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Optoelectronic properties n:CdS:In/p-Si heterojunction photodetector

Salwan K. J. Al-Ani · Raid A. Ismail ·
Hana F. A. Al-Ta'ay

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Abstract Optoelectronic properties of CdS:In/Si anisotype heterojunction photodetector fabricated by depositing of polycrystalline CdS and indium doped CdS films *used* thermal resistive technique on clean monocrystalline p-type silicon substrates are presented. The effect of In diffusion temperature(T_d)in CdS layer on the optoelectronic characteristics of these devices has been studied. Two peaks situated at 650 and 800 nm with values of 0.32 and 0.43 A/W, respectively, were observed in the responsivity plot. Other optoelectronics properties such as detectivity, photovoltaic, and response time are also presented.

1 Introduction

Heterojunctions have interesting optical and electrical properties which make them attractive for use in solar cells and other optoelectronic devices. Polycrystalline cadmium sulphide films deposited onto silicon have also received considerable interest in photovoltaic applications in which the material has represented a large gap window material in the visible and near infrared regions [1]. CdS films are generally prepared by many methods such as chemical spray pyrolysis [2, 3], vacuum evaporation method [4] and chemical bath deposition (CBD) [5]. The CdS films prepared by vacuum thermal evaporation technique possess uniform thickness, homogeneity and partially free of contamination [6]. However, due to the high resistivity of such films this exhibits limitation in their applications. In doped CdS films are promising materials for optoelectronics devices [7, 8]. Different methods have been applied for In doping of CdS [4, 9]. Earlier results [10] confirms that the doping of CdS with In by thermal diffusion method has the ability of controlling the concentration of In in the CdS films.

In this work a CdS/Si and CdS:In/Si heterojunction photodetectors have been prepared by thermal evaporation and using thermal diffusion of In into CdS films. The second objective of the work is to present full optoelectronic properties of these photodetectors.

2 Experimental

(500 ± 50)μm thick p-type single crystal silicon wafer of (111) direction of electrical resistivity (1–5 Ωcm) is used. These wafers were immersed in 10% of HF for 3–4 min to get rid of the dirt and the oxide layers. CdS films deposition was carried out by thermal resistive technique onto Si substrate at temperature $T_s \sim 100$ °C. 20 nm thick high purity (99.999%) indium films were then deposited onto the CdS film.

Thermal diffusion of indium into CdS at temperature T_d = (200–300)°C is conducted using a vacuum tube furnace. Ohmic contacts were achieved by

S. K. J. Al-Ani (✉)
Department of Physics, College of science, Al-Mustansiriya University, P.O. Box 47121, Al-Jadirya, Baghdad, Iraq
e-mail: salwan_kamal@yahoo.com

R. A. Ismail
School of Applied Science, University of Technology, Baghdad, Iraq

H. F. A. Al-Ta'ay
College of Science for Women, Baghdad University, Baghdad, Iraq

depositing high purity aluminum films on both surfaces CdS and Si.

The type of conductivity of CdS and CdS:In films was determined by Hall effect technique. *J–V* measurements of heterojunctions where taken under dark and illumination conditions. The spectral responsivity measurement of CdS/Si and CdS:In/Si heterojunction photodetectors were investigated using a model (SRD100) monochromator in the spectral range (400–1100)nm after making power calibration using an accurate Si power meter. Response time measurement was carried out using laser diode (λ = 904 nm,τ = 100 ns) with 200 MHz storage CRO.

3 Results and discussions

3.1 Hall effect

The Hall effect method is applied to determine the type of the doped and undoped CdS conductivity. These experiments show the n-type conductivity of CdS and CdS:In films (Fig. 1). These results agree with previous findings [4, 9] this explains the reason *behind* choosing a p-type Si substrate in this work.

