Influence of doping and thickness on the performance of CIGS PV cell

M. Bouchaour*, L. Merad, A. Ould-abbas and N.E Chabane Sari

Abstract— The most important aim of Photovoltaic (PV) manufacturers is to reduce the price of solar cells and increase their efficiencies above the Shockley Queisser limit. Back in the day, thin film technologies like CdTe, CIGS, etc. looked promising and started gaining meaningful market share. In this work, a numerical study of thin film CIGS based PV cells with Solar Cell Capacitance Simulator software (SCAPS) is reported. The influence of thickness and doping concentration on PV parameters (J_{sc}, η, V_{oc} and FF) under standard illumination is investigated. The analysis of the outputs of the SCAPS model provides a better understanding of thin film PV solar cells. The incorporation of certain impurities into CIGS solar cells can enhance spectral response, short circuit current density and conversion efficiency only under some conditions.

Keywords— Solar cell, CIGS, SCAPS, thickness, doping concentration, electrical parameters.

I. Introduction

A great deal of development is occurring in the research and industrialization of photovoltaic devices, which is a representative clean form of energy production.

Solar cells are described as being photovoltaic irrespective of whether the source is sunlight or an artificial light. The operation of a PV cell is based generally on the following three steps: 1. The absorption of light, generating electron-hole (exciton) pairs. 2. The separation of excitons into free charge carriers (electrons and holes). 3. The transportation of separated charge carriers to their respective anode and cathode of the solar cell, and extraction of those carriers to an external circuit [1].

In an effort to reduce the fabrication costs of the present technology based on Si, and to increase material utilization, thin film materials as CIGS materials have been the subject of intensive research.

Copper indium gallium (di) selenide Cu(In,Ga)Se2 (CIGS) is a I-III-VI semiconductor material composed of copper, indium, gallium, and selenium. The material is important for terrestrial applications because of their high efficiency, long-term stable performance and potential for low-cost production. Thin film solar-cells with polycrystalline $Cu(In,Ga)Se_2$ (CIGS) absorber layers provide a good alternative to wafer based crystalline silicon solar cells, which currently constitute the major share of photovoltaics installed and used worldwide. The CIGS based solar cells exhibit excellent outdoor stability, radiation hardness and highest efficiencies (>19%) [2-3]

The CIGS has a direct bandgap with a high optical absorption coefficient which using absorber of only a few microns thick [4].

In this paper, we report on a quantitative numerical study, using Solar Cell Capacitance Simulator in one dimension (SCAPS-1D), of the effects of thinning the CIGS layer. We initiate the work with the study of effect of thickness the absorber layer, followed by effect of concentration doping of CIGS absorber layer.

University of Tlemcen, Unité de Recherche « *Matériaux et Energies Renouvelables* », BP: 119, Fg Pasteur, Tlemcen, 13000, Algeria.
*Bouchaour.m@gmail.com

II. Device parameters

The main parameters that are used to characterize the performance of solar cells are the peak power, the short-circuit current density, the open-circuit voltage, and the Fill Factor. The conversion efficiency is determined from these parameters.

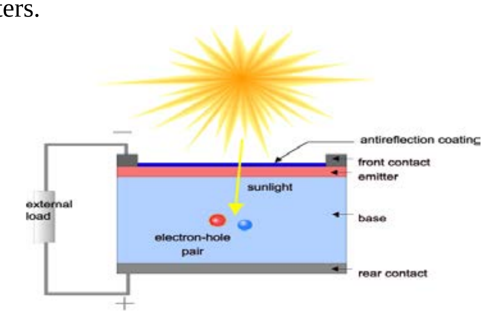


Figure 1. Solar cell

A. *Short-Circuit Current Density; J_{SC}*

The short-circuit current density is the maximum photo-generated current delivered by a solar cell when the terminals of the solar cell are in contact with each other (i.e. short-circuited).

$$J_{SC} = J(V) + J_0\left(e^{qV/mK_BT} - 1\right) \quad (1)$$

Thus, with the electronic charge q and K_B Boltzmann's constant, V is the voltage across the junction, T is the absolute temperature, J_0 is the dark saturation current density and m is the ideality factor with values between 1 and 2[5].

