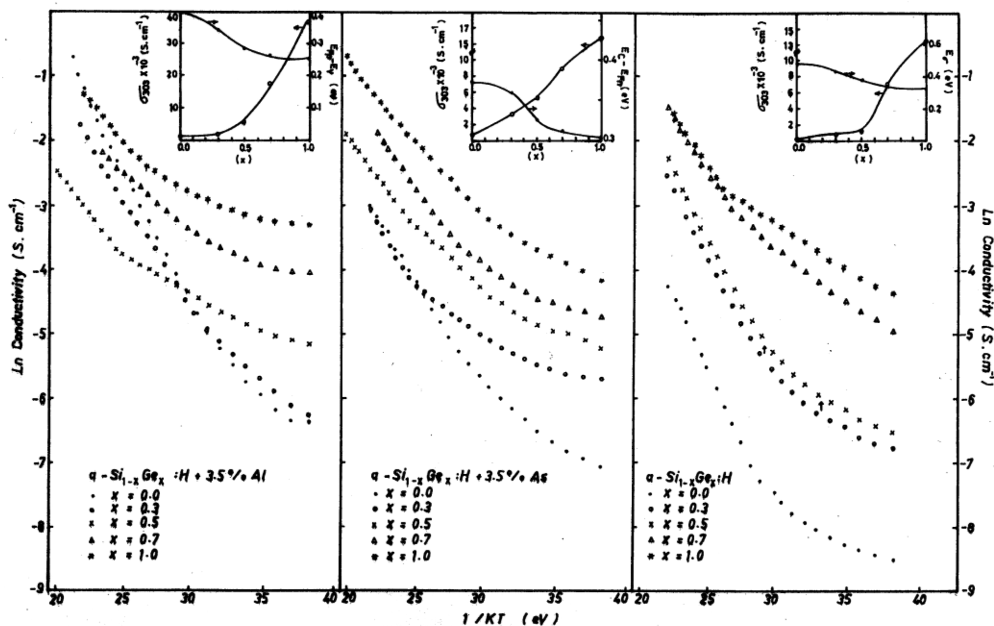

Fig. (1) ln σ vs. 1/KT for pure and doped a-$Si_{1-x}Ge_x$:H deposited at 503 K. The inset shows σ_{303} & E_σ vs. x.

and hopping at energy close to localized state near the conduction band. The third stage (303-373)K of conduction mechanism may be due to carrier transport to localized states near the Fermi level (E_F). We can notice that conductivity at room temperature (σ_{303}) and activation energy (E_σ) differ for each of the three types with various x which is shown in the inset of Fig. (1). The activation energy is slightly decreased with increasing x from 0.5 to 1.0, while the σ_{303} has strongly increased for three types of hydrogenated amorphous films. This may be due to the change in the states, structure and composition of films as well to the rearrangement of atoms on the surface of the substrate which yield fewer defect [12].

The Hall effect measurement for a-$Si_{1-x}Ge_x$:H thin films has been studied only by a very few researchers. Our Hall effect measurement for pure and Al doped a-$Si_{1-x}Ge_x$:H films confirm that holes were predominant in the conduction process (p-type), while the electrons were predominant for As doped films. Our data for the pure a-Ge:H and a-Si:H films were p-type in contrast with Clark results [13].

The Hall coefficient (R_H) were measured using the relation $R_H = - r / e N_H$, where N_H is the carrier density, in which r is the scattering coefficient (r = 1), and the Hall mobility (μ_H) was found using the relation [$\mu_H = | R_H | \sigma$]. It could be noticed in Fig. (2) that N_H is Ge content dependent for pure a-$Si_{1-x}Ge_x$:H films, such that N_H

increases slowly from 2×10^{16} to 20×10^{16} cm^{-3} with an increase of x from 0.0 to 0.5, while rapidly increases from 20×10^{16} to 800×10^{16} cm^{-3} for x > 0.5 up to x = 1. Our explanation is that the increase in Ge content cause to reduce the energy gap, then electrons need lower energy to transit Fermi level to valence band which caused to increase the charge carrier density, also the greater value of N_H for x > 0.5 caused wider valence band tail and shift Fermi level closer to valence band for p-type [2].