3.2 Dark J–V characteristics

The *J–V* properties of CdS/Si and CdS:In/Si heterojunctions in the dark are presented in Fig. 2 under forward and reverse conditions. Table 1 shows that the rectification characteristics are strong and depends on indium diffusion temperature. The maximum rectification factor is obtained for CdS:In/Si prepared at T_d = 300°C. All CdS:In/Si heterojunctions exhibited breakdown voltage of (10–15)V depending on T_d in *comparison* with CdS/Si heterojunction which showed soft breakdown at 2 V. Ideality factor was calculated and found to be 3.3 and 2 for CdS/Si and CdS:In/(T_d = 300°C)/Si devices, respectively. These results show clearly that the indium doped CdS film led to an improved junction interface quality and consequently diode characteristics.

3.3 J–V characteristics under illumination

The *J–V* plot under white light illumination of CdS/Si and doped CdS/Si hetrojunctions is presented in Fig. 3. The maximum photocurrent density obtained for doped CdS/Si was prepared at T_d = 300°C. It is greater than that for undoped CdS/Si hetrojunction by a factor of 2.1 at zero bias voltage and this factor was increased to 6.6 at bias of 3 V. Siginficant degradation in the illuminated *J–V* characteristics of CdS/Si heterojunction was *observed* after doping with indium at T_d = 350 °C.

3.4 Capacitance–voltage measurements

Figure 4 shows the reciprocal of square capacitance versus bias voltage ($1/C^2$–V). This plot shows a linear relationship with bias voltage and indicates that the junction is abrupt. Also built-in potential (V_{bi}) can be calculated from extrapolating of($1/C^2$–V) plot to (($1/C^2$) = 0). Table 2 shows values of V_{bi} calculated for CdS/Si and CdS:In/Si prepared at different T_d values.

3.5 Photovoltaic parameters

Figure 5 shows the variation of both Voc and Jsc parameters versus In diffusion temperature. The maximum values of the two parameters are found to be 453 mV and 58 mA/cm^2, respectively, at T_d = 300°C.

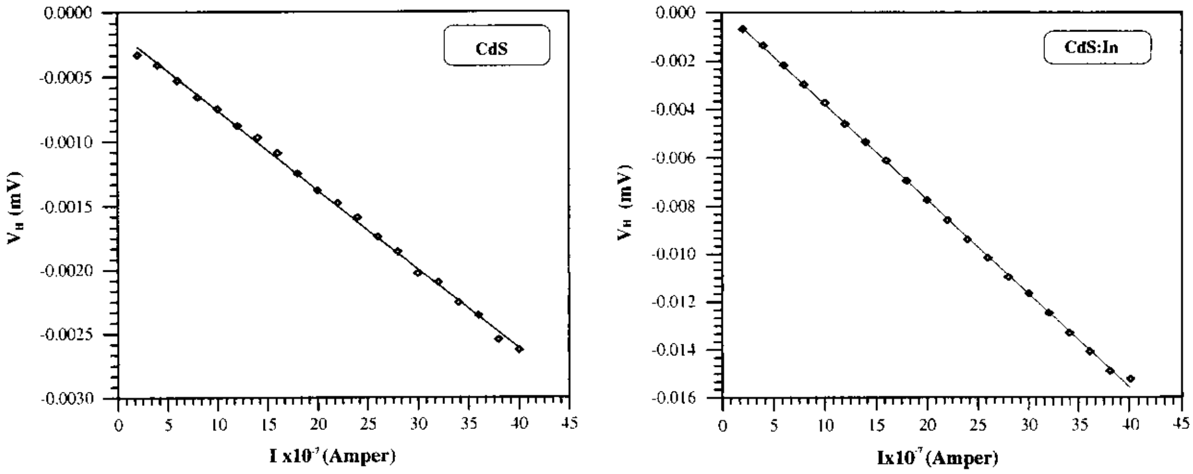

Fig. 1 Relationship between Hall voltage (V_H) and passing current (I) for n-CdS and n-CdS:In films

