International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 - 5161

Available at http://inpressco.com/category/ijcet

Research Article

I-V Characteristics of ITO/CdTe/Al_2O_3/Si/Au Thin Film Solar Cell

Mustafa M. A. Hussein[Á*], Manal M. Abdullah[Á], Wasan R. Saleh[Á] and Kadhim A. Aadem[Á]

[Á]Department of Physics, College of Science, University of Baghdad

Accepted 25 May 2014, Available online 01 June 2014, **Vol.4, No.3 (June 2014)**

Abstract

The CdTe/Al_2O_3/Si solar cells have been fabricated on p-Si wafer by thermal evaporation and ALD methods at different thicknesses of Al_2O_3 (1.7, 3.5, and 4.5nm). In this work, the tunneling effect of the ultrathin oxide layer was studied. The electrical properties including I-V characteristics are studied and interpreted. Gold and indium tin oxide (ITO) are used as back and front contacts, respectively. It was found that the quantum efficiency and filling factor have maximum values at thickness of 1.7nm. The dark current of devices was very close to zero.

Keywords: *Solar cell; CdTe; Al_2O_3; tunneling; efficiency; fill factor.*

1. Introduction

[1]Recently, more attention had been paid to the heterojunction devices research (L. M. Woods *et al*, 1998). Good achievements of heterojunctions are fully established in electronic devices such as solar cells, high quality lasers, and optical detectors (A. F. An-Nadoss *et al*, 1993). By 1984, the highest silicon solar cell efficiency was achieved by using a tunneling SiO_2 layer to passivate the front contact of a full aluminum Back Surface Field (BSF) cell (M. A. Green *et al*, 1984). Later, starting in 1995, the use of an ultra-thin thermal SiO_2 layer (~1.5 nm) under Al contacts is reported by Metz and Hezel (A. Metz *et al*, 1997). Atomic-layer-deposited (ALD) aluminum oxide (AlO_x) was successfully applied in the past for the passivation of *p*-type and *n*-type crystalline silicon wafers (A. Richter *et al*, 2011). On the device level, an excellent rear surface passivation was demonstrated with ALD-AlO_x by different research groups (J. Schmidt *et al*, 2010). Recently, an extremely thin AlO_x layer was implemented as a tunnel layer (D. Zielke *et al*, 2011).

In the present work, I-V characteristics of Si/Al_2O_3/CdTe heterojunction are investigated as a function of the thickness of Al_2O_3 layer.

2. Experimental

In this work CdTe (1:1) powder from Sigma Aldrich Company is used to deposit 100nm thin film on a p-type silicon wafer with 0.7mm thickness as a substrate by thermal evaporation method using [NANO 38] deposition system supplied by Kurt J. Lesker Company. The rate of deposition is set to be about 0.03nm/sec so that the total time of the deposition process takes about one hour. The thickness of CdTe layer is controlled by crystal quartz method. The substrate during the deposition process was not heated. The prepared samples are annealed in air for one hour at 300°C by hot plate. To prepare the silicon wafers for the deposition process, Shiraki cleaning is done then they are itched by HF for one minute to remove the oxide layer from them. The ultrathin Al_2O_3 layers are deposited on the silicon wafer by ALD method. For the back contact, 100nm gold layer is deposited on the back side of silicon substrate by sputtering method. For the front contact, 100nm layer of indium tin oxide, ITO, is deposited on the CdTe layer by sputtering method too. Figure1 illustrates a schematic view of the solar cell layers.

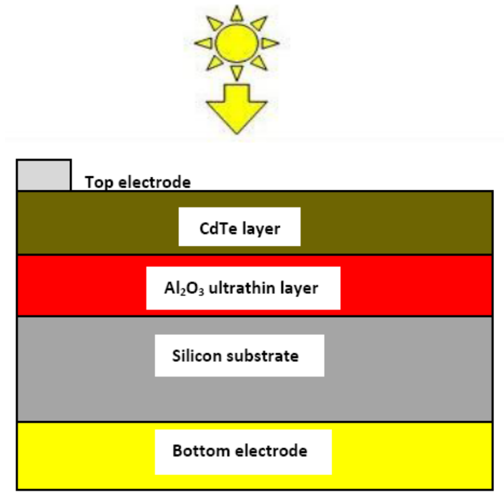

Figure 1: Schematic view of the prepared solar cell

I-V characteristics are measured by KEITHLEY computerized system after contact wires were soldered to each side of samples by indium alloy soldering. This type of soldering guarantees good contacts, as well as its low temperature keeps the structural properties of films unaffected.

