Electrical and Optoelectronic Characterization of $CdTe_{1-x}Se_x$/ZnTe Heterojunction

Raheem G.Kadhu Boraq.Y.Kadhum, Mohsin.K.Abd
Department Physics,Colloge of Science ,Babylon University ,Babylon-Iraq

Abstract

Electrical and optoelectronic properties of $CdTe_{1-x}Se_x$/ZnTe Heterojunctions(x=0.1,0.2,and 0.3) have been investigated .C-V characteristics suggest that the fabricated heterojunction was abrupt type, built in potential determined by extrapolation from C^2-V curve to the point (V=0). Also from C-V measurements, we deduced that the built- in potential and the depletion layer width increases with increasing the value of x,while the charge carrier concentration decreases. The current-voltage characteristics of $CdTe_{1-x}Se_x$/ZnTe Heterojunction for the forward bias at dark condition shows that the ideality factor values varies with varing the value of x. Both the short circuit current and the open circuit voltage increases with increasing the value of x.The spectral responsively has peak at (840)nm wavelength.

ألخلاصه

تمت دراسة الخصائص الكهربائية و الكهربصريه للمفارق الهجينة $CdTe_{1-x}Se_x$/ZnTe عند قيم x مختلفة (x=0.1, 0.2 and 0.3) . أظهرت خصائص السعه – الجهد بان المفا رق ألمصنعه هي من النوع المفاجئ . إن جهد البناء الداخلي يمكن تحديده من تقاطع محور C^2 عند (V=0). كذلك من قياسات السعه- الجهد تمكنا من معرفة بان جهد البناء الداخلي وعرض منطقة النضوب تزداد مع زيادة نسبة x بينما يقل تركيز حاملات ألشحنه . من خصائص تيار- جهد للمفارق ألهجينه عند الانحياز الأمامي في الظلام لاحظنا ان قيم عامل المثالية تتغير بتغير x ، كذلك يزداد كلا من تيار الدائرة القصيرة وفولتية الدائرة المفتوحة بزيادة قيمة x .

إن طيف الاستجابيه لهذه المفارق تظهر قمة واحده عند الطول ألموجي 840 nm .

1. Introduction

Zinc telluride(ZnTe) is an important semiconductor material for the development of various modern technologies of solid state devices(blue light emitting diodes,laser diodes,solar cells,microwave devices,etc)[1-4]. The 11-V1 compound semiconductors have considerable potential for Integrated-optics applications due to their high electro-optics coefficients,wide transparency range from the visible beyond to 10 µm [5].Zinc Telluride (ZnTe) is a 11-V1 compound semiconductor with Zinc-blend structure with lattice constant of 6.1037 Å ,direct band gap of 2.26 eV at room temperature[6],and melting point of 1295 °c. ZnTe and its alloys may effectively be used as window materials in CdTe heterojunction solar cells.These thin films were also used in tandem solar cell structure,which utilizes CdZnTe as the absorber material,and for the fabrication of a CdZnTe/ZnTe quantum well structure[7].Since optical response is of great importance for many device applications,much work has been done to determine the reflectivity,band gaps,and refrective index of ZnTe.Because of its importance several works [8] have made a detailed study on structure of ZnTe thin films.They have observed that these films deposited on glass substrates kept at room temperature have cubic Zinc-blende type structure.Saleem[9] has carried out studies on the optical properties on ZnTe thin films and calculated the optical constants.Raheem G.K[10] has measured structural properties of ZnTe which used as heterojunction as $CdTe_{1-x}Se_x$/ZnTe.A theoretical model has been proposed by Pawlikowski[11]for ZnTe films and he determined the absorption coefficient near the fundamental absorption edge at normal incidence.Mondal *et.al*.[12] have reported the dependence of refractive index,absorption and extinction coefficients on incident photon energy (hυ)for ZnTe films deposited on glass substrates by hot wall evaporation technique.Akkad and Thomas[13]have prepared ZnTe-Cu thin films and measured the room temperature transmission and reflectivity in the wavelength range 300 nm.Rusu *et.al* [14] have deposited ZnTe thin films(d=0.12-180 μm) onto glass substrates by the quasi-closed volume technique under vacuum of 10^{-5} Torr.Optical gap was calculated from the absorption spectra situated in the range of (1.70-2.40)eV .However not much work has been carried out on substrate temperature and optical properties of ZnTe films and their dependence on substrate temperature(T_s).Hence, this paper reports about Electrical and Optoelectronic properties of $CdTe_{1-x}Se_x$/ZnTe Heterojunction.

