International Journal of Scientific Engineering and Technology ISSN:2277-1581
Volume No.5 Issue No.5, pp: 247-251 01 May 2016

The Influence of Temperature on the Electric Parameters of a Solar Cell Based on $Cu(In,Ga)Se_2$

Djimba NIANE*, Alain Kassine EHEMBA*, Demba DIALLO*, Ibrahima WADE*, Moustapha DIENG*

*Laboratory of Semiconductors and Solar Energy, Physics Department, Faculty of Science and Technology

University Cheikh Anta Diop – Dakar - SENEGAL

Corresponding Email: ehembaalain@yahoo.fr

Abstract: ***We used the simulation program Solar Cell Capacitance Sumilator in 1 Dimension (SCAPS-1D) to study the influence of temperature on the electrical parameters of a solar cell based of heterojunction CIGS/CdS/ZnO under constant illumination (1000W/m²) under the conditions AM1.5G. The parameters studied are the short circuit current density(J_{SC}), the open circuit voltage (Voc), the form factor (FF), the efficiency of the cell (η) and the external quantum efficiency (QE) in the range of 273K to 333 K. The simulation shows that the J_{SC} increases while the Voc decreases as a function of temperature. The increase in Jsc causes significant external quantum efficiency and the reduction of Voc and the maximum power affects the FF thus decreasing the efficiency of the solar cell.***

Keywords— Solar cell, CIGS, SCAPS-1D, Temperature, Macroscopic electrical parameters

I. Introduction

The earth receives every year the equivalent of 10000 times of the world consumption into energy with solar irradiation. This resource is thus inexhaustible and when the appeal to the fossil fuels is questioned, the photovoltaic develops increasingly. However, his main inconvenience stays its cost high, due to the fact that the technology of the first generation based on the silicon requires numerous manufacturing processes and high temperatures. Some semiconductor materials may be substituted for silicon, and require only a few microns thickness (against 200 µm approximately for silicon) to absorb all photons of the incident light. Indeed, solar cells based on Copper Indium Gallium Diselenide (CIGS) thin film are those that represent the best technology, with a record performance in laboratory equal to 20.3% [1] and modulus 15% [2]. The best performance is obtained by depositing the CIGS by three steps coevaporation [3].

The structure of a solar cell based on CIGS is formed by a stack of several layers, namely, a metal grid Ni/Al/ Ni, a transparent conductive oxide (TCO) n-ZnO, a buffer layer n-CdS, an absorber layer based on Cu (In, Ga) Se2 p-doped, a metal contact layer of Molybdenum, and finally a substrate (soda lime polyimide and metal).

The study of the behavior of solar cells with the temperature (T) is important, because in the ground applications, they are generally exposed to temperatures ranging from 15 ° C (288 K) at 50 ° C (323 K) [4] and can be higher in the space [5].

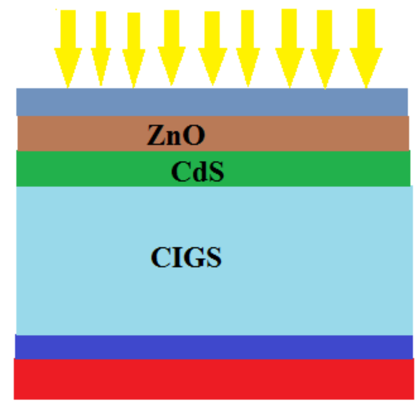

Fig.1: Structure of a heterojunction solar cell n-ZnO/n-CdS/p-CIGS.

In this study we investigate the performance parameters of a heterojunction solar cell n-ZnO/n-CdS/p-CIGS, shown in Fig. 1 as a function of the ambient temperature in the range of 273 to 333 K with the software simulation SCAPS of-1D [6,7] under the illumination of 1000W/m² in AM1.5G conditions. The variations of the density current-voltage characteristics (J-V) of the solar cell, the external quantum efficiency QE (λ), the short circuit current density (J_{SC}), the open circuit voltage (Voc), the form factor (FF) and the photovoltaic conversion efficiency (η) as a function of temperature under constant illumination are determined.

II. Numerical simulation

The comprehension of the mechanisms of functioning of the photovoltaic devices more particularly those of the thin layers based CIGS such as the currents of transport ,the electron-hole generation and recombination phenomena requires the construction of the numerical models. The latter make it possible to elucidate the processes which limit the performances of the cell and to give an optimal design of the structures at the base of these devices.

