------ Raf. J. Sci., Vol. 26, No.1, pp. 133-139, 2017------

Optimum Efficiency of CdS/ CdTe Thin Film Solar Cell

Nawfal Y. Jamil
Department of Physics / College of Science / University of Mosul

(Received 28/ 3 / 2014 ; Accepted 26 / 5 / 2014)

ABSTRACT

In this study, the absorber layer (CdTe) and window layer (CdS) thickness parameters have been investigated through simulation by SCAPS to find out the higher conversion efficiency for the CdS/ CdTe thin film solar cell. It is found that the parameters J_{sc}, V_{oc}, η are increased for the increasing absorber layer thickness, and quantum efficiency show overlapping after the 500 nm wavelength for different CdTe thicknesses. In addition, it is revealed that the highest calculated efficiency can be achieved with the absorber layer thickness of 3.5 µm and window layer of thickness 0.05 µm, was 17.27%. Where the effect of window layer show that the calculations gave, as CdS thickness increased V_{oc}, was nearly constant, but J_{sc}, η decreased. Using best calculated thicknesses in this study for both CdS and CdTe, the fabricated CdS/ CdTe thin film solar cell efficiency measured 13.73%, this is expected may be du to interface layer and density of stats on both films.

Keywords: Semiconductor, solar cell, thin film, SCAPS simulation.

كفاءة التحويل المثلى للخلية الشمسية الرقيقة CdS/CdTe

الملخص

في هذه الدراسة تم بحث تأثير تغيير سمك الطبقة الماصة (CdTe) والطبقة النافذة (CdS) من خلال محاكاة حاسوبية باستخدام برنامج (SCAPS) في الخلايا الشمسية (CdS/CdTe) ذات الاغشية الرقيقة. وقد وجد ان المعاملات V_{oc}, I_{sc} ,η تزداد مع زيادة سمك الطبقة الماصة بحيث ان اعلى كفاءة محسوبة كانت عند سمك الطبقة الماصة 3.5 µm وسمك طبقة النافذة 0.05 µm تساوي 17.27%. بينما سلوك الكفاءة الكمية أظهر تراكبا في الشكل بعد قيمة 500 nm من الاطوال الموجية. أما تأثير زيادة سمك الطبقة النافذة أظهرت تقريبا ثبوتا في قيم V_{oc} ونقصان في قيم I_{sc} مما أدى الى نقصان في قيم η. تم تصنيع خلية شمسية لأفضل سمك للطبقة الماصة والنافذة ومن القياسات كانت كفاءة الخلية المصنعة هي 13.73%.

الكلمات الدالة: اشباه ألموصلات، خلايا شمسية، اغشية رقيقة، محاكاة حاسوبية.

INTRODUCTION

During the last Decade the hetrojuncfion CdS/CdTe have been investigated intensively (Bonnet and Meyers, 1998), (Romeo *et al.*, 2003), (Mathew *et al.*, 2004), (Gessert *et al*., 1996), (Tiwari *et al*., 2004), (Compaan *et al*., 1999), as a part of II-VI material (Mahmood *et al*., 2012) and (Dawad *et al*., 2013) due to calculated upper limit of CdTe solar cell efficiency because of its band gap close 26%. Where CdS/CdTe thin film solar cell with efficiency 8% fabricated on an industrial scale for several years, in same time a lot of works has been done in order to increase CdS/CdTe solar cell efficiency. Later few years the efficiency of CdTe based solar cell devices has raised to 16.5% due to employment technique including post heat treatment in the presence of $CdCl_2$ (Wu *et al*., 2001), (Romeo *et al*., 2004) and (Jahn *et al*., 2001). Where commercial CdTe module efficiency of > 10% have been achieved (Cooke, 2008). Still demands on the best thickness of

CdTe as absorber (Salave *et al*., 2013) and CdS as window layer wanted. This type of solar cell have an advantage of the variety technique of fabrication (Pérez-Hernánde *et al*., 2013) among of them magnetron sputtering (Gupta and Compaan, 2004), (Gupta and Compaan, 2005), (Gupta *et al*., 2006) which gives big chance of producing dense and homogenous layers at low substrate temperature (Hur *et al*., 2008), and also it is good device performance (Hadrich *et al*., 2009), (Luschitz *et al*., 2009) with thin layers (Jaegermann *et al*., 2009).