2. Experimental details

2.1 The Preparation of $CdTe_{1-x}Se_x$ alloy:

The($CdTe_{1-x}Se_x$)compound was synthesized as alloy by using Cadmium,Tereluim and Selenium whose impurity is not less than (99.99%)and then weighting each element according to the atomic weight(Cd=112.4)and (Te=127.6) and (Se=78.96) by using sensitive electrical balance type (Metter H35AR),then mixing these elements. Quartz tube is carefully cleaned in order to remove dust, grease and other possible contaminants, then putting this mixture in it (height of the tube equals to 7cm) which is evacuated by using simple device .When the pressure reached ≈ (10^{-3} mbar), the tube is sealed put in electric furnace of type (Heraeui)and heated slowly to temperature 823 K for about five hours,then the temperature of the furnace was raised to 1023 K for about four hours and finally the temperature of the furnace was raised to 1223 K for about three hours, which is above the melting point of Cd(593K),Te(722.5K) and Se(440K).The quartz tube is periodically stirred to get well homogenous mixture,after that the ampoule was taken out,and cooled rapidly in cold water to reduce segregation and to obtain more homogenous ingot.

2.2 The Preparation of ZnTe alloy:

To prepare ZnTe alloy,appropriate atomic percentage of high purity(99.99%).Zinc (Zn) and Tellurium(Te) were taken by using sensitive electric balance type(Mettler H35 AR).

These elements were put in a clean and dry quartz ampoule to prepare ZnTe.

Then the ampoule was linked by specific design to the vacuum unit.When the pressure reached $2x10^{-5}$ mbar,the ampoule was sealed.Then the ampoule was heated with a rate of (5^0C/min) for (1523 K) using a programmable furnace type carbolite.

The ampole kept at the temperature for 3 hours.After that the ampoule was cooled down in furnace and then broken to bring out the alloy.

Films of $CdTe_{1-x}Se_x$(x=0.1,0.2 and 0.3) powder have been prepared by vapor deposition on glass substrate with 400 nm thickness under a vacuum pressure of the order($2x10^{-6}$ mbar),and at T_s=473K, procedure is as follows:

Weight the required amount of material and then placed into Molybdenum boat,the boat is mounted between two electrodes in the vacuum chamber.The vacuum system is pumped and befor arrival the pressure (10^{-6} mbar),pumping an inert Argon gas to the chamber and when the pressure is reached to steady-state an electric glow discharge has been used for about (15minute).

When the vacuum system reaches the pressure(10^{-6} mbar),the deposition process is carried out and at the end of deposition period,the chamber is allowed to cool at room temperature. The films are stored in inert gas to protect them from moisture.

Ohmic contacts for the prepared films are produced by evaporating Al electrodes of 200 nm thickness, by means of thermal evaporation methods,using Edward 's type E306A unit for this purpose.

3. Results and discussion

Electrical Measurement for $CdTe_{1-x}Se_x$ /ZnTe Heterojunction:

3.1 C-V Characteristics Measurement for $CdTe_{1-x}Se_x$ /ZnTe H.J:

The variation of capacitance as a function of reverse bias voltage in the range(0-0.3)volt at frequency equal to 1 kHz has been studied,for different values of x(x=0.1,0.2, and 0.3)at T_s=473K as shown in Figures(1,2,and 3).It is observed from the above figures that the capacitance decreases with increasing the reverse bias,but not in linear behavior that the capacitance becomes constant approximately at high voltages.This behavior due to the increasing of the depletion region width that causes an increasing in the built-in voltage.

We can see,that the capacitance increases with the decreasing of (x).This is attributed to the increase in the surface states which lead to the decreasing of the depletion layer,and increase the capacitance.The width of the depletion layer(W) can be calculated using equation (1),we can notice that the depletion width decreases with increasing the value of (x) due to the increasing in the carrier concentration which leads to increase the capacitance.

From the relation between inverse capacitance squared against the reverse bias at different values of (x) as shown in Figures(4,5, and 6) the plots reveal a straight line indicating that the junction was an abrupt type.

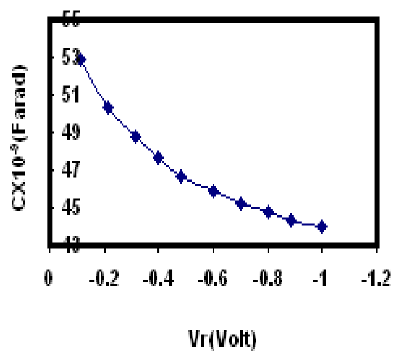


Fig.(1)The variation of capacitance as a function of reverse bias voltage for $CdTe_{0.9}Se_{0.1}$/ZnTe heterojunction

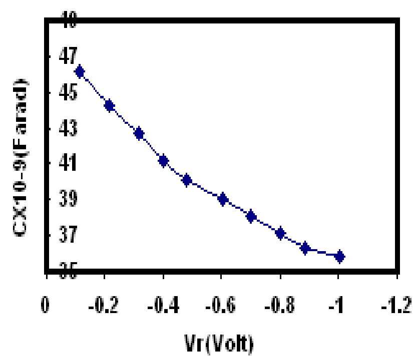


Fig.(2)The variation of capacitance as a function of reverse bias voltage for $CdTe_{0.8}Se_{0.2}$/ZnTe heterojunction

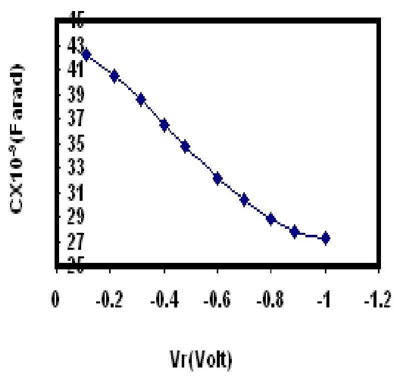


Fig.(3)The variation of capacitance as a function of reverse bias voltage for $CdTe_{0.7}Se_{0.3}$/ZnTe heterojunction

The interception of the straight line with voltage axis at ($1/C^2 = 0$), represent the built-in voltage (V_{bi}),we observed from Table (4.10) that the built-in voltage decreases with increasing the value of (x) as a result of the increase in the capacitance value and the decrease of the depletion width.