ISSN:2277-1581
01 May 2016

Table1: The physical parameters of the different layers used in the simulation.

	ZnO	CdS	CIGS
Thickness (µm)	0,05	0,05	3
band gap (eV)	3,3	2,4	1,2
Dielectric permittivity	9	10	13,6
Electron affinity (eV)	4,45	4,2	4,5
N_c(cm^{-3})	2,2.10^{18}	2,2.10^{18}	2,2.10^{18}
N_V(cm^{-3})	1,8.10^{19}	1,8.10^{19}	1,8.10^{19}
Electron thermal velocity (cm/s)	10^{7}	10^{7}	10^{7}
Hole thermal velocity (cm/s)	10^{7}	10^{7}	10^{7}
Electron mobility (cm^2/Vs)	10^{2}	10^{2}	10^{2}
Hole mobility (cm^2/Vs)	2,5.10^{1}	2,5.10^{1}	2,5.10^{1}
N_D(cm^{-3})	10^{18}	10^{17}	10
N_A (cm^{-3})	10^{0}	10^{0}	2.10^{16}

The SCAPS-1D is a simulation software one-dimensional solar cells based on CdTe and CIGS developed by Marc Burgelman et al. [6,7]. It proceeds by solving three fundamental equations of a semiconductor, the Poisson equation and the continuity equations.

$$\vec{\nabla}.\vec{\varphi} = -q(p - n + N_{D^+} - N_{A^-}) \quad (1)$$

$$\vec{\nabla}.\vec{J_n} = q(R - G) + q\frac{\partial_n}{\partial_t} \quad (2)$$

$$\vec{\nabla}.\vec{J_p} = q(R - G) + q\frac{\partial_p}{\partial_t} \quad (3)$$

Where ε is the dielectric constant, φ the electrostatic potential, n and p the concentration of the free carriers, N_{D^+} and N_{A^-} are the densities of the ionized acceptors and donors, J_n and J_p the current densities of electrons and holes, R the rate of recombination and G the generation rate of electron-hole.
In this work, we model the effect of the temperature in a heterojunction solar cell n-ZnO/n-CdS/p-CIGS, the physical parameters of the different layers used in the simulation are shown by the Table 1.

III. Results and Discussions

The voltage-current density characteristics J (V) are important standard methods for electrical characterization in the case of devices as far as they allow estimating the performances of devices. Under constant illumination 1000W / m², the source used in this work to illuminate the cell is the AM1.5G.The characteristic parameters that are generally used to describe the performance of a solar cell are the open circuit voltage (V_{OC}), the short-circuit current density (J_{SC}) ,the form factor (FF) and the efficiency (η).
In this work we used the equivalent circuit of a solar cell shown in Figure 2. The serial resistances R_S and shunt R_{SH} are neglected in this work because their variations with the temperature affect slightly the performances of the solar cell [4-8].

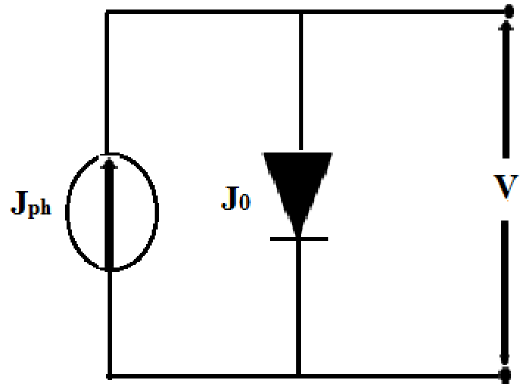

Fig. 2: equivalent circuit of an ideal solar cell

The characteristic current density - voltage J(V) of a solar cell in the absence of the resistances series (R_S=0) and resistances-parallels ($R_P = \infty$) comes down to the equation of a simple diode in the following way:

$$J = J_0 .\left(e^{\frac{qV}{AKT}} - 1\right) - J_{Ph} \quad (4)$$

Where J_{ph} represents the photogenerated current density, J_0 the current density of saturation of the diode, q the elementary charge, A the ideality factor of the diode which is equal to 1 in this document, K is the Boltzmann constant and T the temperature.
The characteristic J (V) as a function of the temperature (J (V, T)) allows studying the electronic transport mechanisms.