In this work a simulation using (SCAPS) (This group of programs includes AMPS-ID, SCAPS-ID, PC-ID, ASA, and AFORS-HET (Burgelman *et al*., 2004). Among these programs is SCAPS-ID that used in this work, (Burgelman *et al*., 2000) on CdS/CdTe thin film solar cell have been used to calculate the extreme values of absorber and window layer of CdS/CdTe thin film solar cell by fixing one of them and varying the other and finding out the best calculated efficiency. Then choosing the thickness of absorber and window layer for CdS and CdTe For fabricating CdS/CdTe thin film solar cell (using magnetron sputtering technique) and from J-V characteristics experimental efficiency value calculateds and comparing between the calculated and experimentally measured efficiency have been done. To find out the effect of thickness variation of CdS/CdTe hetrojunction, the physical model in reference (Burgelman *et al*., 2000) dependent with respecting that high quality ohmic back contact and presence of charged interface states.

THEORETICAL DESIGN

The DC electrical characteristics of thin film heterojunction solar cells (CdS/CdTe) can be investigated with SCAPS ID. In this work SCAPS- program used to study the effect of absorber layer thickness for CdTe thin films solar cells on the solar cell parameters demonstrated, like open circuit voltage (Voc), short circuit current density (Jsc), conversion efficiency (η) and the quantum efficiency (QE). The best electrical performance for CdS and CdTe solar cells can also be simulated. SCAPS is used to imitate and investigate all the available research-level of CdTe/CdS solar cells with various window layers. In the simulation, n-CdS and p-type CdTe layer parameters are emphasized to investigate the benefits of using CdS as window layer in CdTe solar cells and comparative study with CdTe/CdS structure. By incorporating the various material parameters into SCAPS for all of the analysis aspects, changes in the values for efficiency, open circuit voltage, short circuit current, fill factor and the quantum efficiency (QE).

Experimental procedure for fabricating CdS/CdTe solar cell:

The preparation process is included by depositing Al layer (back contact) on glass substrate and followed by depositing p-type CdTe layer on the substrate with magnetron sputtering method (SQM-242, sigma instrument S4160 Hitachi, Japan. Department of physics and nanotechnology, Sumy state university technical, Sumy, Ukraine), the window layer is also deposited on the CdTe solar cell with thickness (0.05µm) using sputtering magnetron method. A figure net of gold to collect the photocurrent also deposited by sputtering method. Schematic structure of the solar cell given as follow:

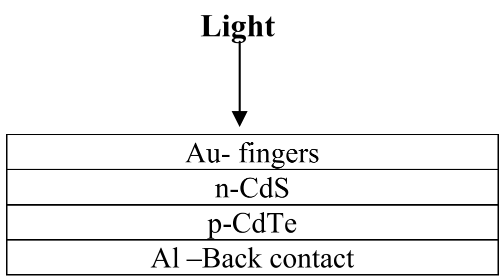

Fig. 1: Schematic diagram for CdS/CdTe thin film solar cell

Electrical measurement has done of the sample at illumination with 100 mw/cm^2 on input power using lamp of 100 watt.

RESULTS AND DISCUSSIONS

Theoretical calculations by SCAPS simulation program:

Solar cell as shown in Fig.(1) of CdS/CdTe designed and SCAPS program used for simulation of the expected characteristics, efficiency and QE values, with varying CdS thickness.

Fig. (2) shows the simulated J-V solar cell characteristics for CdTe with constant thickness (3µm) and varying CdS (0.05-2.5 µm) thin film thickness through SCAPS program. The simulated values of J_{sc}, V_{oc},FF and efficiency as corresponding solar cell output parameters are recorded in Table1. Which show a decrease in the short circuit current with increase of CdS thickness and finally a decrease in the efficiency and that is expected because the solar cell window should be very thin compared to the absorber.