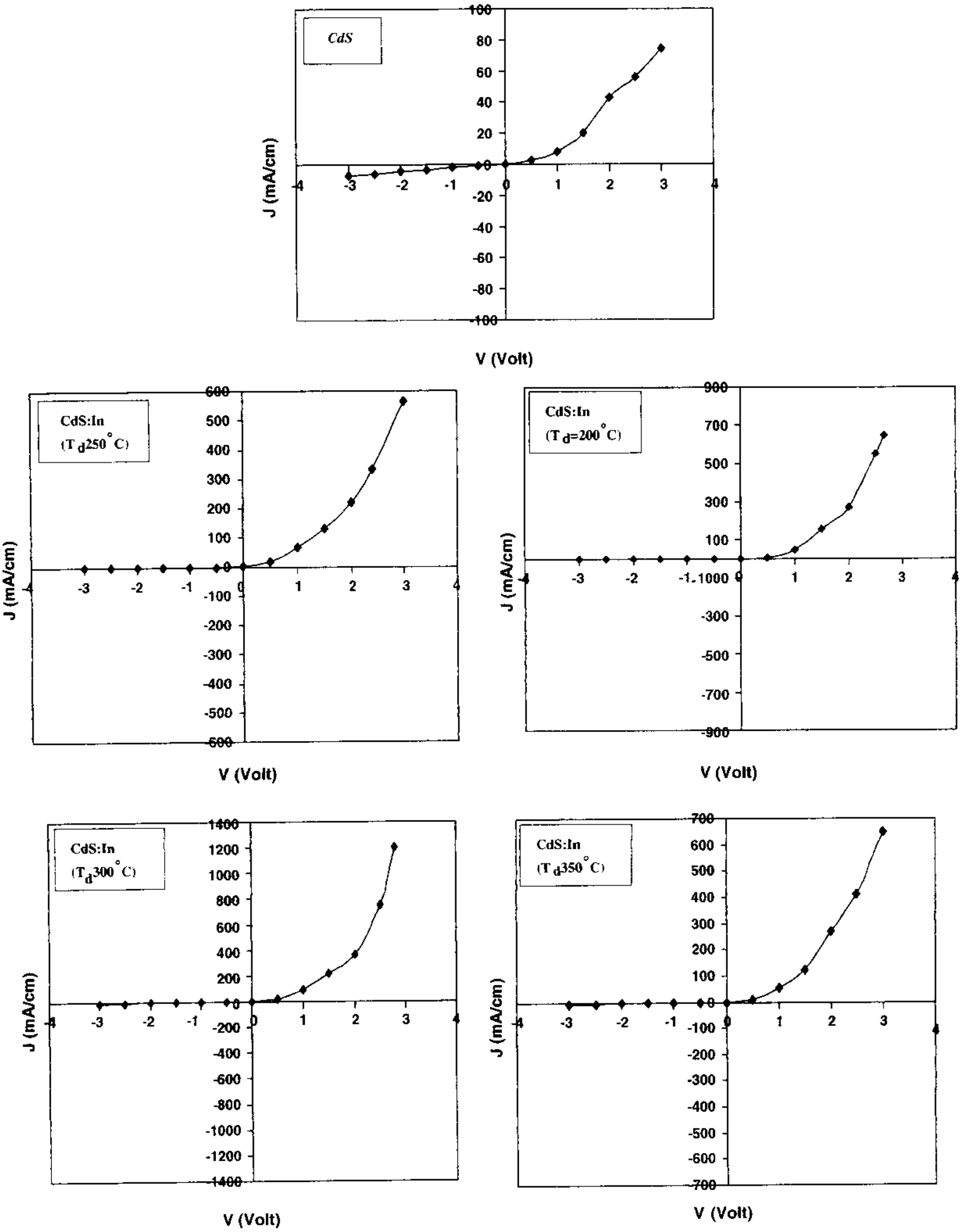

Fig. 2 Current density–voltage characteristics for n-CdS/p-Si and n-CdS:In/p-Si anisotype heterojunctions