B. *Open-circuit voltage; V_{OC}*

The open –circuit voltage, is the voltage at which no current flows through the external circuit when the terminals of the solar cell are not connected to each other. It is the maximum voltage that a solar cell can deliver. It depends on the photogenerated current density, . For the simple p-n junction, It is given by [6]:

$$V_{oc} = \frac{mK_BT}{q} In\left(\frac{J_{ph}}{J_o}+1\right) \quad (2)$$

C. Fill factor; FF

The fill factor is the ratio between the maximum power generated by a solar cell and the product of V_{OC} and J_{SC}. *FF* describes the 'squareness' of the J-V curve. V_{OC} and J_{SC} are the maximum point voltage and current density generated by a solar cell

$$FF = \frac{V_{mp}J_{mp}}{V_{oc}J_{sc}} = \frac{P_{max}}{V_{oc}J_{sc}} \quad (3)$$

D. Power Conversion Efficiency

The power conversion efficiency is calculated as the ratio between the generated maximum power and the incident power. This is given by:

$$\eta = \frac{P_{max}}{P_{in}} = \frac{J_{sc}V_{oc}FF}{P_{in}} \quad (4)$$

The irradiance value, of 1000 W/m2 of AM1.5 spectrum has become a standard for measuring the conversion efficiency of solar cells. Where the irradiance power,P_{inc} , is the standard incident power as function of solar cell area. It has a value of of spectrum [5].

III. NUMERICAL MODELING AND DEVICE SIMULATION

SCAPS-1D Based Numerical Simulation is a crucial and efficient way to investigate the physical mechanism in a solar cell device without actually making the device. It can save both time and money in device development. Much simulation software has been developed and applied in the research of solar cell devices such as AMPS-1D, SCAPS-1D, PC1D, AFORS-HET and so on. SCAPS-1D is a one-dimensional simulation software developed by the University of Gent, Belgium. It has been applied to the study of different types of solar cells such as CZTS, CdTe, CIGS, etc. [7-8]. It was used in this work to explore the real device (CIGS) solar cell with material parameters modified for better performance. The software allows for the inclusion of deep bulk level and interface defect recombination (nonradiative recombination). Some of the recombination losses prevalent in the device under consideration are radiative recombination (ie. direct band-to-band recombination) and interface recombination which is accounted for by the Shockley-Read-Hall recombination (propagated by defects or traps). The flow chart below shows step-by-step stages in running a simulation with SCAPS [9].

There are five defect types and distributions available in the software and a variety of properties related with solar cells, such as energy bands, concentrations, currents, I-V characteristics, C-V, C-f, and QE can be determined by SCAPS. SCAPS can also provide flexible calculation and record functions including single shot, batch calculation, curve fitting, data and diagram recording. [10- 11].

The simulation procedure is given in figure. 2.