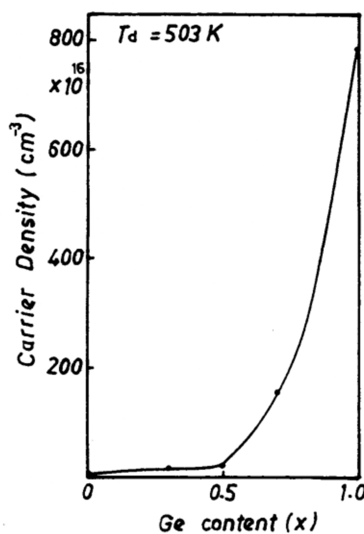

Fig. (2) Carrier densities of a-$Si_{1-x}Ge_x$:H films as a function of x.

Fig. (3) shows the variation of N_H for doped a-$Si_{1-x}Ge_x$:H films with Al and As (0-3.5)%. We should point out that N_H increased about one order of magnitude with increasing doping (As) from 0 to 3.5%, while the increase in Al dopant caused increase about one order of magnitude. Another noticeable result is that Al dopant is more active than as dopant. This confirms the higher value of conductivity and lower activation energy.

We should point out also, that N_H of pure and doped with 3.5% Al and 3.5% As of a-$Si_{0.5}Ge_{0.5}$:H films increases with increasing T_d. Apparently N_H for n- and p-type increased about three times with increasing T_d (303-503) K, while for pure films the increase was about one order of magnitude. Another noticeable result is that N_H for p-type is greater than its

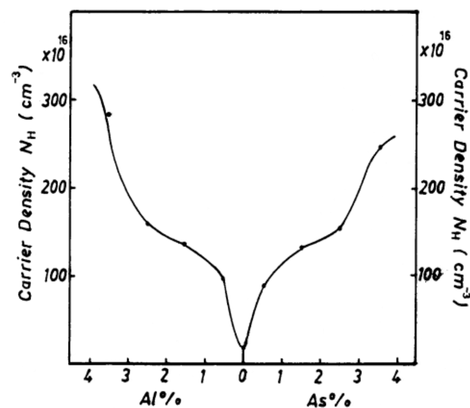

Fig. (3) Carrier density vs. dopant percentages of As and Al for a-SiGe:H films.

counterpart values of n-type and pure films.

Arrhenius plots of lnμ versus T^{-1} with various x for a-$Si_{1-x}Ge_x$:H film which deposited at T_d (503 K) are shown in Fig. (4). The mobility exhibit a linear dependence with temperature for different x. Another noticeable remark is that the μ increases with increasing temperature in the range (303-423) K.

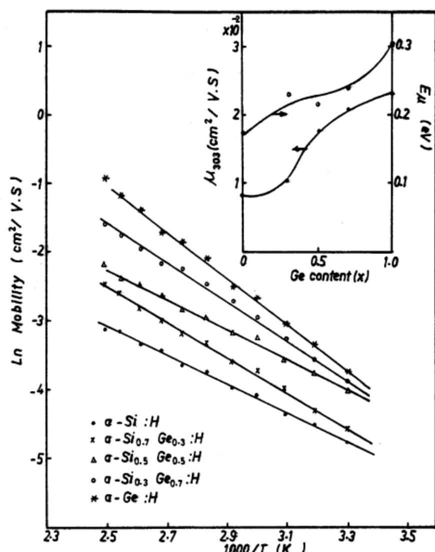

Fig. (4) Variation of ln μ vs. 10^3/T for pure a-$Si_{1-x}Ge_x$:H films with various x deposited at 503 K. The inset shows the variation of μ_{303} and E_μ vs. x.

We can deduce from this figure that the mobility at room temperature (μ_{303}) increases sharply about three times with increasing x (0-1) and its activation energy (E_μ) has increased from 0.17 eV for (x = 0) to 0.30 eV for (x = 1) as shown in the inset of Fig. (4). The variation of μ_{303} and E_μ versus type of films for pure and doped with 3.5% Al and 3.5% As of a-$Si_{0.5}Ge_{0.5}$:H thin films deposited at 503 K as shown in Fig. (5). It is interesting to note that μ_{303} decreases as going from pure to doped a- $Si_{0.5}Ge_{0.5}$:H films with 3.5% Al and 3.5% As about three and half, and two times respectively, whereas opposite behavior was observed for its E_μ. The decrease in μ_{303} can be explained as follows: doping has caused an increase in carrier density and impurity states which result in more collisions between carriers and also has been increased the trapping center of charge. Our results of Hall effect measurement are in agreement with the results given by Dresner et al. [13] for samples prepared by glow discharge. A similar behaviour of E_μ has been, also, observed also by Karg et al [14].

