Optoelectronic Properties of CdSe/Si Heterojunction

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ABSTRACT

In this paper *n*-CdSe/*p*-Si heteroj unction photodetector was fabricated by thermal-evaporation technique of CdSe thin film grown onto single crystalline Si substrate . The energy gap of CdSe film was estimated from transmittance spectra and found to be (1.89 eV) . The temperature dependence of Seebeck coefficient was studied . The conductivity of CdSe thin film is *n*-type and the value of activation energy is (0.59 eV). Heterojunction properties included dark and illuminated current-voltage (*I-V*) and capacitance-voltage (*C-V*) characteristics. From *I-V* plot, junction ideality factor for heterojunction was calculated to be 1.43, and providing information about the current transport mechanism. The linear variation of the experimental curve C^{-2} vs. V is indicative of the presence of abrupt heterojunction and it used to determine the experimental value of built-in-junction potential V_{bi} . From illuminated *I-V* plot at different intensity levels (90,180,240) mW/cm^2 , the linearity behavior of CdSe/Si heterojunction was investigated .

Keywords: CdSe thin film; Si; Heterojunction; Thermal evaporation; Energy band gap; Seebeck coefficient; *I-V* characteristics; *C-V* measurements.

الخصائص الكهروبصرية للمفرق الهجين CdSe/Si

الخلاصة

في هذا البحث تم تصنيع كاشف ضوئي من المفرق الهجين *n*-CdSe/*p*-Si بتقنية التبخير الحراري في الفراغ لأغشية CdSe المنماة على قواعد من السيليكون Si احادي التبلور . ان قيمة فجوة الطاقة لأغشية CdSe المحضرة حددت من خلال دراسة طيف النفاذية للأغشية والتي بلغت حوالي (1.89 eV) . من خلال دراسة تغير معامل سيبك مع درجة الحرارة تبين ان نوع التوصيلية لأغشية CdSe هي من النوع المانح *n*-type وان قيمة طاقة التنشيط لهذه الأغشية هي (0.59 eV). تضمنت خصائص المفرق الهجين دراسة خصائص تيار- جهد في حالتي الظلام والاضاءة وخصائص سعة – جهد . بينت خصائص تيار- جهد ان قيمة عامل المثالية للمفرق الهجين كانت (1.43) ، اضافة الى توضيح الية نقل التيار عند مناطق الفولتيات الواطئة والعالية . ان العلاقة الخطية مابين مقلوب مربع السعة C^{-2} وفولتية الانحياز العكسي V اوضحت ان المفرق الهجين غير المتماثل من النوع الحاد وأستخدمت هذه العلاقة في تحديد قيمة جهد البناء الداخلي للمفرق . من خلال دراسة خصائص تيار- جهد في حالة الاضاءة عند قدرات ضوئية مختلفة mW/cm^2 (90,180,240) وجد ان المفرق الهجين CdSe/Si يعطي خصائص خطية جيدة لمديات القدرة الضوئية الساقطة .

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INTRODUCTION

Among chalcogenide semiconductors ,II-VI compound chalcogenide semiconductors have drawn interest of many researchers, due to their direct and rather large bandgap . Actually, these semiconductor materials are important because of their applications in optoelectronic devices and thus, have received much attention [1-3]. CdSe is one of such compound in this group having suitable energy gap (1.74 eV) with high absorption coefficient near the band edge and offered heterostructure formations, which makes it an interesting material for many opto-electronic devices such as photoelectrochemical (PEC) cells , solar cells, light emitting diodes, gas sensors, photo-detector, electron-beam pumped lasers, etc [4-6].