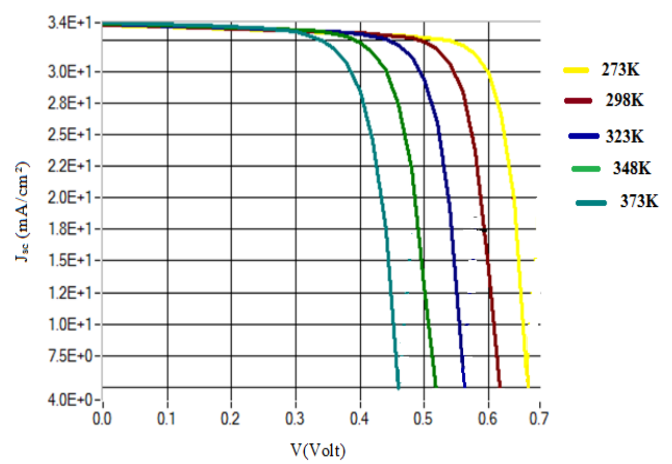

Fig. 3: the characteristics J (V) for different temperature.

The Fig. 3 shows the characteristics J (V) as a function of the temperature in the range 273K -373K.It is observed that the increase in temperature leads to an increase of the current density of short -Circuit (Jsc) and a decrease of the open circuit voltage (Voc).

Short-circuit current density (J_{SC})
The current density of short -Circuit (Jsc) is the current value when the voltage of cell is zero (V = 0), so according to Equation (4) it is equal to the current density photogenerated:

$J_{SC} = - J_{Ph}$ (5)

The Fig. 4 shows the variation of the short-circuit current density as a function of temperature. It is observed that the increase in temperature leads to an increase J_{SC}. This is attributed to shrinkage of the width of the band gap E_g. Indeed, the energy band gap semiconductors tend to decrease with increasing temperature. This behavior is due to inter-atomic spacing which increases as the amplitude of atomic vibrations increases due to the increased thermal energy. The variation in the energy gap for the semiconductor according to the temperature is described approximately by the Varshni's relationship [9,10].

$$E_g(T) = E_g(0) - \frac{\alpha T^2}{(T+\beta)} \quad (6)$$

With $E_g(T)$ is the bandwidth of the semiconductor at a temperature T, which may be direct or indirect, $E_g(0)$ corresponds the value when T ≈ 0 K and α, β are the constants. For the CIS $E_g(0)$=1.04eV , α=1,1.10^{-4}eV when β=0 [11].

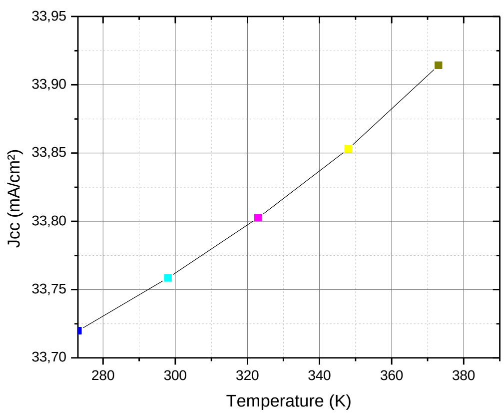

Fig. 4: variation of the short-circuit current density as a function of temperature

Open circuit voltage

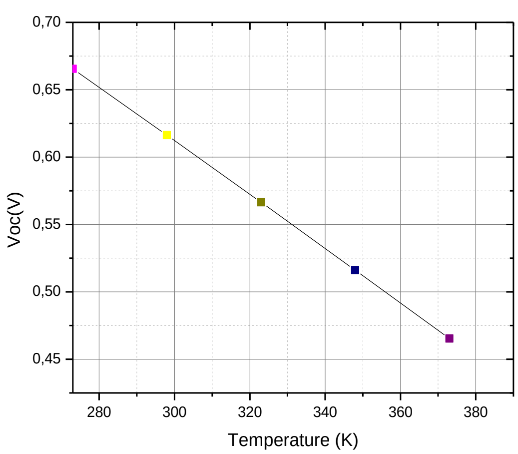

Fig. 5: the variation of the open circuit voltage (V_{CO}) as a function of temperature

The open circuit voltage Voc is the maximum voltage measured when the current density in the borders of cell is zero (J = 0). It is expressed by:

$$V_{oc} = \frac{kT}{q} \ln\left(\frac{J_{sc}}{J_0} + 1 \right) \quad (7)$$

Thus the variation of the open circuit voltage as a function of temperature is given by [12].

$$\frac{dV_{oc}}{dT} = \left(\frac{V_{oc}}{T} \right) + V_{th} \frac{1}{J_{sc}} \frac{dJ_{sc}}{dT} - \left(\frac{E_g(0)}{T} + \frac{\alpha T}{(T+\beta)^2} \right) \quad (8)$$

With $V_{th} = \frac{KT}{q}$

The Fig. 5 illustrates the variation of the open circuit voltage (Voc) as a function of temperature. We observe a decrease of Voc when the temperature increases. The linear thermal behavior of Voc is attributed to a decrease of the width of the band gap and an increase of the current density of saturation J_0 when the temperature increases. Indeed, the current density of saturation of the diode J_0 is very sensitive and increases exponentially with the evolution of the temperature in the solar cell. This sensitivity is strongly related to the minority carriers generated by thermal agitation in the heterojunction n-ZnO/n-CdS/p-CIGS.