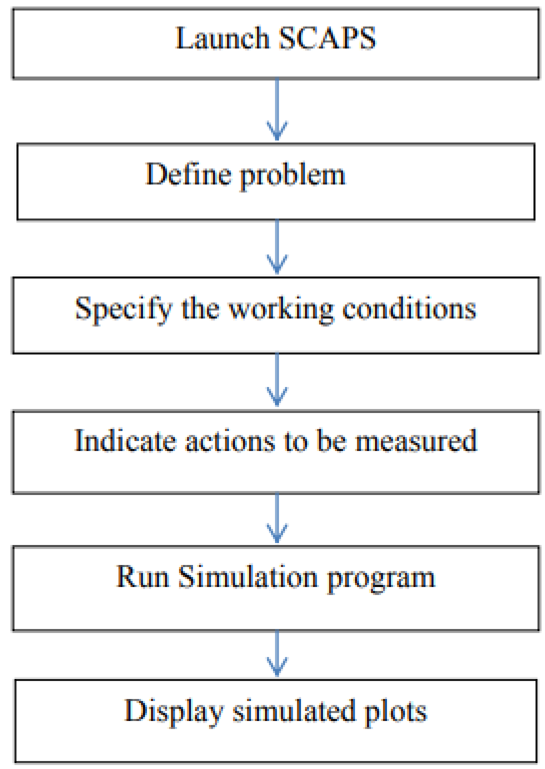


Figure 2. Simulation procedure

The various physical parameters used in the simulation are summarized in Table 1

Parameter	CIGS	CdS	i-ZnO	ZnO
Thickness (μm)	0.5 - 4	0.03 – 0.240	0.05	0.15
ε_r	13.6	9	9	9
$\mu_n\ (cm^2/Vs)$	300	10	200	200
$\mu_p\ (cm^2/Vs)$	30	1	25	25
$N_A\ (cm^{-3})$	10^{12} - 10^{18}	0	0	0
$N_D\ (cm^{-3})$	0	10^{12} - 10^{18}	1	5×10^{17}
$E_g\ (eV)$	1.1 – 1.5	2.40	3.3	3.3
$N_c\ (cm^{-3})$	2.2×10^{18}	2.2×10^{18}	2.2×10^{18}	2.2×10^{18}
$N_v\ (cm^{-3})$	1.9×10^{19}	1.8×10^{19}	1.8×10^{19}	1.8×10^{19}
$v_{t-h}(cm/s)$	1×10^7	1×10^7	1×10^7	1×10^7
$v_{t-e}(cm/s)$	1×10^7	1×10^7	1×10^7	1×10^7
χ (eV)	4.4	4.2	4.6	4.6

Table 1. Physical parameters

The structure has been adopted for CIGS based solar cell with layer configuration of glass substrate /CIGS absorber/CdS buffer/ZnO:i layer as shown in figure 3.

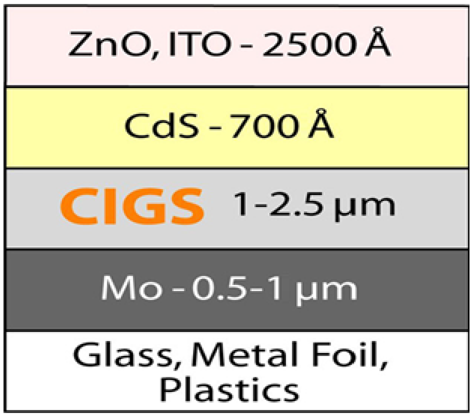


Figure 3. CIGS structure [16]

CIGS solar cell is composed of impure aluminum with zinc oxide (ZnO: Al) whose duty is to guide the photons received [12].

The layer of ZnO: i as TCO (Transparent Conductive Oxide) has a large band gap to ensure maximum absorption of sunlight. It should be a transparent layer that can absorb maximum photons [13].

CdS (sulfide cadmium) layer is n type semiconductor acts as a buffer layer between CIGS and TCO layers [14].

CIGS absorber layer is the core and active layer of the solar cell [15].

The role of Mo layer is to gather the carriers from the absorption layer and to present them to a foreign carrier (not used here).

The solar cell substrate is made in glass or plastic. This material is highly resistant against corrosion and its price is reasonable.