3.6 Spectral response characteristics

Figure 6 reveals the dependence of responsivity on wavelength for doped and undoped CdS/Si photodetectors at 10 mV reverse bias. All photodetectors exhibit two distinct peaks. For CdS/Si photodetector the first peak is situated at 540 nm and second peak at 800 nm while the first peak of CdS:In/Si heterojunction is located at 650 nm and the second peak at 800 nm. No remarkable dependence of the response peak on T_d

Table 1 Rectification factor for CdS/Si and CdS:In/Si photodetectors

Heterojunction	Rectification factor
CdS/Si	5.71
CdS:In/Si (T_d = 200°C)	72.2
CdS:In/Si (T_d = 250°C)	77.17
CdS:In/Si (T_d = 300°C)	92.88
CdS:In/Si (T_d = 350°C)	58.33

was noticed. The highest value of responsivity was 0.46 A/W at 800 nm for doped CdS/Si prepared at T_d = 300°C. All photodetectors have non flat response over the spectral range (500–1100)nm as it clearly shows significant minima and maxima peaks which may be ascribed to the trap defects [11].

3.7 Specific detectivity (D*)

The value of D^* has been obtained from noise current and peak responsivity at λ = 800 nm and found to be 2×10^{12} W^{-1} cm $Hz^{1/2}$. This value is approximately equal to that of other Si-based heterojunction photodetectors such as CdS/Si and Cd/Si heterojunctions prepared by spray pyrolysis technique [12, 13].

3.8 Response time

Time analysis of the best photodetectors exhibits response time of the order of 200 ns which is lower than the value calculated from C–V measurements. This may be attributed to the surface recombination defects arised from the lattice mismatch between CdS and Si.

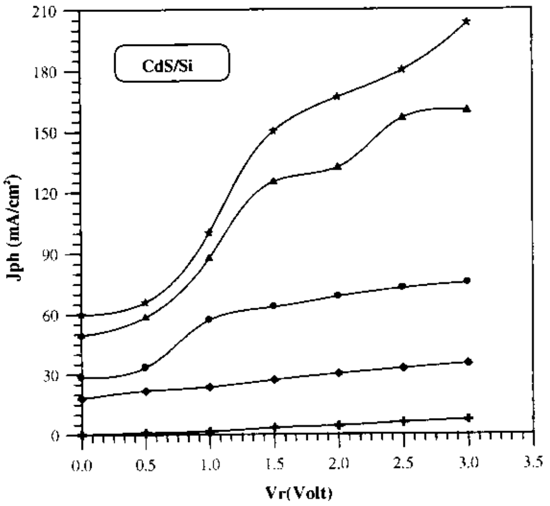

Fig. 3 Illuminated (J–V) characteristices for CdS/p-Si and CdS:In/p-Si anisotype heterojunction under reverse bias for various illuminating power densities

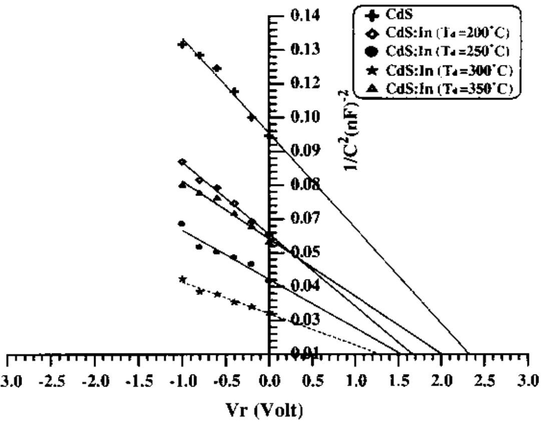

Fig. 4 $1/C^2$ versus reverse bias voltage plot

4 Conclusions

n–p hetero-junctions prepared by depositing a polycrystalline CdS and CdS:In films on p-type Si substrates were presented. The J–V characteristics at dark and illumination conditions of doped CdS/Si were function of indium diffusion temperature. The doped photodetector that prepared with T_d = 300°C exhibits the best junction quality. The spectral responsivity was highly improved after doping In into CdS film at optimum conditions. Two peaks have been noticed in the spectral responsivity profile of all photodetectors. The D^*