The Maximum Power Point (MPP)

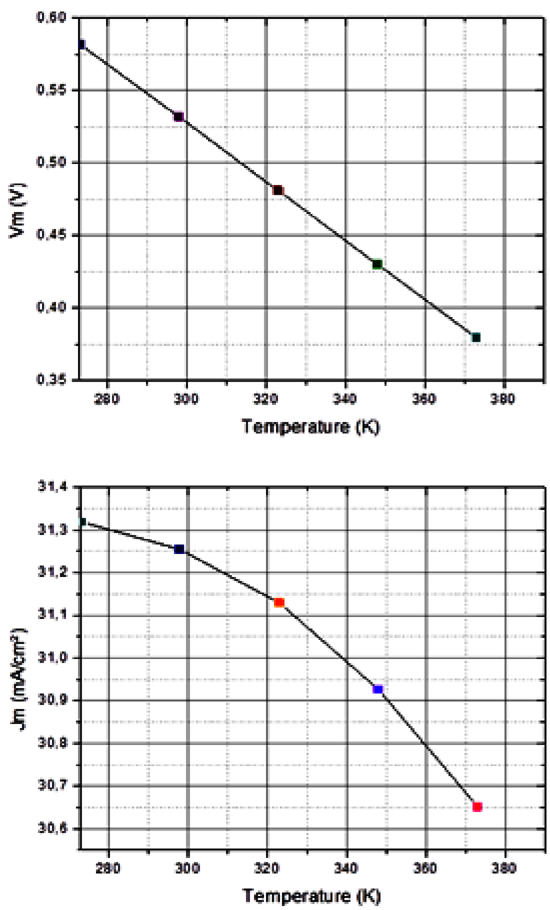

Fig. 6: evolution of the voltage and current at the maximum point as a function of temperature

ISSN:2277-1581
01 May 2016

The maximum power of illuminated photovoltaic cell is the essential parameter for evaluating its performance; it is given by the equation:

$P_m = V_m I_m$ (9)

Where V_m and I_m are also denoted voltage and maximum current respectively.

The Fig. 6 shows the evolution of the voltage and current at the maximum point respectively as a function of temperature. We observe a reduction of V_m and I_m when the temperature increases, thus causing a decrease of the maximum power Pm generated by the solar cell.

The Form Factor (FF)

The form factor F is defined as the ratio between the maximum power and the product of the open circuit voltage and the short-circuit current density. It represents the ratio between the area of the rectangle of diagonal (V_{CO}, J_{CC}) and the area of a rectangle touching the J (V) to the optimum functioning point, its expression is given by:

$$FF = \frac{Pm}{Voc \times Jsc} \quad (10)$$

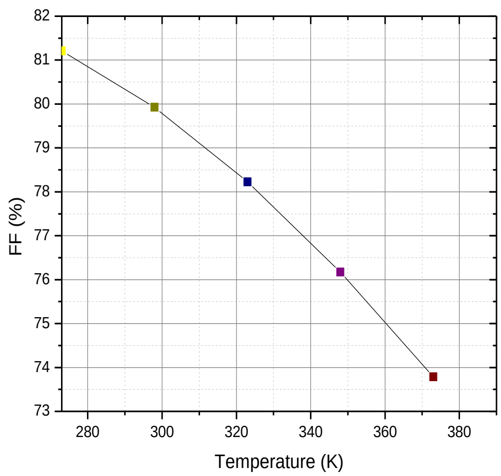

Fig. 7: evolution of the form factor (FF) according to the temperature

Green has given an expression of excellent precision to show the dependence of FF with the open circuit voltage [13]:

$$FF = \frac{V_{oc} - \ln(V_{oc} + 0{,}72)}{V_{oc} + 1} \quad (11)$$

Where $V_{oc} = \frac{V_{oc}}{V_{th}}$ is defined for normalized V_{CO}.