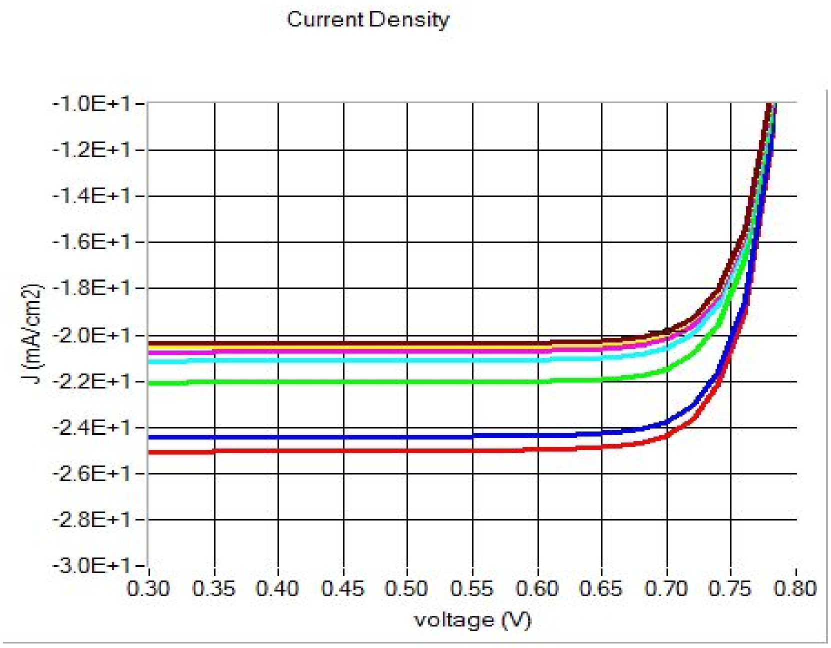

Fig. 2: J.V spectra for different CdS thickness (Red=0.05 µm, brown=2.5 µm) CdTe=3µm

Table 1: Solar cell parameters using SCAPS program with thickness of CdTe (3µm) and variant CdS thickness

№	*CdS/Thickness/µm*	V_{oc}, V	J_{sc}, mA/cm2	FF, %	η, %
1	**0.05**	0.798	25.11	85.55	**17.1**
2	**0.1**	0.797	24.50	85.53	**16.6**
3	**0.5**	0.796	22.10	85.50	**15.0**
4	**1**	0.796	21.15	85.48	**14.4**
5	**1.5**	0.795	20.77	85.46	**14.1**
6	**2**	0.794	20.55	85.45	**14.0**
7	**2.5**	0.794	20.44	85.45	**13.9**

Fig. (2) and Table1. Show that the efficiency decreased as CdS thickness increase. The optimum conversion efficiency is about 17.1 % at 0.050µm CdS thickness.

Fig. (3) shows the simulated quantum efficiency (QE) spectra for different CdS thickness which shows that at lowest (0.05µm) thickness of CdS more photons transmutes, which improves the overall efficiency of the theoretical design of solar cell.

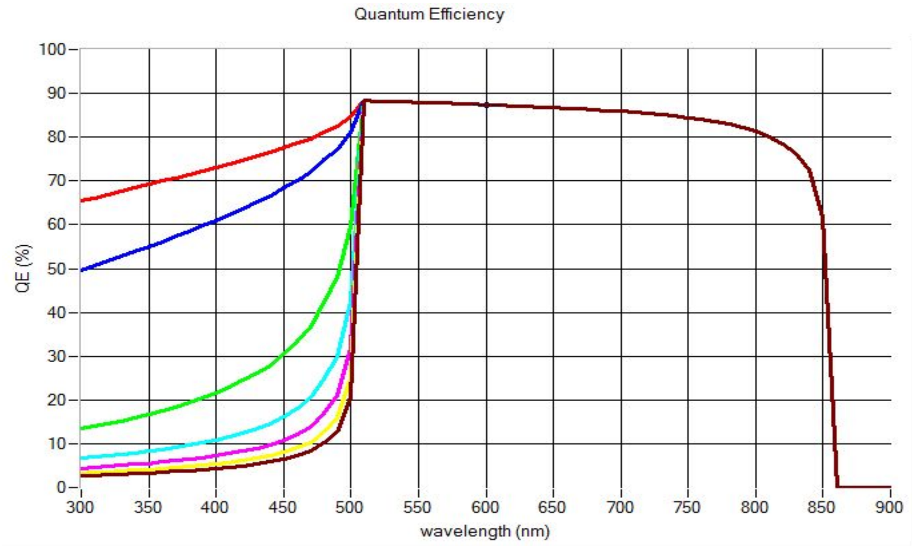

Fig. 3: Simulated QE spectra for different CdS thickness (Red=0.05 µm, brown=2.5 µm) CdTe=3µm