The slope yields the impurity concentration in the substrates,using equation(2).The slope of the curve is inversely proportional to the doping concentration,the values of N_A increase with increasing value of (x) as shown in Table (1).

The rise (τ_{rise}) and response time($\tau_{response}$) could be calculated from C_0 values using equations (3),(4) repectively as shown in Table (1),they increase with increasing the value of (x); the rise time values increases from $2.15x10^{-10}$ to $2.65x10^{-10}$ s.

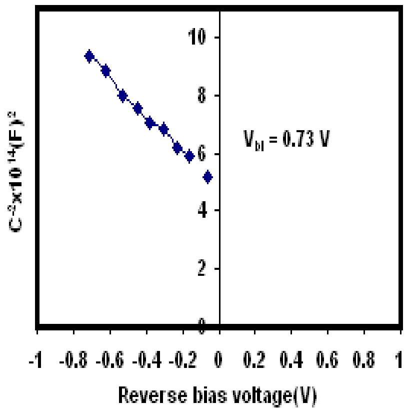


Fig.(4)The variation of $1/C^2$ as a function of reverse bias voltage for $CdTe_{0.9}Se_{0.1}/ZnTe$ heterojunction

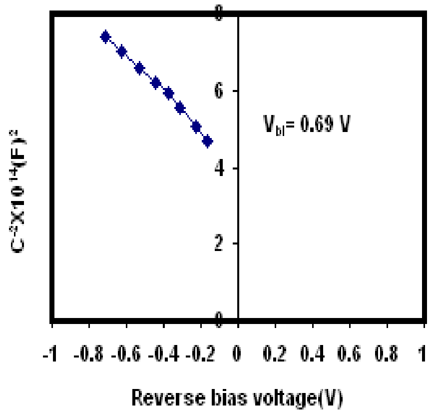


Fig.(5) The variation of of $1/C^2$ as a function of reverse bias voltage for $CdTe_{0.8}Se_{0.2}/ZnTe$ heterojunction

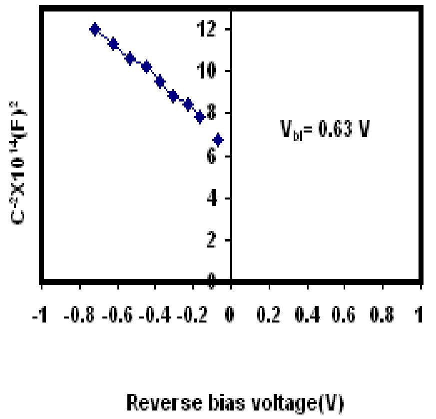


Fig.(6) variation of $1/C^2$ as a function of reverse bias voltage for $CdTe_{0.7}Se_{0.3}/ZnTe$ heterojunction

3-2 I-V Characteristics for $CdTe_{1-x}Se_x/ZnTe$ Heterojunction:

Current-Voltage (I-V) curves are the most commonly used characterization tool for photovoltaic devices.In this technique, the current is measured as a function of voltage of the heterojunction,in both light and dark.

Table 1. The variation of the C_0,W,V_D,N_A,τ_{rise}, $\tau_{response}$ with variation of x

Parameters	Variation of x		
	X=0.1	X=0.2	X=0.3
C_0 (F)	$44x10^{-9}$	$48x10^{-9}$	$53x10^{-9}$
W(μm)	0.51	0.59	0.64
V_{bi}(V)	0.73	0.69	0.63
$N_A(cm)^{-3}$	$3.89x10^{12}$	$2.21x10^{12}$	$1.78x10^{12}$
τ_{rise}(s)	$2.65x10^{-10}$	$2.4x10^{-10}$	$2.15x10^{-10}$
$\tau_{response}$ (s)	$1.20x10^{-10}$	$1.09x10^{-10}$	$0.97x10^{-10}$

3-2-1 I-V Characteristics for $CdTe_{1-x}Se_x/ZnTe$ HJ at Dark:

The current-voltage characteristics at dark are important parameters to identify the significance of the various components under reverse and forward bias.

The dark currents under reverse bias have various components.The total dark current in photodiodes can expressed as the relation(4.3).

For the forward characteristics, the dominant current is almost exclusively due to diffusion and surface generation-recombination[13].

Figures(7,8 and 9)show the I-V characteristics for $CdTe_{1-x}Se_x/ZnTe$ heterojunctions at dark for forward and reverse bias at different value of (x) at T_s= 473K.