In the case of heterojunctions , the properties of the interface vary greatly from material to material and largely depend on the method of formation . Literature survey on heterojunction devices fabricated using various methods in combination such as, chemical-displacement technique, chemical vapour deposition, liquid epitaxial growth, alloying method, coevaporation technique, electrodeposition, sputtering method, etc, although the method of fabrication is particularly important since heterojunction properties are invariably observed to be a function of the manner [7,8]. Among other preparation techniques single evaporation technique under vacuum is a very convenient method for obtaining uniform films under different deposition parameters. Perna et al. [9] have prepared CdSe and Zn-doped CdSe (CdSe:Zn) thin films on silicon (Si) substrates using pulsed laser deposition technique and studied their properties using electrical, structural, optical, photoluminescence, and raman spectroscopic measurement techniques . Maly et al. [10] report the luminescence properties of CdSe nanocrystalline films prepared by chemical bath deposition technique onto (100) surface of silicon single crystal of the *p*-type with resistivity of approximately 10 ΧΩm . G. Perna & V. Capozzi. [11] study the structural and optical properties of CdSe thin films deposited by laser ablation technique on silicon (100)- and (111)- oriented substrates . Konda et al. [12] prepared ***pn*** heterojunction diode , consisting of *n*-CdSe/*p*-Si by pulsed laser deposition technique and study surface plasmon excitation via Au nanoparticles .

The aim of the present work is to study the optoelectronic properties of *n*-CdSe/*p*-Si heterojunction based on thermal evaporating method of CdSe thin films grown onto single crystalline silicon substrate .

EXPERIMENTAL

Heterojunction was prepared by evaporating a layer of CdSe with thickness of approximately (0.4µm) onto single crystal *p*-type silicon substrate . The CdSe film was deposited by single evaporating technique of CdSe high purity (99.999%) powders from a resistance heated crucible . The deposition chamber was evacuated to a residual pressure between 10^{-5}-10^{-6} torr before starting the deposition process, The film deposited at room temperature and kept inside the deposition chamber for 24h to achieve the metastable equilibrium .

Film thickness was measured by gravimetric weight difference method after and before films deposition using a sensitive microbalance (K-Roy instruments) and the rate of error (±0.02µm).

The optical transmittance spectrum of CdSe films deposited on glass is recorded from (400-900nm) wavelength using (metertech UV-VIS-NIR spectrophotometer, SP 8001) at room temperature (300K). Absorption and transmission spectra are obtained directly through the computer connected with spectrophotometer.

It is well known that electronic properties of polycrystalline thin films are strongly influenced by their structural characteristics and nature of purity .To determined the type of conductivity thermo emf (Seebeck) was measured for the sample by establishing a temperature gradient and measuring the resulting voltage across the ends of each sample .The Seebeck coefficient (*S*) of CdSe film was measured using thermoelectric power measurements in the temperature range (303-343)K , Seebeck voltage was determined by a standard potentiometric method using a Keithley 616 multimeter.

The temperature dependence of the Seebeck coefficient can be accounted using the following relation [16]:

$$S = \frac{k_B}{q}\left[\frac{(E_C - E_F)}{k_B T}\right] \quad (1)$$

where *S* is the Seebeck coefficient, k_B is the Boltzmann's constant , $\Delta E_s = E_C - E_F$ is the activation energy for the thermoelectric power , T is the absolute temperature .

From current-voltage (*I-V*) characteristic in dark the sample was fixed in a dark chamber , this data was obtained by applying a dc voltage from (FARNELL DC. Power supply LTD) a cross the diode and measuring the current with a Keithley model 616 Digital electrometer . These measurements were made for a range of (0.1 to 0.45) Volts . From *I-V* characteristic in photo, the data was obtained by measured the current as a function of bias voltage under different white light intensities ranging from (90 – 240) mW/cm^2.

The measurements of capacitance-voltage (*C-V*) characteristic were made using (LCR Meter operating instructions) at frequency of (100 kHz) and DC. bias ranging from (0 to 6)V .

RESULTS AND DISCUSSION

Optical properties of CdSe films

Optical transmittance in the visible region for CdSe thin film is shown in (Figure.1) . The transmittance starts with wavelength from 400nm to approximately 800nm . For wavelengths larger than 800nm the transmittance remains almost constant at a net value (whole sample film and substrate) which is typically between 77% and 80% . The CdSe films are highly tranaparent (≥ 80% transmission over the white light spectrum), therefore a large fraction of light passes through this wide band-gap window and is absorbed in silicon to produce photogenerated carriers [13].