Fig. (4) shows the simulated J-V solar cell characteristics for CdTe with varied thickness and constant CdS thin film thickness (0.05 µm) through SCAPS program. The simulated values of J_{sc}, V_{oc}, FF and efficiency as corresponding solar cell output parameters are recorded in Table2, which show an increase in the short circuit current and slow increase in the open circuit voltage with increase of CdTe thickness and finally an increase in the our goal the efficiency and that is expected because the absorber should be thicker as compared to the window of the solar sell. In Fig. (4) and (Table 2) Show efficiency increasing as CdTe thickness increased. The optimum conversion efficiency is about 17.27 % at 3.5µm CdTe thickness.

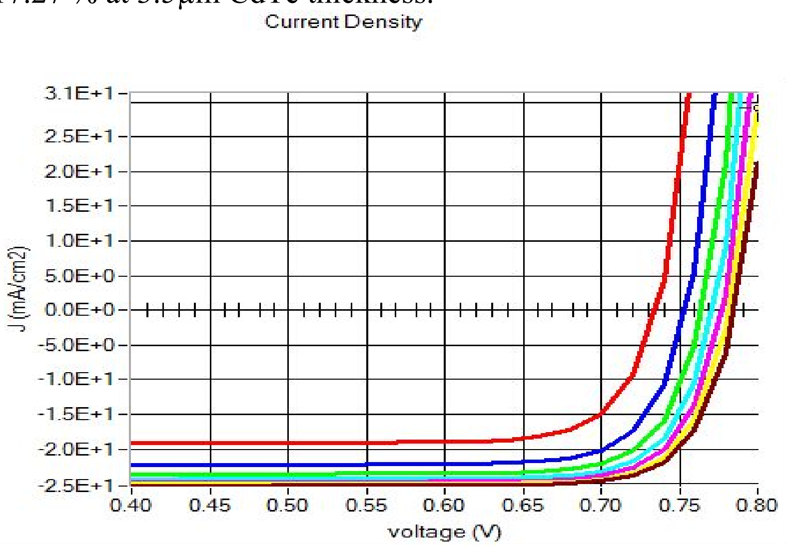

Fig. 4: J.V spectra for different CdTe thickness (Red=0.5 µm, brown=3.5 µm) CdS thickness=0.05µm

Table 2: Simulated solar cell parameters with thickness of CdS (0.05µm) and variable CdTe thickness

№	*CdTe/Thickness/* µm	V_{oc}, *V*	J_{sc}, мА/см2	*FF*, %	***η*, %**
1	**0.5**	0.734	19.51	83.98	**12.04**
2	**1.0**	0.754	22.50	85.47	**14.51**
3	**1.5**	0.764	23.73	86.02	**15.62**
4	**2**	0.772	24.40	86.36	**16.27**
5	**2.5**	0.777	24.81	86.52	**16.70**
6	**3**	0.782	25.10	86.65	**17.01**
7	**3.5**	0.785	25.31	86.80	**17.27**

Fig. (5) shows the simulated quantum efficiency (QE) spectra for different CdTe thickness which shows that at thickness 3.5µm more photons absorbed, which improves the overall efficiency of theoretical design solar cell.