For the forward characteristics,the dominant current is almost exclusively due to diffusion and surface generation-recombination[14].
The forward bias current can be divided into two distinct regions:

1. The Low Voltage Region:
The recombination current dominats at low bias voltage(lower than $3k_BT/e$).This current develops the number of product of generated majority. The minority charge carriers is greater than that of the square intrinsic carrier (i.e. $nxp > n_i^2$).To reach equilibrium there is recombination.

2. The High Voltage Region:
The diffusion current in the forward bias dominates for bias value (greater than $3k_BT/e$).This behavior fits well with the shookley equation.
The reverse bias current can be divided into two distinct regions:

A. The Low Voltage Region:
In this region,the current increases with the increasing the applied voltage,and the generation current dominates which is expressed by the relation (6).

B. The High Voltage Region:
The reverse bias stabilizes and becomes independent of the bias potential.This is called the diffusion current(I_{dif}),which is given as relation (6).
It appears from figures(7,8and 9)that current decrease with increasing value of (x) due to decreaing in the resistivity,we explain as follows:
The trapping centers cause by the impurity and defects in the crystal structures,and it acts as trapping centers of electrons and holes that causes to bind it for limiting period, which increase the electrical conductivity.
At increasing value of (x) these trapping centers would capture the holes instead of electrons due to the lifetime of holes larger than that of electrons; this causes to increase the material receptivity[15].
We can notice from the above figures that the value of the current decrease with increasing value of (x) due to the decrease in the grain size (as we see in the x-ray diffraction analysis).

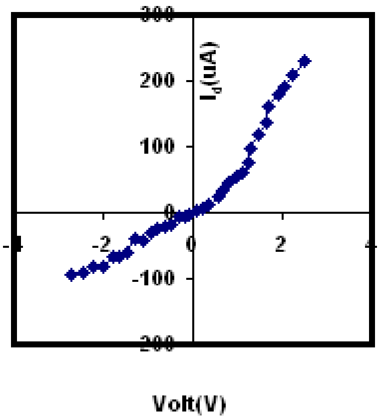


Fig.(7)I-V characteristics for $CdTe_{0.9}Se_{0.1}/ZnTe$ heterojunction at dark for forward and reverse bias at Ts= 473K

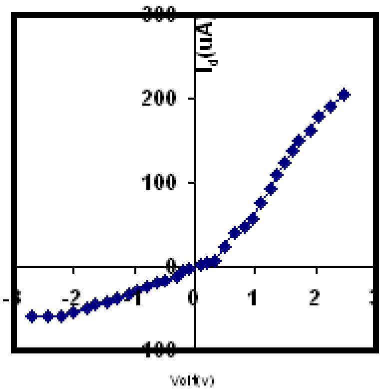


Fig.(8)I-V characteristics for $CdTe_{0.8}Se_{0.2}/ZnTe$ heterojunction at dark for forward and reverse bias at Ts= 473K

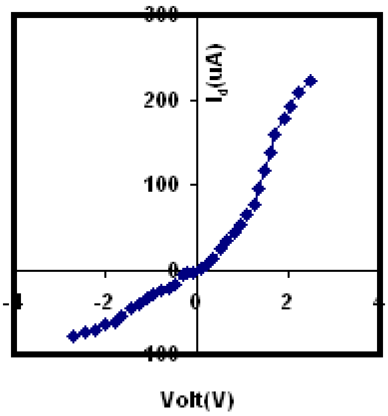


Fig.(9)I-V characteristics for $CdTe_{0.7}Se_{0.3}/ZnTe$ heterojunction at dark for forward and reverse bias at Ts= 473K

Semi-log I-V characteristics for the forward bias is presented in Figure (10).The ideality factor(β),which is calculated in the first region using equation(8),decreases with increasing value of (x)due to the decreasing of the interfacial dislocations at the interface of the heterojunction.This

produces a small number of electrically active interface states. These interface states like the surface states are both acceptor and donor in nature[13].
The mechanism of charge carrier transport vary with the variation of the value of (x). At T_s =473 K , when x=0.1.The ideality factor value β=2.20,the mechanism coincide with emission models. At T_s=473K and x=0.2 ,the value of β=1.96.So,the mechanism in this case agrees with emission-recombination models, at T_s=473K , and x=0.3 ,β=1.75.In other words, the mechanism of transport is due to the tunneling model[14]as shown in Table(2).
The height barrier was 0.75,0.72 and 0.70 respectively as shown in Table (2).