*Corresponding author: **Mustafa M. A. Hussein**

3. Results and discussion

The efficiency, η, and the fill factor, FF, are calculated from I-V characteristics diagrams. Figure (2) demonstrates the current vs., the voltage behavior in the dark, while figure (3) demonstrates the light condition, both in the absence of the Al_2O_3 layer. The dark current in the reverse bias is very close to zero which could be considered as an ideal case for diode characteristics. Figures (4) to (9) show the I-V curves in the presence of the oxide layer with different thicknesses: 1.7nm, 3.5nm, and 4.5nm for both dark and light currents.

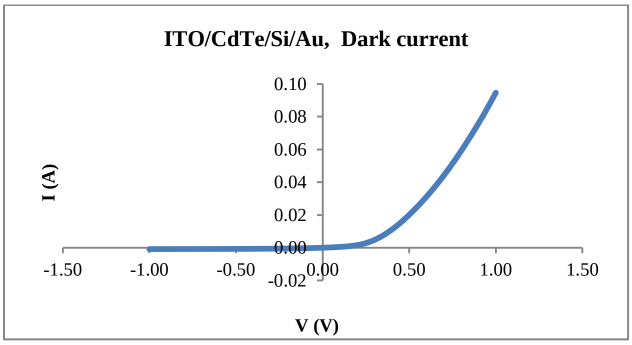

Figure (2): I-V curve of dark current for ITO/CdTe/Al_2O_3Si/Au device in the absence of Al_2O_3 layer

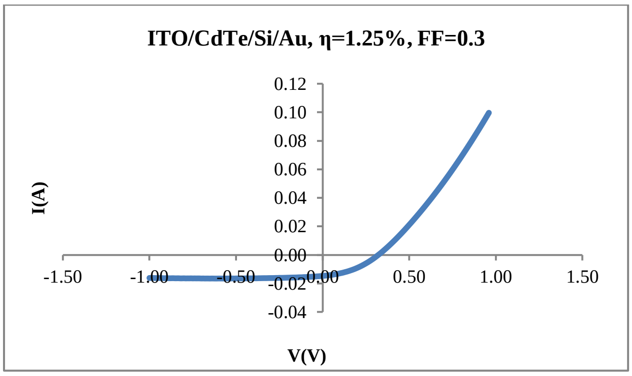

Figure (3): I-V curve of light current for ITO/CdTe/Al_2O_3Si/Au device in which the absence of Al_2O_3 layer

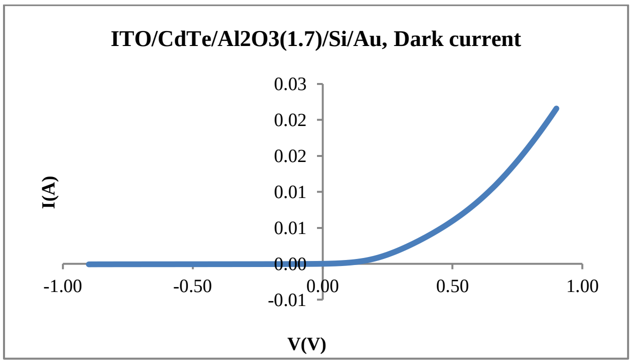

Figure (4): I-V curve of dark current for ITO/CdTe/Al_2O_3/Si/Au device in which the thickness of Al_2O_3 is 1.7nm

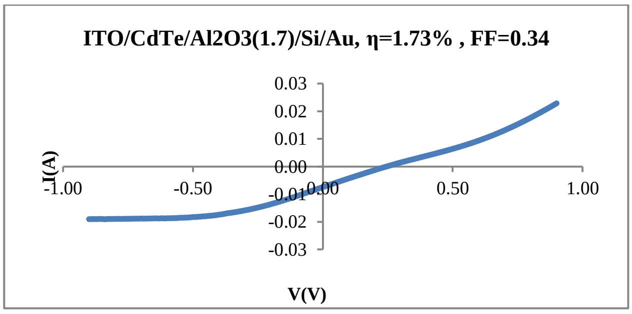

Figure (5): I-V curve of light current for ITO/CdTe/Al_2O_3Si/Au device in which the thickness of Al_2O_3 is 1.7nm

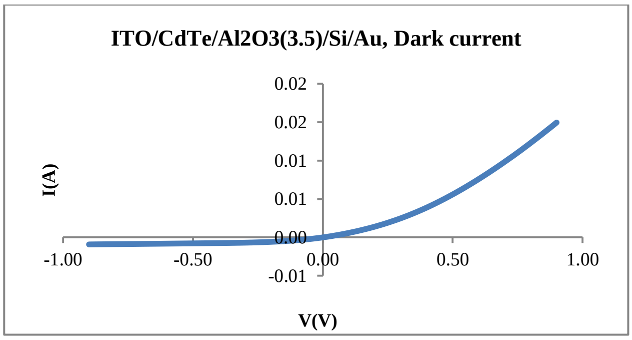

Figure (6): I-V curve of dark current for ITO/CdTe/Al_2O_3/Si/Au device in which the thickness of Al_2O_3 is 3.5nm