The absorption coefficient (α) and energy gap (E_g) were calculated using the following classical relation for near absorption edge in semiconductor [5]:

$$ahu = A(hu - E_g)^{1/2} \tag{2}$$

where h is the planck constant , u is the photon frequency, A is a constant, E_g is the direct energy gap. The plot of $(ahu)^2$ vs hu is shown in (Fig.2) which is linear at the absorption edge, indicating a direct transition. The energy gap is determined by extrapolating the straight line portion to the energy axis at $(ahu)^2$=0, the intercept gives the value of energy gap which is found to be 1.89 eV for CdSe films , this result is agree well with the value reported elsewhere [14].

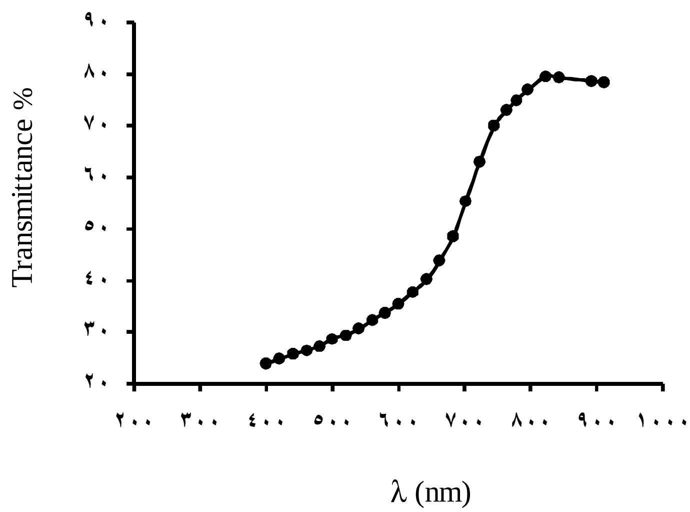

Figure (1) Transmittance spectrum of CdSe thin film

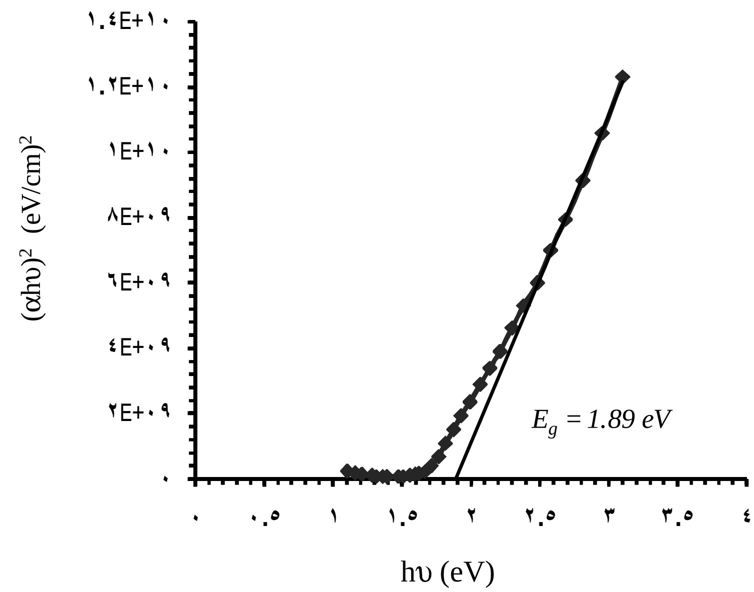

Figure (2) (a hu)^2 versus hu plot of CdSe thin film.

Electrical properties of CdSe films

The thermo emf voltage was found to be negative in sample. Hence the sign of the Seebeck coefficient was negative , indicating that the electrons are the majority charge carriers and the studied samples have *n*-type conduction [5,15] .