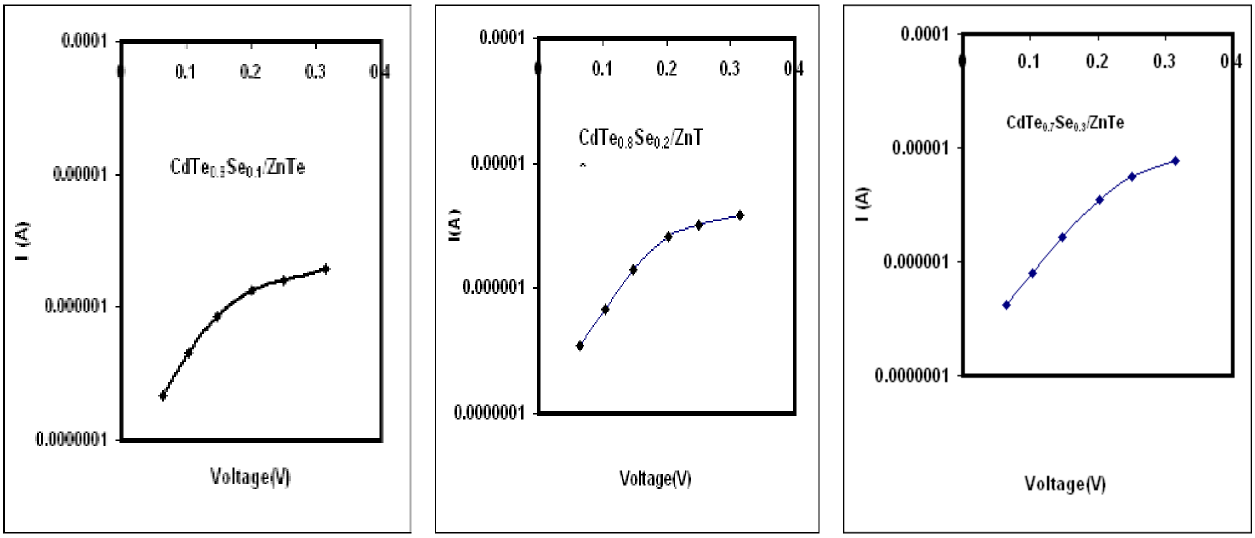


Fig.(10)The I-V characteristics at forward bias voltage on semilogarithim scale for $CdTe_{1-x}Se_x$/ZnTe heterojunction at T_s= 473K.

3-2-2 I-V Characteristics for $CdTe_{1-x}Se_x$/ZnTe HJ Under Illumination:

The photocurrent is the current generated by the absorption of photons;it is considered as an important parameter, which acts on the spectral responsivity .
A photovoltaic effect occurs in a material in which there is a space charge a photoexited electron-hole pair enters the layer, the layer,when the electron and hole are separated by the space charge field to give a photocurrent, the magnitude of the electric field in the space charge region decreases so the receptivity inverses[16].

The photocurrent is always in the reverse bias direction due to its increases by increasing the depletion region width.

Increasing the reverse bias voltages leads to increase the internal electric field which leads to an increasing the probability of the separated electron-hole pairs.The photocurrent increases with increasing the incident power intensity,due to the increasing the number of the generated photocarriers in the depletion region with the diffusion depth for carriers. These depends on the life time of the minority carriers on the two sides of the depletion region[17].
The variation of the reverse current under illumination for different value of (x) at T_s=473K are shown in Figures.(11,12 and 13).

The photocurrent increases with increasing the value of (x)which is due to the increasing in the grain size and reducing in the grain boundaries.These lead to increase the mobility and increase the photovurrent and increase the depletion width.This, in turn,leads to increase the absorption through it and the creation of electron-hole pairs.

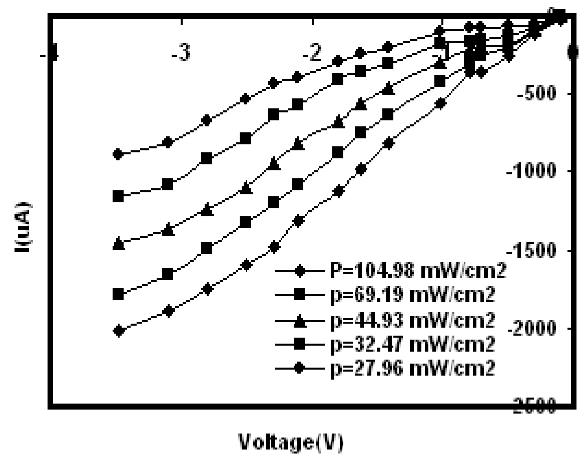


Fig.(11) The I-V characteristics at reverse bias voltage at illumance for $CdTe_{0.9}Se_{0.1}$/ZnTe heterojunction at Ts= 473K

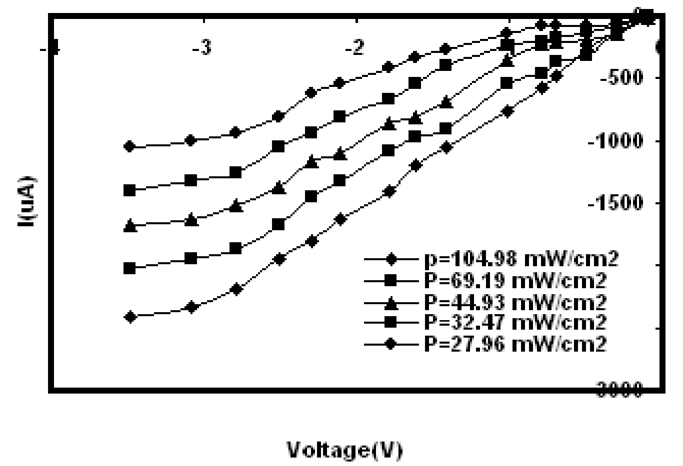


Fig.(12) The I-V characteristics at reverse bias voltage at illumance for $CdTe_{0.8}Se_{0.2}$/ZnTe heterojunction at Ts =473K

