International Journal of Electronics Engineering (ISSN: 0973-7383)
Volume 10 • Issue 2 pp. 92-96 June 2018-Dec 2018 www.csjournals.com

Dependence of Temperature of CdTe/CdS Based Solar Cell Performance

Sudipta Banerjee
Asst. Professor, Department of Electronics and Communication Engineering
NSHM Knowledge Campus, Durgapur, India

Abstract: In this paper analytical work has been carried out on the temperature dependence of the performance of solar cells in the temperature range 273–373 K. The parameters such as open circuit voltage (Voc), short circuit current density (Isc), fill factor (FF) and efficiency (η) determines the performance of solar cell. CdTe and CdS were the material under consideration. Reverse saturation current density (Jo) is an important diode parameter which controls the change in performance parameters with temperature. The maximum achievable Voc, Jsc, FF and η of solar cells are calculated for AM1.5G spectra. The impact of temperature on efficiency has been discussed.

Keywords: CdTe; Efficiency; Fill Factor; Solar Cell; Temperature effect.

Introduction

Solar cell is one of the most important optoelectronic devices that is used to convert the solar energy to electrical energy [1]. As the cell performances are mostly affected by the temperature (T), the temperature effect on solar cell disclosed to draw attention among the photovoltaic researchers. Cadmium telluride is a promising material for thin-film solar cells due to its direct optical bandgap with energy of about Eg=1.5 eV and high absorption co-efficient of 5×10^5/cm [1–4]. Record conversion efficiency of 17.3% was recently reported by First Solar for polycrystalline CdTe thin-film solar cell [5]. Recently, the CdTe based solar cell has attained the highest efficiency of 22.1% [2]. However, the record efficiency of CdTe solar cells is much less than its theoretical maximum due to several reasons.

However, the temperature usually ranges from 273 K to 323 K in terrestrial applications , whereas the temperature grading in concentrator and space systems is typically higher than in terrestrial system [3]. Several previous works showed that the cell performance deteriorates with enhancing temperature [3-6]. The effect of temperature on solar cell performance parameters is controlled by two important diode parameters, ideality factor (n) and reverse saturation current density (Jo) [6]. Moreover the shunt resistance (R_{sh}) and the series resistance(Rs), along with those diode parameters contribute to control the effect of temperature on fill factor and power conversion efficiency [6].

It has been observed that the open circuit voltage (Voc) decreases and the short circuit current density(Jsc) increases slightly when temperature increases [3-7]. Due to this degradation in V_{oc} the fill factor and the efficiency decreases with the increasing temperature. Meanwhile efficiency is slightly affected by R_{sh} and R_s and with the exponential increase in J_o with increasing the T creates rapid degradation of $V_{oc.}$ Thus J_o is a critical material to affect efficiency of solar cell. The band gap of the optoelectronic materials used in solar cell design, affect this reverse saturation current density. Few authors have already calculated the temperature dependence of the following solar cell parameters: E_g, V_{oc}, J_{sc}, FF and η of single junction solar cells ignoring the series and shunt resistances. In this study, the temperature effect on the performance parameters of CdTe based solar cells in the temperature range from 273K to 373K has been investigated. This study will be helpful to design and utilize the further analysis of the performance of single junction and tandem solar cells with respect to temperature.

Theoretical Analysis

The equivalent electric circuit of an ideal photovoltaic cell has been shown in Figure 1.

The current vs voltage characteristics also familiar as I-V characteristics' of a solar cell that forms a p-n junction under steady state illumination condition can simply be presented using a particular exponential model as,

$$\mathbf{I = I_0}\left(\exp\left(\frac{qV}{kT}\right)-1\right) \mathbf{- I_L} \qquad (1)$$

Where I_L is the illuminated current produced by the solar cell. Ignoring the effect of $R_{sh,}$ R_s and also considering the ideality factor = 1,