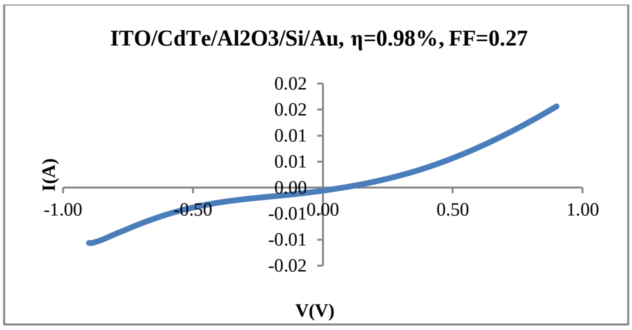

Figure (7): I-V curve of light current for ITO/CdTe/Al_2O_3Si/Au device in which the thickness of Al_2O_3 is 3.5nm

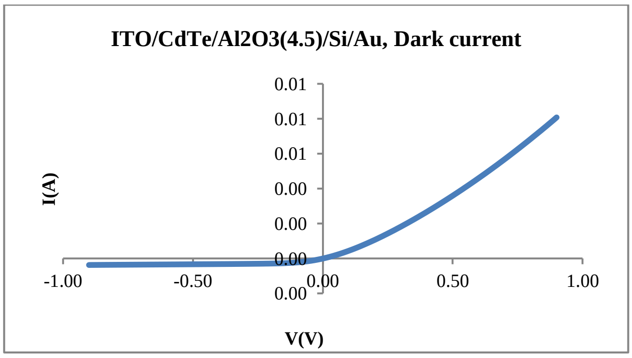

Figure (8): I-V curve of dark current for ITO/CdTe/Al_2O_3/Si/Au device in which the thickness of Al_2O_3 is 4.5nm

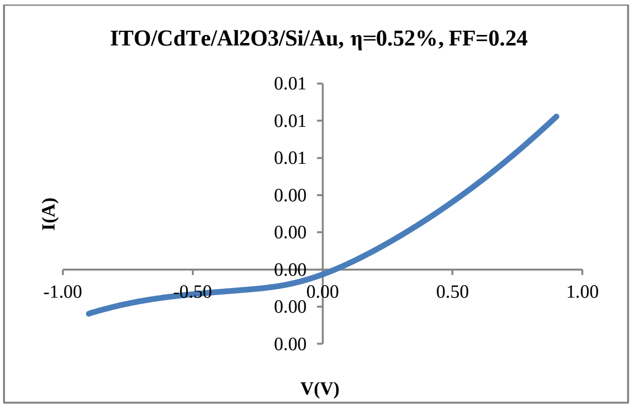

Figure (9): I-V curve of light current for ITO/CdTe/Al_2O_3Si/Au device in which the thickness of Al_2O_3 is 4.5nm

The fabricated solar cell's efficiency was calculated using the following relationship

$$\eta = P_{out}/P_{in} \quad (1)$$

Where P_{in}=0.06 W/cm^2 is the power per area for the halogen lamp measured by power meter.

$$P_{out} = P_{max}/A \quad (2)$$

where A is the effective area of the device in units of cm^2 and P_{max} is the maximum absolute value of the product of 'I' and 'V' data in the fourth region of coordinates. The filling factor for the solar sell is:

$$FF = P_{max}/ (V_{oc} * I_{sc}) \quad (3)$$

where V_{oc} is the open circuit voltage and I_{sc} is the short circuit current. The I-V results for all samples are summarized in table (1).

Table (1): Values of η and FF for fabricated solar cells with different thicknesses of Al_2O_3 films

Thickness of Al_2O_3 layer (nm)	0	1.7	3.5	4.5
Quantum efficiency, (η %)	1.25	1.73	0.98	0.52
Fill factor, FF	0.3	0.34	0.27	0.24

From table (1) one can conclude that both η and FF increase with increase the thickness of Al_2O_3 layer up to maximum values 1.73% and 0.34 respectively, and then decrease. This behavior shows that the ultrathin oxide layer improve the efficiency of the solar cell because of the tunneling effect. When the thickness of this layer accede 1.7nm, the efficiency of the solar cell decrease and it can be concluded that the effect of tunneling can be observed only for less than 2nm oxide layers. For thicknesses more than 2nm, the dielectric properties will prevail.