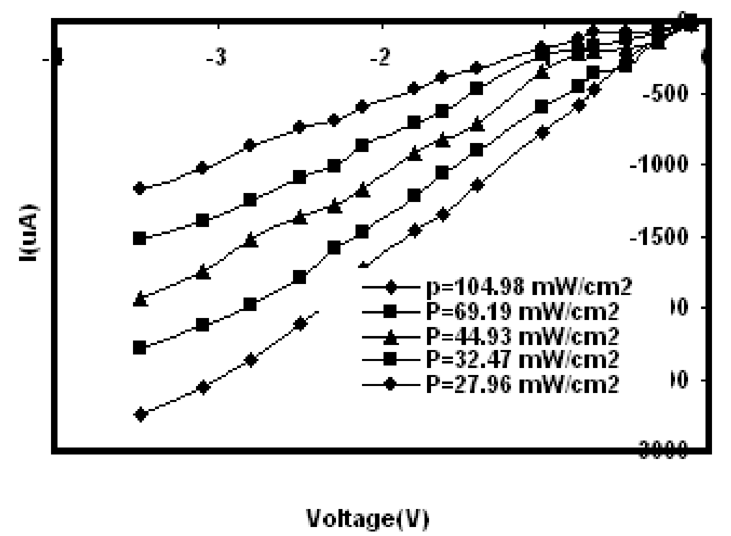


Fig.(13) The I-V characteristics at reverse bias voltage at illumance for $CdTe_{0.7}Se_{03}$/ZnTe heterojunction at Ts =473K

3-3 Short Circuit Current and Open Circuit Voltage Measurements for $CdTe_{1-x}Se_{1-x}$/ZnTe HJ:

The short circuit current(I_{sc}) and the open circuit voltage(V_{oc}) are the basic distinction between photovoltaic heterojunction and the sorts of heterojunctions because it demonstrates the region at which the heterojunction operate in,due to the separation of the electron-hole pairs by the internal electric field with out an applied external electric field.

The variation of the I_{sc} with the light power intensity for $CdTe_{1-x}Se_x/ZnTe$ heterojunction at various values of (x) at T_s is shown in Fig.(14,15, and 16) can be divided into two regions:

A linear region at low values of the power intensity in the range (26-50) mW/cm^2 at which the current increases slightly with the increasing the power intensity and the saturation region at higher values of the power intensity > 52 mW/cm^2 as a result of excitation and separation of the electrons from their atoms by the incident photons.

The I_{sc} increases with the increasing the value of (x) due to the increase of the energy gap which is caused due to the decrease in the density of state.The reason behined this is that agreat number of photons have enough energy to create electron-hole pairs when the photon energy is larger than the energy gap[16]as shown in Table 2.

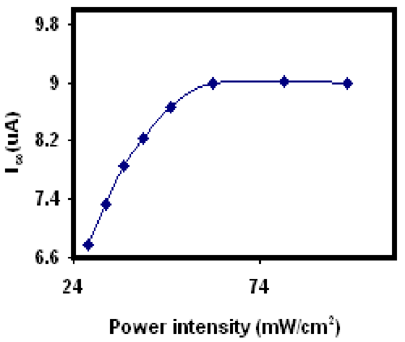


Fig.(14) Short circuit current versus light power intensity for $cdTe_{0.9}Se_{0.1}/ZnTe$ Heterojunction

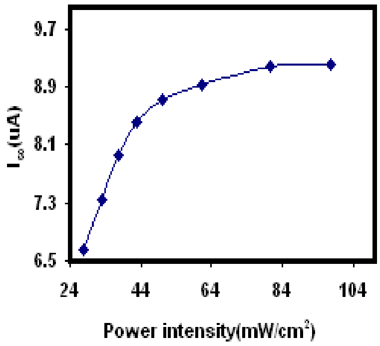


Fig.(15)Short circuit current versus light power intensity for $CdTe_{0.8}Se_{0.2}/ZnTe$ Heterojunction

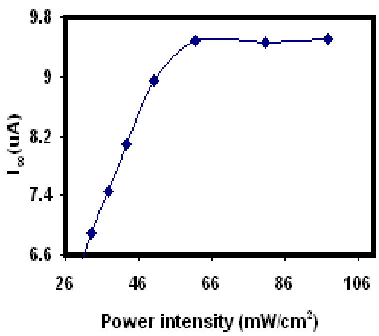


Fig.(16) Short circuit current versus light power intensity for $CdTe_{0.7}Se_{0.3}/ZnTe$ Heterojunction