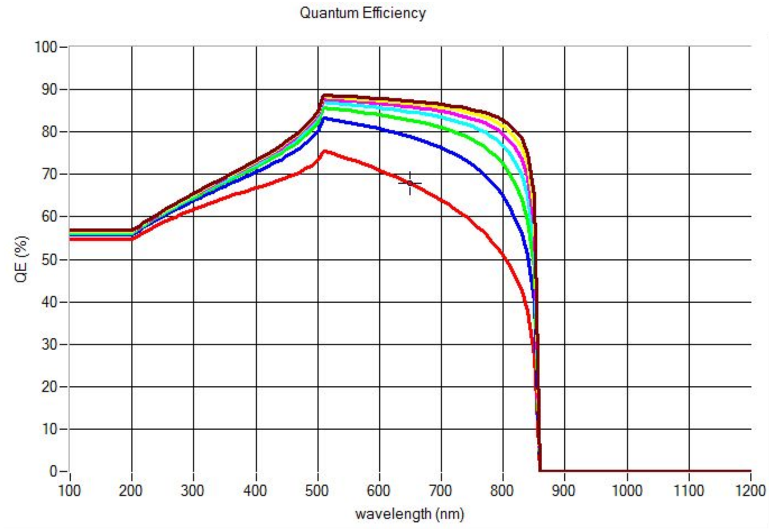

Fig. 5: Simulated QE spectra for different CdTe thickness (Red=0.5 µm, brown=3.5 µm) CdS thickness=0.05µm

It is clear from Fig. (4) and (Table 2) that values of V_{oc}, J_{sc} of the solar cell parameters increased as CdTe thickness increased. The conversion efficiency increased until the thickness reached at around 3.5µm. Further increase in the thickness of the films does not show any improvement in the efficiency. The optimum conversion efficiency is nearly 7.27 % observed. Also it is appear that the efficiency increases as the thickness increase and saturates after 500 nm which is shown in Fig. (4).

Experimental Calculation for fabricated solar cell:

As explained before the CdS/CdTe thin film solar cell fabricated with CdS thickness 0.05µm and CdTe thickness 3.5µm. From experimental measurements J_{sc}, V_{oc}, the FF, and efficiency were calculated .

Comparing simulated results with the practical results for prepared solar cell n-CdS (0.05 µm/ CdTe (3.5µm) as shown in Table (3) it is clear that the practical efficiency is smaller than simulated with same thicknesses by 20% which practically acceptable in addition to the surface density states of both material (CdTe, CdS) also the interface layer between two material.

Table 3: Output of practical fabricated n-CdS/p-CdTe solar cell

V_{oc}, V	J_{sc}, **mA/cm2**	***FF*, %**	***η*, %**
0.7850	20.525	85.20	**13.73**

The conversion efficiency (η %) of solar cell is calculated from the relation.

$$\eta = \left[\frac{I_{sc} V_{oc} FF}{P_{h\nu}} \right] \times 100\,\%$$

Where $P_{h\nu}$ is the power density of the incident radiation. The fill factor (FF) which is a measure of the ideality of the system, is calculated from the relation:

$$FF = \left[\frac{I_m V_m}{I_{sc} V_{oc}} \right] \times 100\,\%$$

Where I_m and V_m are respectively the current and voltage obtained at maximum power point on the photovoltaic power output curve. The fill factor values are in agreement with theoretically calculated.

CONCLUSION

From this numerical analysis of heterojunction- solar cells with CdTe and CdS window layers, electrical performances for the CdS/CdTe solar cells have been investigated in terms of absorber layer thickness and window. The increasing of CdTe absorber layer thickness results in higher Jsc, Voc and η better performance. Where window layer showed as it is very thin it gives best performance. Where the fabricated solar cell device gave lower efficiency about 20 %.

REFERENCES

Bonnet, D.; Meyers, P.V.; Mater, J.R. (1998). Cadimuim Telluride for thin film solar cell. **13**, 2740.

Burgelman, M.; Nollet P.J.; Degrave, S. (2000). Modelling polycrystalline semiconductor solar cells. *Thin solid films*. **361**,527-532.

Burgelman, M.; Verschaegen, J.; Degrave, S.; Nellet, P. (2004). "Modelling Thin Film PV Devices". Progress in photovoltaic: Research and application; John Wiley and sons.

Compaan, A.D.; Sites, J.R.; Birkmire, R.W.; Ferekides, C.S.; Fahrenbruch, A.L. (1999). Critical issues and research needs for CdTebased splar cell. *Electrochem. Soc. Proc*., **241**, 99.

Cooke, M. (2008). Semiconductor today compounds and advanced silicon. **3**, 74.

Dawad, Z.A.; Najim, L.A.; Jamil, N.Y. (2013). The study of the effect of gamma ray and neutrons on thr physical properties of Zinc Oxide thin film. *Raf. S. J.*, **24**(4A), 88-98.