Thus the variation of the form factor as a function of the temperature was determined using [13] by [12].

$$\frac{dFF}{dT} = \frac{(dV_{oc}/dT - V_{oc}/T)}{(V_{oc} + V_{th})}\left\{\frac{V_{oc}/V_{th} - 0{,}28}{V_{oc}/V_{th} + 0{,}72} - FF\right\} \quad (12)$$

The Fig. 7 shows the evolution of the form factor (FF) according to the temperature. We notice that the form factor decreases as the temperature increases. This decrease is strongly caused by the reduction of V_{CO} and the maximal power point P_m.

Cell efficiency

The most important parameter of a solar cell is its efficiency η. It is defined as the ratio of the maximum power (electricity) produced by the photovoltaic cell on the incident light power (P_i).

$$\eta = \frac{P_m}{P_i} = \frac{V_{oc} \times J_{sc} \times FF}{P_i} \quad (13)$$

Thus the variation of cell efficiency as a function of the temperature $\frac{d\eta}{dT}$ depends to $\frac{dV_{oc}}{dT}$, $\frac{dJ_{sc}}{dT}$ and $\frac{dFF}{dT}$.

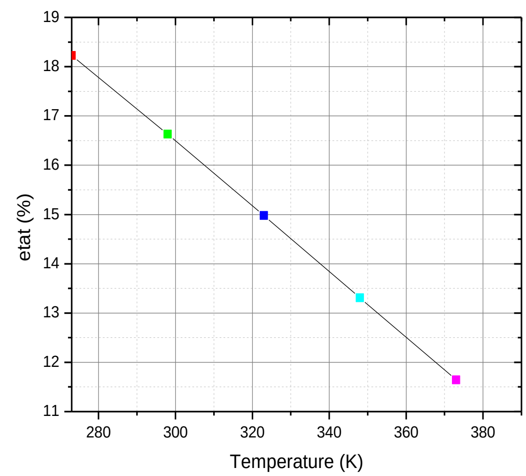

Fig. 8: evolution of the cell efficiency η depending on the temperature

The Fig. 8 illustrates the evolution of the cell efficiency η depending on the temperature. We note a decrease of the efficiency when the temperature increases. The linear thermal behavior of η is strongly linked to the reduction of the open circuit voltage and form factor.

Table 2: The electric parameters of the cell according to the temperature

Temperature (K)	Voc (Volt)	Jsc (mA/cm²)	FF (%)	Ƞ(%)
273	0.66	33.72	81.21	18.22
298	0.61	33.76	79.93	16.63
323	0.56	33.80	78.22	14.98
348	0.51	33.85	76.17	13.31
373	0.46	33.91	73.78	11.64

External quantum efficiency

The external quantum efficiency noted (QE), represents the ratio of the number of charges collected on the number of incident photons as a function of the wavelength. These measurements are used to characterize the photocurrent of cells and determine the origin of losses J_{CC}, his expression is given by:

$$QE(\lambda) = \frac{J(\lambda)}{q \times \varphi(\lambda)} \quad (14)$$

Whit J (λ) the current collected at one hundred wavelength λ, q the elementary charge, and φ (λ) the photon flux at the chosen wavelength.

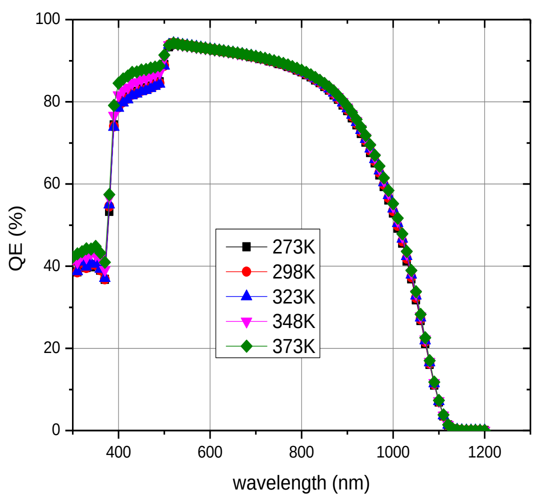

Fig.9: Variation of the external quantum efficiency at various temperatures depending on the wavelength