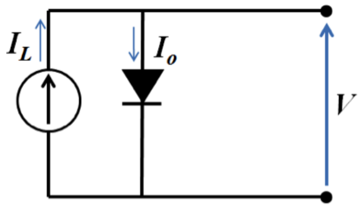

Figure 1: Equivalent circuit of solar cell

The mathematical equations described in this section are taken from the literature [3, 11-13]. The simulation results are analyzed by a one-dimensional photovoltaic simulator, PC1D [10]. However, when the photons have energy higher than the energy band gap (Eg) of the semiconductor materials, then those photons are absorbed and make electron-hole pairs [1]. Moreover, the cut-off wavelength of any photons is useful for carrier generation. And this band gap dependent cut-off wavelength and temperature dependent band gap are defined by Equation (2) and (3) [11, 12].

$$\lambda_g = \frac{1240}{E_g(eV)} \text{ nm} \qquad (2)$$

$$E_g(T) = E_g(0) - \frac{\alpha T^2}{(T+\beta)} \qquad (3)$$

Where $E_g(T)$ is the bandgap of the semiconductor at some temperature T, which may be direct or indirect, $E_g(0)$, its value at 0 K and a and b are constants. Table 1 lists the values of Eg (0), α and β for the semiconductor materials CdTe and CdS [19].

TABLE 1: ENERGY GAP BAND GAP PARAMETERS

Material	$E_g(0)$(eV)	α(eV/K)×10^4	β(K)
CdTe [19]	1.6077	3.100	108
CdS [19]	2.583	4.020	147

Device Simulation

The PC1D is a computer program written for IBM-compatible personal computers which solves the fully coupled nonlinear equations for the quasi-one-dimensional transport of electrons and holes in crystalline semiconductor devices, with emphasis on photovoltaic devices. The program was initially written at Sandia National Labs by Dr. Paul Basore and co-workers and was further developed by Dr. Don Clugston at the University of New South Wales, Australia. The global AM1.5 (1000 Wm^{-2}, AM1.5G) is the solar spectrum for incident light on the earth. It includes direct as well as diffuse rays of light from the sun and used as a standard in the photovoltaic (PV) industries.

TABLE 2: TYPICAL ELECTRICAL PARAMETERS FOR CDTE AND CDS FILMS

Parameter	CdTe	CdS
Thickness (μm)	8	0.025
Bandgap (eV)	1.5	2.4
Electron affinity (eV)	3.9	4
Dielectric permittivity (relative)	9.4	10
Electron mobility (cm2/V-s)	500	350
Hole mobility (cm^2/V-s)	60	50
Electron density (cm^{-3})	-	1.00E+15
Hole density (cm^{-3})	1.00E+17	-
Effective density of states in the conduction band, (cm^{-3})	2.20E+18	8.00E+17
Effective density of states in the valence band, (cm^{-3})	1.80E+19	1.80E+19
Light Intensity (W/cm^2)	0.1	

International Journal of Electronics Engineering (ISSN: 0973-7383)
Volume 10 • Issue 2 pp. 92-96 June 2018-Dec 2018 www.csjournals.com

Result and Discussion

As we know that solar cell is used in different atmospheric condition. Since temperature of ambient gets changed with respect to time during day hence solar cell performance might get varied with respect to temperature. The performance, essentially, the efficiency of a solar cell has been calculated as a function of temperature under the AM1.5G illumination condition. This value has been used to compute the performance parameters of the photovoltaic cells. The performance variation in the cell due to varying temperature from 273 K to 373 K has been plotted in Figure 2:

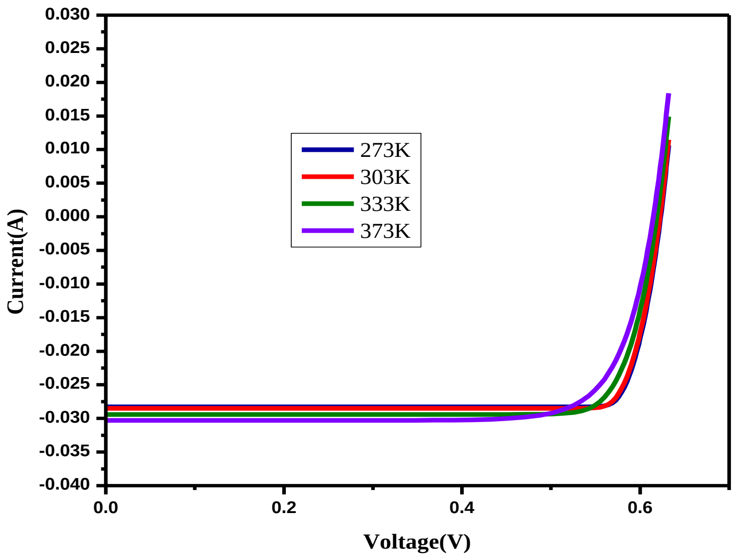

Figure 2**:** I-V characteristics of CdTe/CdS solar cell with temperature 273-373K