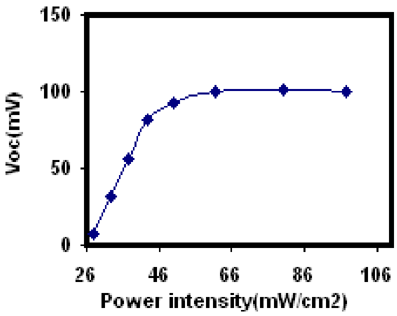


Fig.(17).Voltage open circuit versus light power intensity for CdTe0.9Se0.1/ZnTe Heterojunction

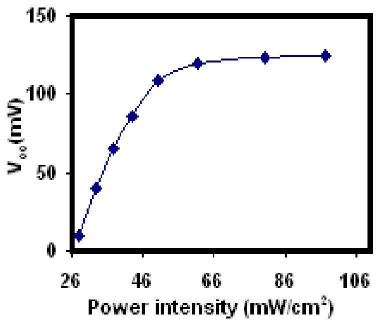
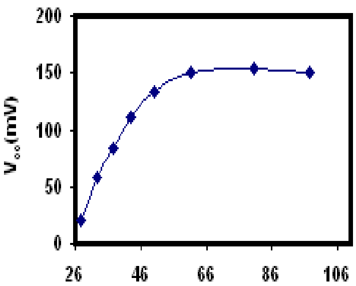


Fig.(18)voltage open circuit versus light power intensity for $CdTe_{0.8}Se_{0.2}/ZnTe$ Heterojunction



Power intensity (mW/cm²)
Fig.(19)Open circuit voltage versus light power intensity for $CdTe_{0.7}Se_{0.3}/ZnTe$ Heterojunction

The variation of the V_{oc} with power intensity at different values of (x) are shown in Figures (17,18,and 19).We can observe that the figures could be divided into two regions:

The first regions in the range(22-64)mW/cm^2 (i.e the low illumination intensity).The V_{oc} increases slightly with increasing the power intensity whereas,the second region for the higher power intensity exhibited a saturation behavior.The small values of incident intensity determines the generation rate and proportional to it,the V_{oc} is proportional to the incident intensity up a limit,whereas for large values of the incident intensity this is certainly not so. Approximately saturated condition is set up in which the voltage increases logarithmically with the incident intensity [16].

The V_{oc} increases with increasing the value of (x) as shown in Figures (20,21,and 22),which is due to the decrease the recombination processes in the semiconductors by the trapping levels in the depletion region (which being active in this region[16]as shown in Table(2).

3-4 Spectral Measurements for $CdTe_{1-x}Se_x$/ZnTe Heterojunctions:

The mechanism by which photocurrent produced is by photon absorption in the heterojunction energy gap regions may be analyed as follows:

Figures(20)presents a spectral response of $CdTe_{1-x}Se_x$/ZnTe Heterojunction fabricated .This response was measured for spectrum of interest and was (400-1000)nm.It is noted that the responsivity curve shows good band-pass behavior(window effect),and it is comprised of three distinct regions. The first region(corresponding to the wavelengths shorter than 800 nm) shows an increase in responsivity with wavelength and attains the maximum value at λ = 780 nm.The lower responsivity at the shorter wavelength region may be due to the absorption of the light near the surface (shallow absorption depth)which has large amount of surface recombination of the photogenerated carriers

The second region (830-930)nm represents the region that the high responsivity was obtained,wherein it is to suppose obtaining absorption for light among the depletion layer or on the sides of it by a distance equality to the depth of carriers diffusion.The mean high efficiency to separate the couples is recombined by the internal electric field and the littleness of the recombination operations in comparsion with the first region[18].The third region shows that the responsivity decreases with increase in wavelength.The smaller responsivity at longer wavelengths is attributed to the absorption at the long wavelength obtained among the material and that caused bulk recombination operations.For that reason the probability gathering the carriers in the depletion region was little ,in other way decreased in the responsivity .