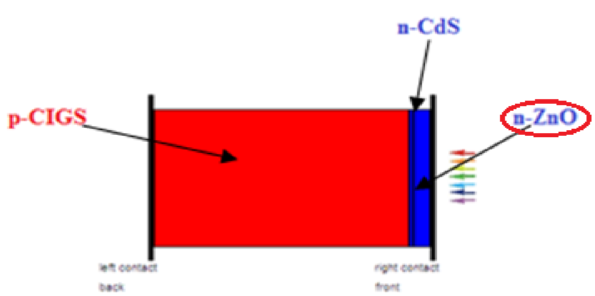


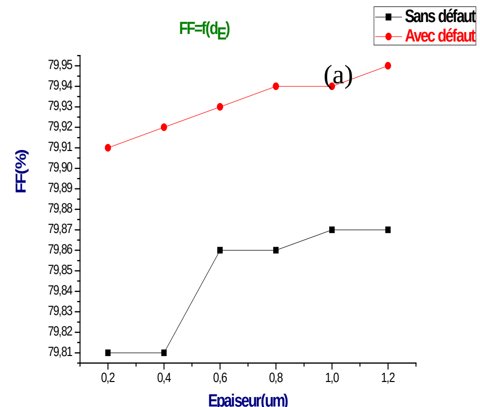
Figure 4. Structure of CIGS given by SCAPS-1 D software without Mo layer

IV. Results and Discussion

A. Effect of the absorber thickness on the device parameters

The plots below show the thickness variation from (0.2-1,2) µm of the absorber against the performance parameters of the device. Fig. 5 shows a decrease in Jsc, Voc, PCE (η) with thickness with an optimum thickness of 0.2 µm.

Thin film of CIGS reduces the device cost, as Indium and Gallium are the costly materials. We do not consider a buffer layer that is the reason of our results. In fact, the increase of when the photons of higher energy incident on the front panel of the device then they easily penetrates the absorber layer and recombination of electron hole takes place at the back contact due to this there is decrease in current density on decreasing thickness of absorber layer.



J_{SC} changes from 33.4129 Am/cm to 32.0690 m/cm

Tension changes from 0.6119v to 0.611v

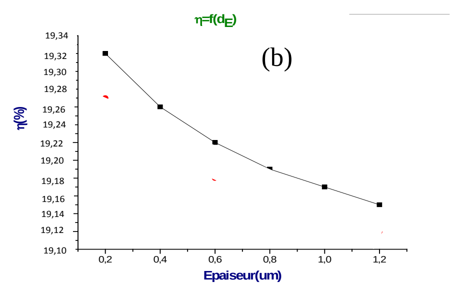
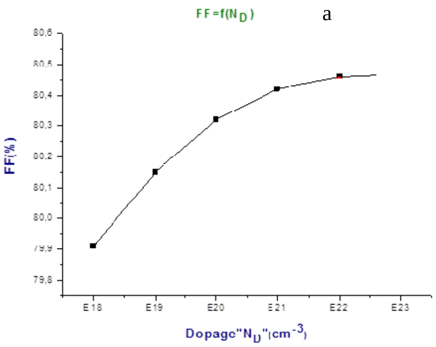


Figure 5. The simulated electrical performance parameters as a function of thickness: (a) fill factor, (b) conversion efficiency

B. Effect of doping concentration of the absorber on the simulated device

We performed device simulations for this system at different values of N_A. The resulting FF and conversion Efficiency characteristics are shown in Figure 6. From these results, we observe that there is a increase in device performance (η) as doping concentration increases. Increased doping concentration, increases recombination and reduces the lifetime of carrier according, see Ref [16].

Voc is independent of absorber thickness but depend on the space charge region width. Therefore Voc increases on increasing hole density because diffusion length decreases. The short circuit current is decreased this is because the collection of charge carriers reduces at the junction. This saturation shows that for high doping density the space charge region width should be reduced [16]. The maximum values of V_{OC} and J_{SC} were 0.6124V and 33.713 Am/cm^2.



$V_{OC\ max}$ (v)=0,6124
J_{SCmax} (Am/cm^2)=33,7713

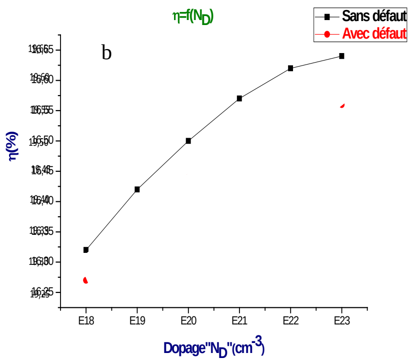


Figure 6. Effect of concentration doping on (a) FF and (b) conversion efficiency

V. CONCLUSION

The planar configuration proposed in this work was to enable the simulation with SCAPS. Solar cells with CIGS structure. A highly conversion efficiency (~19 %) has been obtained. We need in future to consider other layers in order to reduce the thickness and the doping concentration.