The Seebeck coefficient was found to increase with increasing temperature as can be shown in (Fig.3) . From $S= f(10^3/T)$ dependence [4] , the value of Seebeck coefficient (S) is (-0.4×10^{-3} V/K) at room temperature and the activation energy of CdSe film is found to be (0.59 eV) in the temperature range (303-343)K . This behavior has been usually found for CdSe films [4], where Se vacancies (Cd donor excess) are present.

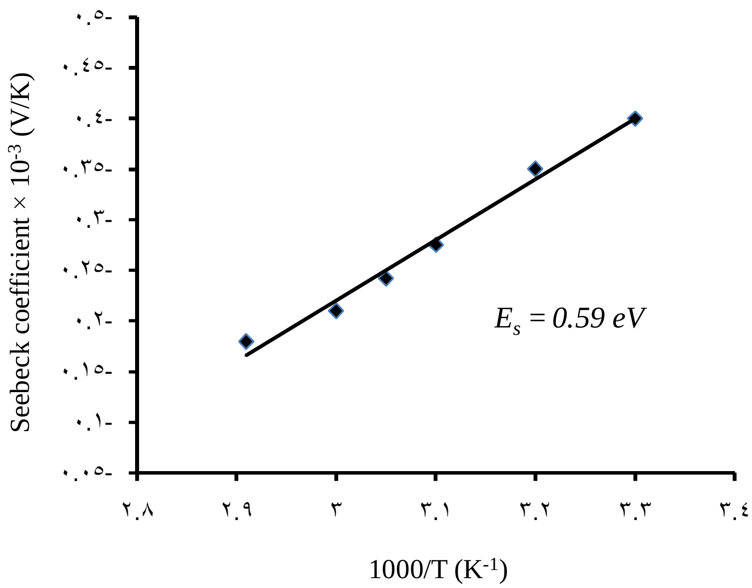

Figure (3) Temperature dependence of Seebeck coefficient For CdSe thin film.

CHARACTERIZATION OF *N*-CDSE/*P*-SI HETEROJUNCTION

Current - voltage characteristics

Dark I-V characteristics of *n*-CdSe/*p*-Si heterojunction is shown in (Figure.4). The measurement was made in the range of (0.1 to 0.45)V. For relatively small forward bias, the dependence of current on voltage is exponential which is given by the diode equation [17]:

with
$$I = I_s\left[\exp\left(\frac{qV}{nk_BT}\right)-1\right] \tag{3}$$

$$I_s = B\exp\left[-\frac{q(\Delta E_c + V_{bi})}{k_BT}\right] \tag{4}$$

where I_s is the reverse saturation current, V is the applied voltage and n is the junction ideality factor of the diode which is related to the various physical properties of the heterojunction.

The magnitude of (I_s)yields information about the current path involved; a high reverse saturation current indicates transport via the semiconductor heterointerface

[8]. ΔE_c is the discontinuity in the conduction band edges of the two semiconductors , B is a constant and V_{bi} is the built-in voltage [17].