Gessert, T.,; Mason, A.; Sheldon, P.; Swartzlander, A.; Niles, D.; Coutts, T. (1996). Development of Cu-doped ZnTe as a back contact interface layer for thin film CdS/CdTe solar cell. *J. Vac.Sci. Technol*. A **14**(3), 806.

Gupta, A.; Compaan, A.D. (2004). All-sputtered 14% CdS/CdTe thin film solar cellwith ZnO:Al transparent conducting oxide. *Appl. Phys. Lett.* **85**, 684.

Gupta, A.; Compaan, A.D. (2005). High efficiency , 0.8 micron CdS/CdTe solar cell. *Mater. Res. Soc. Symp. Proc*. **865**, F14, 33.

Gupta, A.; Parikh, V.; Compaan, A.D. (2006). High efficiency ultra- thin film sputtered CdTe solar cell. *Sol. Energy Mater. Sol. Cells*. **90**, 2263.

Hadrich, M.; Kraft, C.; Metzner, H.; Reislohner, U.; Loffler, C.; Witthuhn, W. (2009). Formation of CdS_x Te_{1-x} at the p-n junction of CdS-CdTe solar cells. *Phy. Status Solidi*, **C 6/5**, 1257–1260.

Hur, S.G.; Kim, E.T.; Lee, J.H.; Kim, G.H.; Yoona, S.G. (2008). Characterization of photoconductive cdS thin films prepared on glass substrate for photoconductive senser applications. *J. Vac. Sci. Technol*. **B 26**, 1334–1337.

Jaegermann, W.; Klein, A.; Mayer, T. (2009). Interface engineering of energanic thin film solar cell-material- science challenges for advanced physical concepts. *Adv. Mater*. **21**, 4196–4206.

Jahn,U.; Okamoto, T.; Yamada, A. (2001). Doping and intermixing in CdS/CdTe thin filmsolar cell. *Appl. Phys.* **90**, 2553.

Luschitz, J.; Siepchen, B.; Schaffner, J.; Lakus-Wollny, K.; Haindl, G.; Klein, A.; aegermann, W. (2009). CdTe thin film solar cells : interrelation of nucleation, structure, and performance. *Thin Solid Films,* **517**, 2125–2131.

Mahmood, M.T.; Jamil, N.Y.; Mostafa, N. A. (2012). The optical and electrical properties of Cdse thin films prepared by CBD technique. *Raf. Sci. J*., **23**(1), 116-125.

Mathew, X.; Enriquez, J.P.; Romeo, A.; Tiwari, A.N. (2004). CdTe/CdS solar cell on flexible substrate. *Sol. Energy* , **77**.

Pérez-Hernández, G., Pantoja-Enríquez, J.; Escobar-Morales, B.; Martinez-Hernández, D.; Díaz-Flores, L.L.; Ricardez-Jiménez, C. Mathews, N.R.; Mathew, X. (2013). Comparative study of CdS thin films depositing by different techniques. *Thin Solid Film*, **535**, 154-157

Romeo, A.; Arnold, D.; Bätzner, D.L.; Zogg, H.; Tiwari, A. (2002-2003). Development of high efficiency flexible CdTe solar cell. Proceedings of the Conference “PV in Europe from PV Technology to Energy Solutions”; *Rome; Italy,* October 7–11, 154.

Romeo, N.; Bosio, A.; Canevari, V.; Podestà, A. (2004). Recent progress on CdS/CdTe thin film solar cell. *Sol. Energy*, **77**, 795

Salavei, A.; Rimmaudo, I.; Piccinelli, F.; Romeo A. (2013). Influence of CdTe thickness on the structural and electrical properties of CdTe/CdS solar cell. *Thin Solid Film* , **535**, 257-260.

Tiwari, A.N.; Khrypunov, G.; Kurdzesau, F.; Bätzner, D.L.; Romeo, A. (2004). CdTe solar cell in novel configuration. *Progress in Photovoltaics: Research and Applications*, **12**, 33.

Wu, X.; Keane, J.C.; Dhere, R.G.; DeHart,C.; Albin, D.S.; Duda, A.; Gessert, T.A.; Asher, S.; Levi, D.H.; Sheldon, P. (2001). 16.5% efficeint CdS/CdTe polycrystalline thin film solar cells. Proceedings of the 17th European Photov. *Solar Energy Conf*., Munich, Germany, p. 995: II.