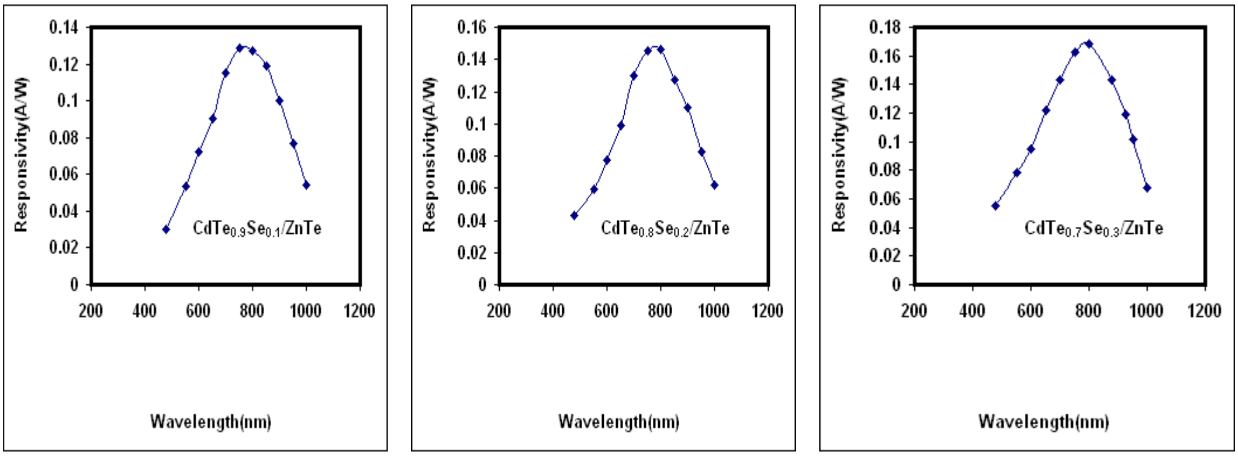


Fig.(20) Spectral response of $CdTe_{1-x}Se_x$/ZnTe heterojunction

Table 2. The parameters of $CdTe_{1-x}Se_x$/ZnTe photovoltaic heterojunctions and Ideality factor(β),Height barrier and photopesponsivity

Heterojunctions	V_{bi} (V)	Ideality factor(β)	Height barrier(eV)	I_{sc}(μm)	V_{oc}(mV)	R_λ(A/W)
$CdTe_{0.9}Se_{0.1}$/ZnTe	0.73	2.20	0.75	9.1	100	0.13
$CdTe_{0.8}Se_{0.2}$/ZnTe	0.69	1.96	0.72	9.2	125	0.15
$CdTe_{0.7}Se_{0.3}$/ZnTe	0.63	1.75	0.70	9.5	150	0.17

Conclusions

1.The electrical and photovoltaic characteristics of $CdTe_{1-x}$ Se_x / ZnTe heterojunction strongly depends on the preparation substrate temperature and the value of x .

2. I-V characteristics showed that the anisotype n-$CdTe_{1-x}$ Se_x / p-ZnTe heterojunction obeys the tunneling –recombination model.

3.C-V measurements revealed that n-$CdTe_{1-x}$ Se_x / p-ZnTe heterojunction Are of an abrupt type.

4. The spectral responsivity for n-$CdTe_{1-x}$ Se_x / p-ZnTe heterojunction included one peak at λ = 840 nm.

References

1. M.Jain(ed),1993,” 11-V1 Semiconductor Compounds”,World Scientific,Singapor.
 11-V1 Semiconductors,Inspec.London. R.Bhargava (ed),1997,Properties of Wide 2.
3 . M.Schall,M.Walther,P.Uhd Jepsen,2001,Phys.Rev.B64,94301.
4. G.I.Rusu,P.Prepelita,N.Apetroaei,G.Popa,2005,The Electronic Transport and Optical Properties of ZnTe thin films,Jornal of Optoelectronics and Advanced Materials,Vol.7,No.2,P.829-835.
5. R.Amutha,A.Subbarayan, and R.Sathyamoorthy,2006,”Influnce of substrate temperature on microcrystalline structure and optical properties of ZnTe thin films”,Cryst.Res.Technol.Vol.41,No.12,p.1174-1179.
6. M.Nishio,K.Hayashida,Q.Guo,and H.Ogawa ,2001,Appl.Surf.Sci,Vol.129,No.223.
7. B.Maiti,P.Gupta,S.Chaudhuri,and A.K.Pal,1994,Thin Solid Films,Volume,239,No.239.p. 1322-1328.
8. U.Pal,S.Saha,A.K Chaudhuri,V.V.Rao,and H.D.Banerjee,1989,Optical properties
9. S.Ezara ,2006,Study of Al-CdTepAl and Al-ZnTe-Al for switching applications, PhD Thesis,Baghdad university.
10. R.G.K Almorshdy,2007,”Study of structural,electrical and optical Characterization of the Heterojunction $Cd(Te_{1-x}Se)$/ZnS(Te)”,PhD Thesis,Baghdad university.
11. J.M.Pawlikowski,1985,”The effect of thickness on some optical properties of ZnTe films”,Thin Solid Films,Vol.39,No.127..p 798-805.
12. A.Mondal,S.Chaudhuri,and A.K.Pal,1987,”Study of some optical properties of ZnTe films by hot wall evaporation technique”,Appl.Phys.A,Vol.43,N0.81, p.2321-2326.
13.Yoon Soo Park , 1998, ” Journal of the Korean Physics Socieaty ” , Vol.32,N0.3, p.443-451.
14. Ahmettevke and Cengin , ”Solid State Electronics” ,Vol.42,No.6,1998,pp.1039-1044.
15. M.Pollak,1971,Phil.Mag. , Vol .123, p.519.
16. E.D.Hinkley and R.H.Rediker, 1967, ” Solid State Electronic ” , Vol.10, ,pp.671-687.
17. A.S.Grove , 1967,” Physice and Technology of Semiconductor Devices ”, John Wiley and Sons, Inc , Calefornia ,
18. R.A.Smiith , F.E.Jones and B.p Chasmer, 1986. ” The dedection and Measurement of Infrared Radiation ” ,2nd ed., Oxford.