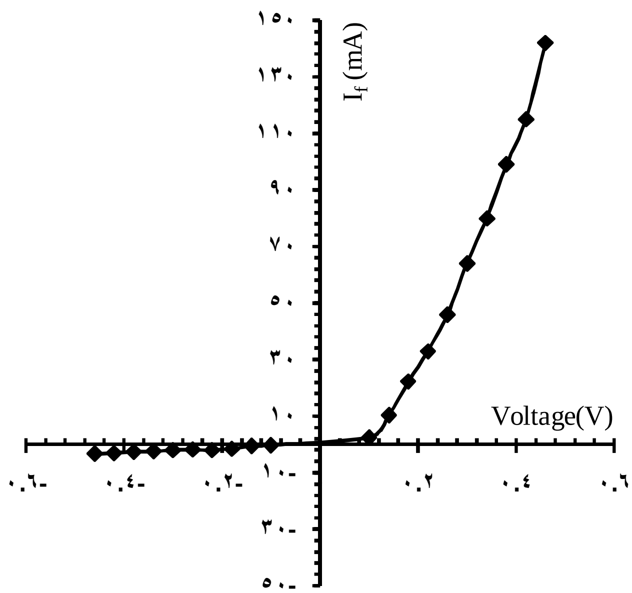

Figure (4) Current-voltage characteristics for N-CdSe/p-Si heterojunction

Depending on the polarity of the applied voltage these characteristics can be classified as forward or reverse bias. A typical forward-bias characteristics, is shown in (Figure.5) , The forward bias characteristics of *n*-CdSe/*p*-Si heterojunction can be divided into two distinct regions at room temperature. In the low-voltage region (for voltage < 0.2 V) the current contribution is mainly due to the recombination-limited current and can be represented by an expression similar to equation (3) with (*n*) having a value of 1.43 , estimation from linear nature of plot. While, in the high-voltage region the current due to tunneling dominates across the junction [7], so that carrier transport mechanism is coincide to the tunneling-recombination mechanism. These results are in agreement with Donnelly and Milnes for some heterodiode [18]. The value of reverse saturation current density (J_s) can be calculated from the intercept of the straight line with the current axis at zero voltage bias , which is found to be 8×10^{-3} A/cm^2 .

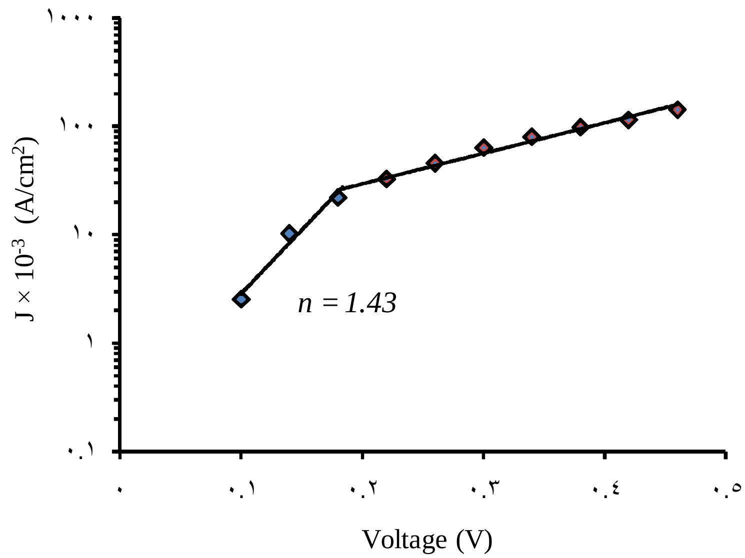

Figure (5) forward bias characteristics of a (n-CdSe/p-Si) heterojunction at room temperature.

Illuminated I-V characteristics

The dark current-voltage characteristics of heterojunction , already discussed in the previous section , get modified when they are irradiated with photons . The modified expression for current-voltage relation of an ideal anisotype heterojunction, can be written as [7,19]:

$$I = I_S\left[\exp\left(\frac{qV}{k_BT}\right)-1\right]-I_{ph} \tag{5}$$

where I_{ph} is the photocurrent and I_S is the dark reverse saturation current . This characteristics determine the performance of the detector and its suitability for use . Figure.(6) shows the plot of the values of current as a function of reverse bias voltage at different photo-power density (90, 180, 240) mW/cm^2. Noting increase photocurrent with increasing reverse bias voltage at a certain photo-power density , the reason is due to light absorption in the depletion region (this is a result due to increase in the width of the depletion region) [20]. Thus we get rise the number of photons absorbed through the depletion region or area within the vicinity, leading to increased density of photo generated charge carriers, which that contributes to the photocurrent. It is possible to note that increasing the power of the incident light results in increasing the photo-current.