The Fig. 9 shows the variation of the external quantum efficiency at various temperatures depending on the wavelength. From 300 to 400nm and from 400 to 500 nm which corresponds respectively to the absorption zone of the window layer ZnO and the buffer layer CdS, we see clearly that the increase in temperature causes greater quantum efficiency. Beyond 500 nm corresponding to the absorption zone of the absorber layer CIGS, the external quantum efficiency doesn't vary more with increasing temperature, but nevertheless decreases with increasing wavelength. This can be explained by the fact that the CIGS has a direct gap, the absorption in the heterojunction is greater in the base, and improves with increasing temperature caused by the reduction of the width band gap and the multiplication of phonon [14]. The minority carrier generation mechanism dominates the recombination mechanism in this range of wavelengths, thus resulting in increasing the current density, therefore, the QE. Moreover, the losses linked to an incomplete collection in the CIGS observed from the large wavelengths [850nm-1200nm] are caused to the change of the threshold of absorption to lower energies and depend on the diffusion length of the minority carriers in the CIGS [15].

IV Conclusion

The temperature is a very important parameter in the behavior of solar cells because they are exposed to the sun rays. In this work, we studied its influence on the parameters of a heterojunction solar cell n-ZnO/n-CdS/p-CIGS. The increase in temperature affects the band gap decreases as the V_{co} and increases the J_{cc}, and therefore the external quantum efficiency. The reduction of the V_{CO} and the maximum power affects the form factor, and therefore the efficiency of the solar cell decreases.

Reference

i. *P. Jackson, D. Hariskos, E. Lotter, S. Paetel, R. Wuerz, R. Menner, W. Wischmann, and M. Powalla, "New world record efficiency for Cu(In,Ga)Se_2 thin-film solar cells beyond 20%" Progress in Photovoltaics: Research and Applications, vol. 19, no. 7, pp. 894–897, 2011.*

ii. *http://www.greentechmedia.com/articles/read/MiaSole-Sets-Efficiency-Record-for-Solar-on Flexible-Substrate.*

iii. *R. Caballero, V. Izquierdo-Roca, X. Fontané, C.A. Kaufmann, J. Álvarez-García, A. Eicke, L. Calvo-Barrio, A. Pérez-Rodríguez, H.W. Schock, J.R. Morante, "Cu defficiency in multi-stage co-evaporated Cu(In.Ga)Se2 for solar cells applications: Microstructure and Ga in-depth alloying", Acta Mater. 58 (2010) pp.3468–3476.*

iv. *S.M. Sze, Physics of Semiconductor Devices, John Wiley & Sons, NewYork, 1981, p. 264 (Chapter 14).*

v. *G. Landis, R. Rafaelle, D. Merritt, High temperature solar cell development, 19th European Photovoltaic Science and Engineering Conference, Paris, France, June 7–11, 2004.*

vi. *H. Movla, D. Salami, S.V. Sadreddini, Simulation analysis of the effect of defect density on the performance of p-i-n InGaN solar cell, Appl. Phys. A 109 (2012), pp.497–502.*

vii. *M. Burgelman, P. Nollet, S. Degrave, Modelling polycrystalline semiconductor solar cells, Thin Solid Films 361/362 (2000) pp.527–532.*

viii. *M.J. Jeng, Yu.L. Lee, L.B. Chang, Temperature dependences of lnxGa_{1-x}N multiple quantum well solar cells, Journal of Physics D: Applied Physics 42 (2009) 105101. (pp. 6).*

ix. *Y.P. Varshni, Temperature dependence of the energy gap in semiconductors, Physica 34 (1967) pp.149–154.*

x. *R. Passler, Parameter sets due to fittings of the temperature dependencies of fundamental bandgaps in semiconductors, Physica Status Solidi (b) 216 (1999) pp.975–1007.*

xi. *Nakanishi, H., S. Endo, T. Irie, and B.H. Chang, in Ternary and Multinary Compounds, Proceedings of the 7th International Conference, 1986 (Materials Research Society, Pittsburgh), p. 99.*

xii. *Priyanka Singh, N.M. Ravindra "Temperature dependence of solar cell performance-and analysis", Solar Energy Materials & Solar cells, 101 (2012), pp.36-45.*

xiii. *M.A. Green, Solar Cells, Prentice-Hall, Englewood Cliffs, NJ, 1982, p. 88.*

xiv. *William N. Shafarman, Susanne Siebentritt, and Lars Stolt. Cu(InGa)Se2 Solar Cells, In Handbook of Photovoltaic Science and Engineering, (2011), pp 546*

xv. *H.J. Hovel, 'Semiconductors and Semimetals', Edition R. K. Willardson, Academic New York, vol 11 (1975), pp 189.*