Table 2 Built-in potential for n-CdS/p-Si and n-CdS:In/p-Si heterojunctions

Cells	V_{bi}(V)
CdS/Si	2.29
CdS:In/Si (T_d = 200°C)	1.61
CdS:In/Si (T_d = 250°C)	1.50
CdS:In/Si (T_d = 300°C)	1.25
CdS:In/Si (T_d = 350°C)	2.00

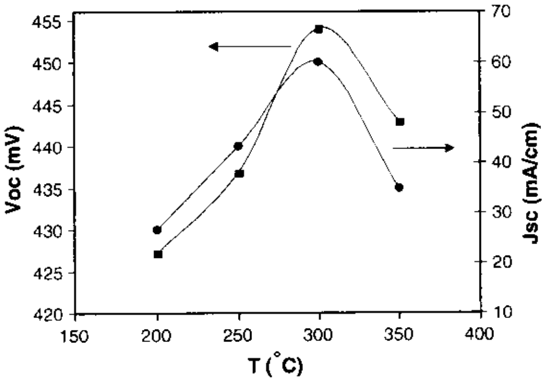

Fig. 5 Voc and Isc as function of In diffusion temperature

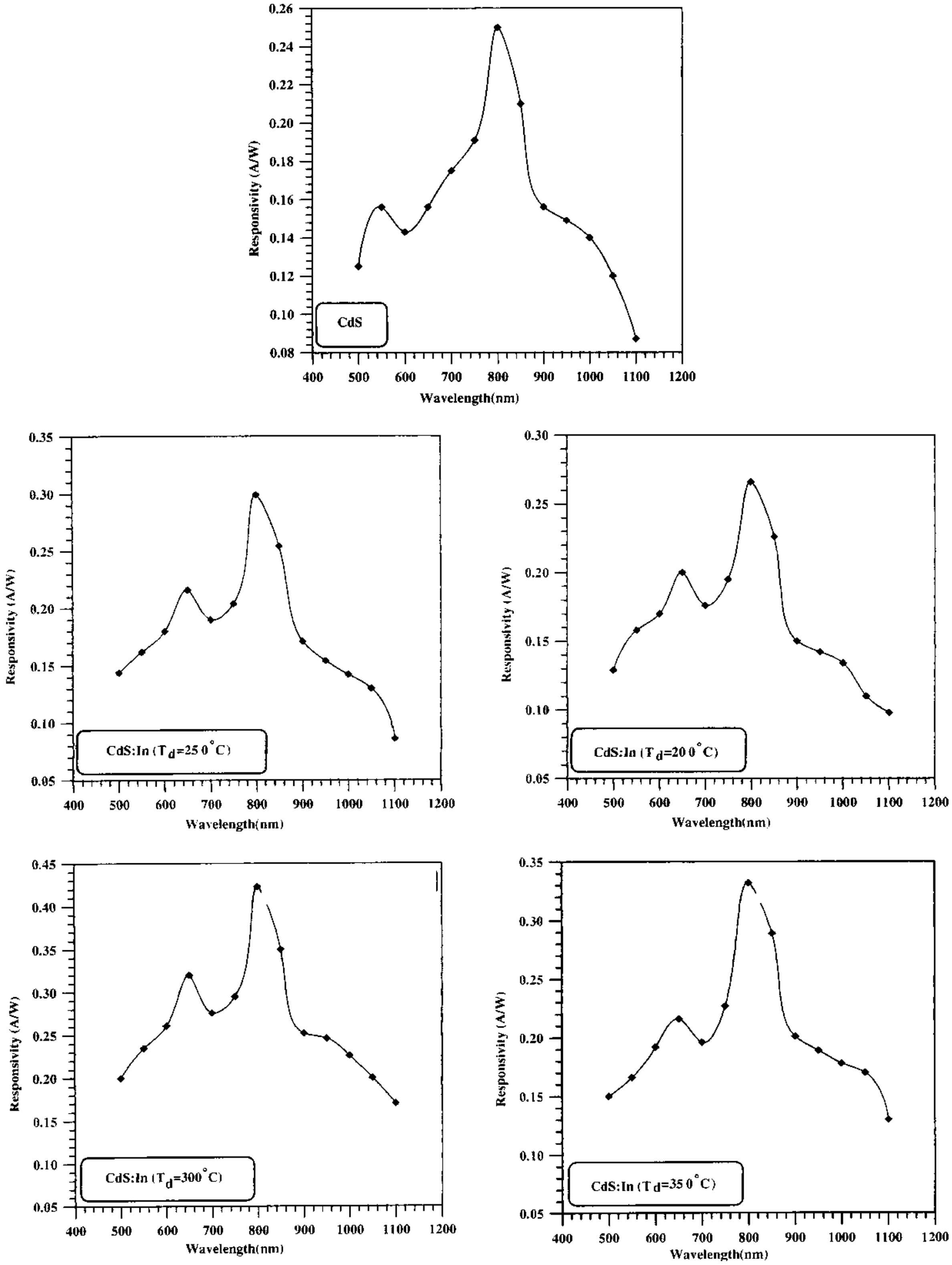

Fig. 6 Spectral responsivity plots of hetrojunctions prepared at different conditions

and rise time results of the best photodetector presented here are encouraging and promsing for optoelectronic applications.

References

1. T.L. Chu, S.S. Chu, N. Schultz, C. Wang, C.Q. Wu, J. Electrochem. Soc. **139**(9), 2443 (1992)
2. R.A. Ismail, S.K.J. Al-Ani, A.N.E. Al-Samarai, O.A.A. Sultan, H.F.A. Al-Taai, 1st Conference on Energy and Environment, (Changsha, China, Oct.11–14, 2003), pp. 39–44.
3. A. Ashour, Turk. J. Phys. **27**, 551 (2003)