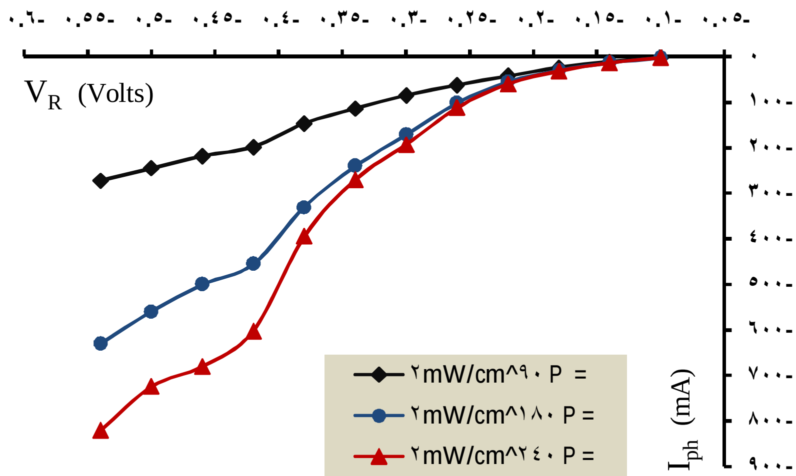

Figure (6) Reverse bias characteristics under illumination at different intensity level .

Figure(7). shows that good linearity characteristics of *n*-CdSe/*p*-Si heterojunction , as the figure shows a good linearity of photo-current versus power density, reflecting the possibility of operating *n*-CdSe/*p*-Si junction diode as a measure of the photo power density through the work of the calibration scheme. No saturation effect has been observed even at high light intensity.

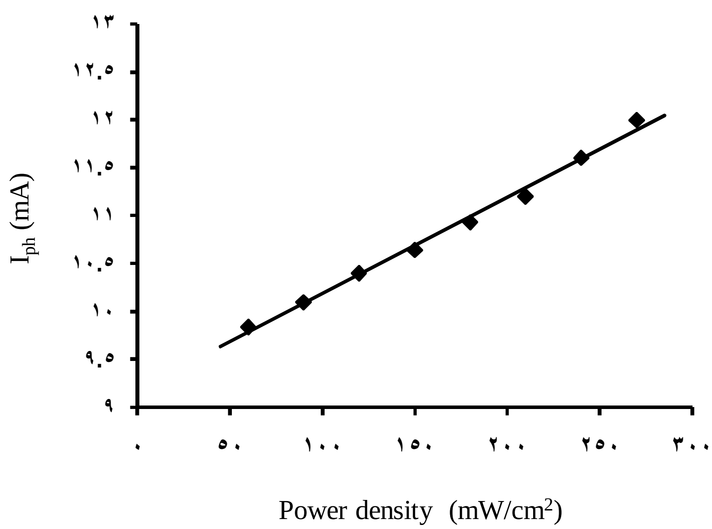

Figure (7) Photo current versus incident power density for n-CdSe/p-Si junction

Capacitance-voltage characteristics

The capacitance-voltage characteristics have been studied for *n*-CdSe/*p*-Si heterojunction.The measurement of the junction capacitance as afunction of reverse bias V_R is often used as a powerful experimental technique for the analysis of the depletion region potential and the charge distribution in a heterojunction. This variation is shown in Figure(8) . It is observed that the capacitance decreases (non-linear) with increasing the reverse bias voltage according to the following equation [21]:

$$C = \frac{dQ}{dV} = \frac{e_s}{w} \qquad (6)$$

where ε_s is the semiconductor permittivity, C is the capacitance per unit area and w is the width of depletion region . This behavior is attributed to the increasing of depletion region width, leading to decrease the capacitance at the junction sides.