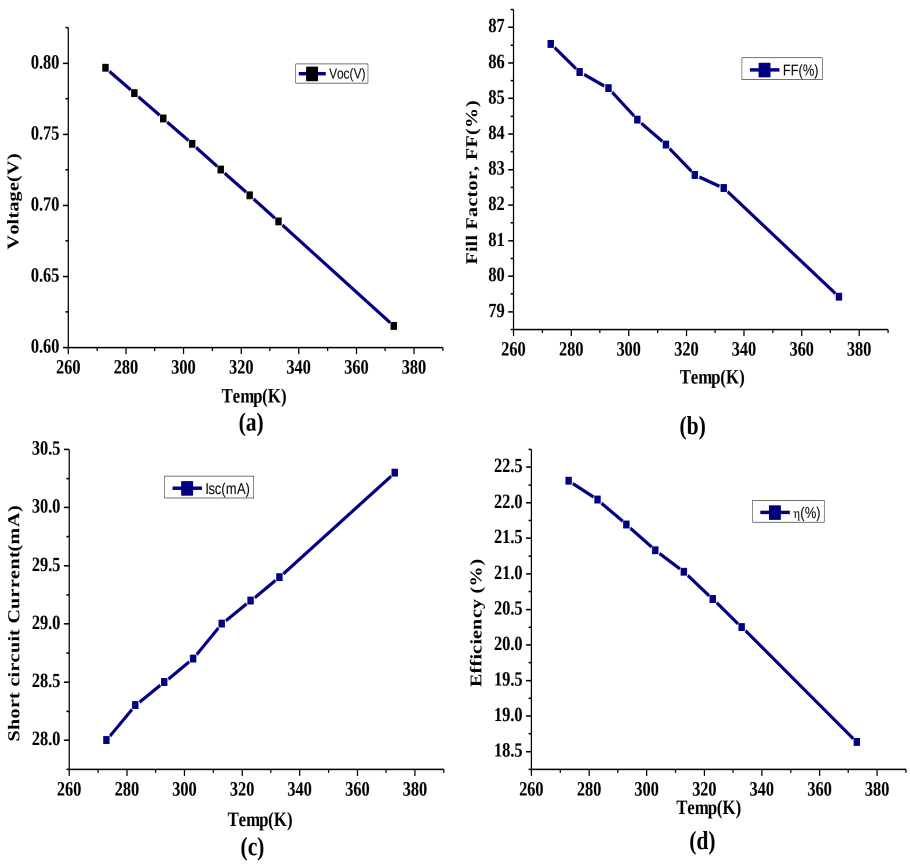

Figure 3: Different characteristics variation with respect to temperature for CdTe/CdS thin film solar cell (a) open circuit voltage variation with temperature, (b) Fill Factor variation with temperature, (c) short circuit current variation with temperature and (d) Efficiency variation with temperature.

TABLE 3: EXTRACTED OUTPUT PARAMETERS FOR CDTE AND CDS FILMS

Temp(K)	CdS(µm)	Voc(V)	Isc(mA)	FF(%)	η(%)
273	0.05	0.7966	28	86.53	22.30
283	0.05	0.7789	28.3	85.74	22.04
293	0.05	0.7611	28.5	85.29	21.69
303	0.05	0.7431	28.7	84.40	21.33
313	0.05	0.7251	29	83.70	21.03
323	0.05	0.7069	29.2	82.84	20.64
333	0.05	0.6887	29.4	82.48	20.25
373	0.05	0.615	30.3	79.42	18.63

The conversion efficiency for solar cells depends on several factors, for example, high ambient temperature has a serious effect on the performance of solar cells. Increasing the temperature would increase Isc exponentially. Recombination in depletion region dominated at T > 283 K but it changed to tunneling at lower temperatures. This results in a considerable decrease in both Voc and FF as seen from Table 2. Therefore, the efficiency of the cell is significantly reduced as temperature increases.