4. S.K.J. Al-Ani, R.A. Ismail and H.F. Al-Taay, Iraqi J. Appl. Phys. **1**(2), 13 (2005)
5. H. Metin and R. Esen, Erciyes Universitesi Fen Bilinlery Enstitusu Dergisi **19**(1–2), 96 (2003)
6. H. Tashiya, T. Nishihura and Y. Ema. Jpn. J. Appl. Phys. **28**, 1174 (1989)
7. D.K. Acosta, G. Romero, Solar Energy Mater. Solar cells **55**(1–2), 31 (1998)
8. F.M. Living Stone, W.M. Tsang and W. Dancan, J. Phys. D **10**, 1959 (1977)
9. E. Cigdem and B. Murat, Solar Cells **26**, 253 (1989)
10. H.F. Al-Ta'ay, M.Sc. thesis, College of Science for Women, Baghdad University, Baghdad-Iraq, (2002)
11. F.M. Livingstone, W.M. Tsang, A.J. Barlow, R.M. De La Rue and W. Dumcan, J. Phys. D: Appl. Phys. **19**, 1959 (1977)
12. O.A. Sultan, M.Sc. thesis, Al-Mustansiriya University, Baghdad- Iraq, (2002)
13. R.A. Ismail , S.K.J. Al-Ani , M.A. Al-Gafar , World Renewable Energy Congress, (Scotland-UK, 22–27 May 2005), eds., M.S. Imbabi, C.P. Mitchell, Elsevier Ltd., pp. 513–519 (2005)