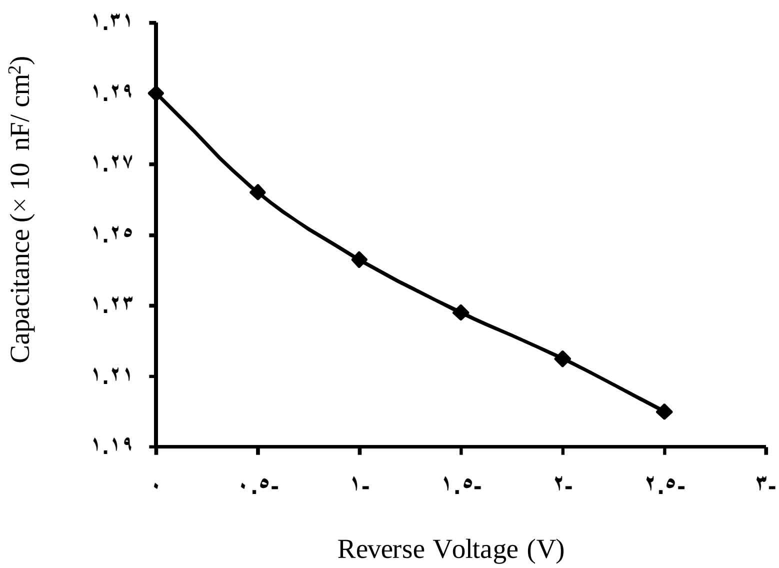

Figure (8) The variation of capacitance versus reverse bias voltage for CdSe/Si heterojunction

Figure(9). Show the plot of $1/C^2$ versus voltage V for CdSe/Si junction. Heterojunction has shown linear variation of the experimental curve C^{-2} vs. V indicating the presence of an abrupt heterojunction and often used to determine the experimental value of built-in-junction potential (V_{bi}) from extrapolated intercept on the voltage axis [8]. The value of V_{bi} was found to be 0.81V .

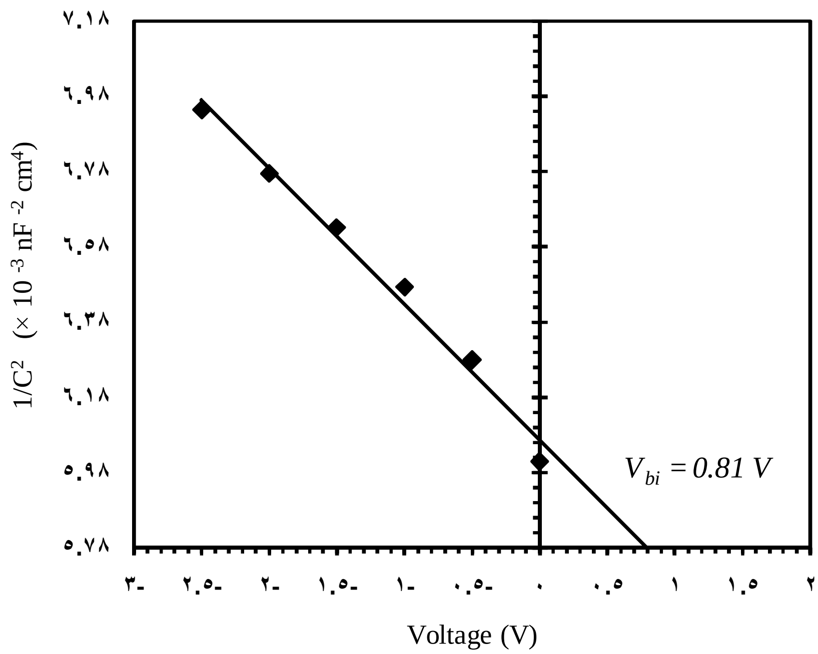

Figure (9) $1/C^2$ vs V_R for n-CdSe/p-Si heterojunction.

CONCLUSIONS

Heterojunction has been fabricated by thermal evaporation of *n*-CdSe film on *p*-Si substrate . The experimental results showed that the direct band gap of CdSe film was (1.89 eV) . From the temperature dependence of Seebeck coefficient the activation energy E_s and the type of major charge carriers in obtained films were determined . *I-V* characteristics study revealed presence two distinct regions in forward bias and the value of ideality factor was found to be 1.43. The *n*-CdSe/*p*-Si heterojunction exhibited good linearity characteristics for photo-current with power density. Heterojunction has shown linear variation of C^{-2} with V indicating the presence of an abrupt junction and the value of built-in-junction potential was (0.81V) .

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