ACKNOWLEDGMENT

We would like to thank UGC for financial support and a very special thanks to professor Burgelman of the department of electronics and information systems at the University of Gent, Belgium for the development and use of the SCAPS software package.

REFERENCES

[1] S. O. Oyedele, B. M. Soucase, , B. Aka, " Numerical Simulation And Performance Optimization Of Cu(In,Ga)Se2 Solar Cells", IOSR Journal of Applied Physics Volume 8, 2016, 1-11.

[2]J.Lindahl, U.Zimmermann , P.Szaniawski, T.Törndahl, A.Hultqvist, P.Salomé, C.Platzer-Björkman and M.Edoff , " Inline Cu(In,Ga)Se2Co-evaporation for high efficiencysolar cells and modules", IEEEJ.Photovolt , 2013, 1100–1105.

[3]M.Powalla, P.Jackson, W.Witte, D.Hariskos, S.Paetel, C.Tschamber and W.Wischmann, "High-efficiency Cu(In,Ga)Se2 cells and modules", Solar Energy Mater. Solar Cells, 2013, p 51–58.

[4]M. Mostefaoui, H. Mazaria, S. Khelifi, A. Bouraiou, R. Dabou, "Simulation of high efficiency CIGS cells with SCAPS -1D software", Energy Procedia, 74, 2015, 736– 744.

[5] M. Zeman, Introduction to photovoltaic solar energy. pp. 1–139.

[6] M. Burgelman, P. Nollet and S. Degrave, "Modelling polycrystalline semiconductor solar cells", *Thin Solid Films*, 361-362, 2000, 527-532.

[7] Niemegeers, A., Burgelman, M., Decock, K., Verschraegen, J., & Degrave, S.). SCAPS manual. University of Gent, 2014.

[8] T. AlZoubi, M. Moustafa, "Numerical optimization of absorber and CdS buffer layers in CIGS solar cells using SCAPS", International Journal of Smart Grid and Clean Energy, 8, 3, 2019.

[9] D. Graham-Rowe, "Solar cells get flexible" Nature Photonics, 1 43, 2007, 435.

[10] Numerical modelling of CIGS/CdS solar cell Nisha Devi, Anver

[11] Simya OK, Mahaboobbatcha A, Balachander, "Compositional grading of CZTSSe alloy using exponential and uniform grading laws in SCAPS-ID simulation", Superlattices and Microstructures, 285, 2016, 92-93.

[12] Khoshsirat N, Yunus NA, Hamidon MN, Shafie S, Amin N, "Analysis of absorber layer properties effect on CIGS solar cell performance using SCAPS", Optik-International Journal for Light and Electron Optics, 126, 2015.

[13] I. Repins, S. Glynn, J. Duenow, T. J. Coutts, W. K. Metzger and M. A. Contreras, "Required Material Properties for High-Efficiency CIGS Modules", National Renewable Energy Laboratory,2002 .

[14] P .Chelvanathan, MI .Hossain, N .Amin," Performance analysis of copper-indium-galliumdeselenide(CIGS) solar cell with various buffer layers by SCAPS", Curr. Appl. Phys., 3,2000, 323-390.

[15] S. M. S. Hashemi Nassab, M. Imanieh , A. Kamaly, "The Effect of Doping And The Thickness Of The Layers On Cigs Solar Cell Efficiency", Science Journal, 36, 2015

[16] N. Rommel; k. Zweibel," High-efficiency cdte and cigs thin-film solar cells: highlights and challenges", National renewable energy laboratory. IEEE 4th World Conference on Photovoltaic Energy Conversion (WCPEC-4) Waikoloa, Hawaii May 7–12, 2006.