Choosing gold for back contact is due to its suitable work function (5.1eV) with respect to electron affinity and energy gap of silicon. The electron affinity of p-Si is 4.05eV and its energy gap at 300K is 1.12eV (U. K. Mishra *et al*, 2008). The work function of a metal to be a good ohmic contact for some material must be equal or higher than the sum of electron affinity and energy gap of that material. The work function of gold is in the range of 5.1 and 5.47eV which could be ideal for this goal (B. V. Zeghbroeck, 2011).

On the other hand, for n-CdTe thin film, the ohmic contact on the junction is not difficult to be achieved (S. Chusnutdinow *et al*, 2012). Although the sum of electron affinity and energy gap of CdTe is 5.73eV (MD. S. Hossain *et al*, 2011) which is greater than the work function of ITO, 5.53eV (R. Schlaf *et al*, 2001), but for n-type semiconductors the case is different. For an n-type semiconductor an ohmic contact means that the work function of the metal must be closer or smaller than the electron affinity of the semiconductor (B. V. Zeghbroeck, 2011). The most important property of ITO to be chosen as front contact is its transparency. So, in contrary with other conductors, it allows light to pass through it without any problem.

Conclusions

By varying the thickness of Al_2O_3 film, the efficiency and filling factor of the solar cells increase, reach their maximum values at the thickness of 1.7nm, and then decrease. So, it can be concluded that at 1.7nm, the tunneling effect takes place. For more than this thickness, the dielectric properties of oxide layer prevail the tunneling effect. Gold at the back side and ITO at front side of devices are suitable contacts for the CdTe/Al_2O_3/Si heterojunction.

Acknowledgements

The authors wish to thank Prof. Shubhra Gangopadhyay and Dr. Joseph Mathai from the University of Missouri-Columbia for useful discussions and help.

References

Woods, L.M.; Levi, D.H.; Kaydonov, V.; Robinson, G.Y.; Ahrenkiel, R.K. (1998), Electrical Characterization of CdTe Grain Boundary Properties from as-Processed CdTe/CdS Solar Cells, *Presented at the 2nd World Conference and Exhibition on Photovoltaic Solar Energy Conversion*, Vienna, Austria.

An-Nadoss, A.F.; Ahmed, H.A.; Hayatee, F.G. (1993), Characterization and vacuum deposition of CdS layer on silicon wafers, *Fourth Arab International Solar Energy Conference*, Amman, Jordan, Vol. 1.

Green, M.A.; Blakers, A.W.; Shi, J.; Keller, E.M.; Wenham, S.R. (1984), High-efficiency silicon solar cells, *IEEE Trans. Electron Devices*, 31, pp 679-683.

Metz, A.; Hezel, R. (1997), Record efficiencies above 21% for MIS-contacted diffused junction silicon solar cells, *Proceedings of the 26th IEEE Photovoltaic Specialist Conference*, pp 283-286.

Richter, A.; Benick, J.; Hermle, M.; Glunz, S.W. (2011), Excellent silicon surface passivation with 5 Å thin ALD Al_2O_3 layers: Influence of different thermal post-deposition treatments, *Phys. Status Solidi RRL* 5 (5-6), pp 202-204.

Schmidt, J.; Werner, F.; Veith, B.; Zielke, D.; Bock, R.; Tiba, V.; Poodt, P.; Roozeboom, F.; Li, A.; Cuevas, A.; Brendel, R. (2010), Surface passivation of silicon solar cells using industrially relevant Al_2O_3 deposition techniques, *Proc. 25th Europe. Photovolt. Solar Energy Conf.,* Valencia, Spain, p. 1130.

Zielke, D.; Petermann, J.H.; Werner, F.; Veith, B.; Brendel, R.; Schmidt, J. (2011), Contact passivation in silicon solar cells using atomiclayer-deposited aluminum oxide layers, *Phys. Status Solidi RRL*; 5, pp 298-300.

Mishra, U.K.; Singh, J. (2008), Semiconductor Device Physics and Design, Springer.

Zeghbroeck, B.V. (2011), Principles of Semiconductor Devices, Chapter 3

Chusnutdinow, S.; Makhniy, V.P.; Wojtowicz, T.; Karczewski, G. (2012), Electrical Properties of p-ZnTe/n-CdTe Photodiodes, *Acta Physica Polonica A*, 122, p. 6.

Hossain, MD. S.; Amin, N.; Matin, M.A.; Aliyu, M.M.; Razykov, T.; Sopian, K. (2011), A numerical study on the prospects of high efficiency ultra thin ZnxCd1-xS/CdTe Solar Cell. *Chalcogenide Letters*, 8 (3), p. 263.

Schlaf, R.; Murata, H.; Kafafi, Z.H. (2001), Work function measurements on indium tin oxide films, *Journal of Electron Spectroscopy and Related Phenomena*, 120, p. 149.