Acknowledgment

The author wants to acknowledge PC1D photovoltaic simulation tool developed by Dr. Paul Basore and Dr. Don Clugston at the University of New South Wales, Australia.

References

[1] P. Singh and N.M.Ravindra, "*Temperature dependence of solar cell performance – An analysis,*" Solar Energy Materials and Solar Cells, vol. 101, pp. 36–45, Jun. 2012.

[2] J. J. Wysocki and P. Rappaport, "*Effect of Temperature on Photovoltaic Solar Energy Conversion,*" Journal of Applied Physics, vol. 31, no. 3, pp. 571–578, Mar. 1960.

[3] J. C. C. Fan, "*Theoretical temperature dependence of solar cell parameters,*" Solar Cells,vol. 17, no. 2, pp. 309–315, Apr. 1986.

[4] P. Singh, S. N. Singh, M. Lal, and M. Husain, "*Temperature dependence of I–V characteristics and performance parameters of silicon solar cell*," Solar Energy Materials and Solar Cells, vol. 92, no. 12, pp. 1611–1616, Dec. 2008.

[5] A. Mahfoud, F. Mohamed, S. Mekhilef, and F. Djahli, "*Effect of Temperature on the GaInP/GaAs Tandem Solar Cell Performances*," International Journal of Renewable Energy Research (IJRER), vol. 5, no. 2, pp. 629–634, Jun. 2015.

[6] M.-J. Jeng, Y.-L. Lee, and L.-B. Chang, "*Temperature dependences of InxGa1− xN multiple quantum well solar cells,*" J. Phys. D: Appl. Phys., vol. 42, no. 10, p. 105101, 2009.

[7] X. Wu, "*High-efficiency polycrystalline CdTe thin-film solar cells*," Solar Energy, vol. 77, no. 6, pp. 803–814, Dec. 2004.

[8] S. Banerjee, "*Performance Analysis of Cadmium Sulfide/Cadmium Telluride (CdS/CdTe)Thin Film Solar Cell using PC1D*", 2017 Devices for Integrated Circuit (DevIC), pp. 730-733, 23-24 March, 2017.

[9] J. Gray, X. Wang, R. V. K. Chavali, X. Sun, A. Kanti, and J. R. Wilcox, "ADEPT 2.1," 2015.

[10] Y. P. Varshni, "*Temperature dependence of the energy gap in semiconductors*," Physica, vol. 34, no. 1, pp. 149–154, Jan. 1967.

[11] R. Pässler, "*Parameter Sets Due to Fittings of the Temperature Dependencies of Fundamental Bandgaps in Semiconductors*," phys. stat. sol. (b), vol. 216, no. 2, pp. 975–1007, Dec. 1999.

[12] M. A. Green, E. Cliffs, "Solar cells : operating principles, technology, and system applications", Prentice-Hall, 1982.

[13] R. C. Rai, M. Guminiak, S. Wilser, B. Cai, and M. L. Nakarmi, "*Elevated temperature dependence of energy band gap of ZnO thin films grown by e-beam deposition,*" Journal of Applied Physics, vol. 111, no. 7, p. 073511, Apr. 2012.

[14] C. Riordan and R. Hulstron, "*What is an air mass 1.5 spectrum? [solar cell performance calculations]*," in IEEE Conference on Photovoltaic Specialists, Vol. 2, pp. 1085–1088,1990.

[15] J.M. Burst, et al., "*CdTe solar cells with open-circuit voltage breaking the 1 V barrier*," Nature Energy, vol. 1, p. 16015, Feb. 2016.

[16] T. Aramoto, et al., "*16.0% Efficient Thin-Film CdS/CdTe Solar Cells*," Jpn. J. Appl. Phys., vol. 36, no. 10R, pp. 6304, Oct. 1997.

[17] M.A. Green, Keith Emery, Yoshihiro Hishikawa, Wilhelm Warta, "*Solar cell efficiency tables (version 37)*", Progress in Photovoltaics: Research and Applications Vol.19, pp.84–92, 2011.

[18] M. E. Nell and A. M. Barnett, "*The spectral p-n junction model for tandem solar-cell design*," IEEE Transactions on Electron Devices, vol. 34, no. 2, pp. 257–266, 1987.