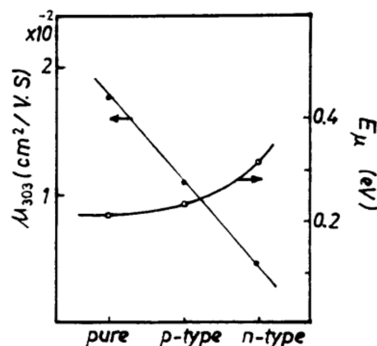

Fig. (5) Variation of μ_{303} and E_μ vs. type of films.

We observed from the comparison between conductivity and mobility with reciprocal temperature for pure a-$Si_{0.5}Ge_{0.5}$:H films deposited at 503 K, that E_μ and E_σ in the temperature range (303-423) K was 0.215 and 0.230 eV respectively. One can deduce that the localized level below the Fermi level by 0.015 eV as shown Fig. (6), so E_μ rising from trapping center in the range of deep localized states at the edge of conduction band and from the hopping in the same states at low temperature [11].

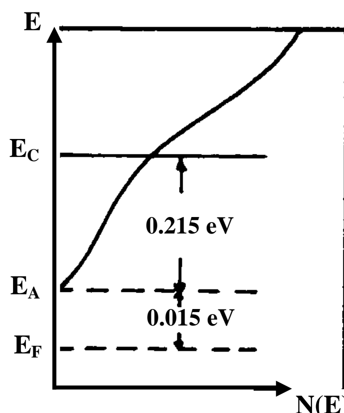

Fig. (6) Band structure of a-$Si_{0.5}Ge_{0.5}$:H film depo-sited at 503 K.

CONCLUSION:

The effect of Ge content, deposition temperature and dopant concentration (Al and As) on the electronic properties of successfully prepared a-$Si_{1-x}Ge_x$:H thin films prepared by thermal evaporation were carried out. Our main conclusion are summarized as follows:

1. Compositional analysis showed that our $Si_{1-x}Ge_x$ alloys as well as a- $Si_{1-x}Ge_x$:H thin films were stoichiometric.
2. The dc conductivity of a- $Si_{1-x}Ge_x$:H films increases with increasing Ge content, and the increase in dopant concentration caused exponential increase in σ_{303}, whereas E_σ decreases with increasing x and dopant concentration.
3. The carrier density increase about one order of magnitude with increasing dopant in the range (0-3.5)% As and Al, while the increase in N_H was about three times for p- and n-type with increasing T_d from 303 to 503 K, but for the pure films the increase was about one order of magnitude.
4. With increasing x from 0 to 1, μ_{303} increased about three times, while the increase was about six times with increasing T_d, whereas μ_{303} decrease with increasing doping Al and As.

References:

[1] D. Malinovska, L. Nedialkova and V. Kudoyarova, Solar Energy Material and Solar Cells, 30, (1993) 27.

[2] D. Malinovska, L. Nedialkova, Renewa. Energy, 5, Part III, (1994) 1682.

[3] S. Hazra, A. Middya and S. Ray, J. Phys. D., 29, (1996) 1666.

[4] K. Rajesh and D. Brodie, Thin Solid Films, 249, (1994) 254.

[5] P. Wickboldt, D. Pang and W. Paul, J. Appl. Phys., 81, (1997) 6252.

[6] A. Middya and S. Ray, J. Appl. Phys., 75, (1994) 7340.

[7] J. Xu, S. Miyazaki and M. Hirose, J. Non-Cryst. Solids, 208, (1996) 277.

[8] M. Alias, Optoelectronic study of a-Si-Ge-Al-(As):H Thin Films, Ph.D. Thesis, College of Science, University of Baghdad, Iraq (1998).

[9] M. Alias and M. Makadsi, Proceeding of the Third Jordanian Mechanical and Industrial Engineering Conference, (1999) 233.

[10] M. Makadsi and M. Alias, World Renewable Energy Congress VI (WREC 2000), (2000) 1948.

[11] N. Mott and E. Davis, Electronic Process in Non-Crystalline Materials. 2nd ed. University Press Oxford (1979).

[12] M. Alias, J. Coll. Educ. for Women, 8, 1, (1997) 127.

[13] J. Dresner, J. Non-Cryst. Solids, 58, (1983) 353.

[14] F. Kary, W. Krühler, M. Möller and K. Klitzing, J. Appl. Phys., 60, (1986) 2016.