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Optimization of the thickness of Absorber and Zinc Oxide Buffer layers of CIGS solar cell using SCAPS-1D

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Abstract: Advancement in the technology forces the science community to expand in the search of energy. Solar energy was proven to be the answer for the problem. Solar Cell Capacitance Simulator (SCAPS) is a code used for studying one dimensional properties of a solar cell. Interest in the study of ZnO properties raised as a result of its capability to substitute the toxic CdS. The thickness of both Absorber and Buffer layers were optimized. It was found that the optimized thicknesses of both the Absorber and buffer layers were found to be 2.25µm and 0.02µm respectively. Also from the optimized materials, the Voc, Jsc, FF and efficiency were found to be 0.9426V, 37.944556mA/cm2, 85.29% and 30.51% respectively. The result shows promising outcome of the replacement of CdS and also in good agreement with literature.

Keyword: Solar cell, Absorber & Buffer layers, Voc, Jsc, FF and Efficiency

I. INTRODUCTION

The energy demand is increasing globally,and with the fast depleting fossil fuel source and ever-rising environmental pollution causing problems like global warming, the use of alternate energy has become much more important than any time in history (Das and Kumar, 2018). As the world struggles to address climatic changes, renewable energy is becoming an increasingly important source of electricity.Solar energy is the most available energy source available on earth. Though technologies for converting sunlight energy to power have made a lot of progress, high capital price and low conversion proficiency are the main obstacles to the common use of this technology (Ali and Hossain, 2015).

Thin-film solar cells are introduced and developed as the second generation of solar cells to provide high production capacity at lower energy and material consumption (Poortmans and Arkhipov, 2006). Main motivations for the growth of thin-film photovoltaic PV are their potential for high-speed and high-throughput manufacturing and minimum material requirements that lead to cost reduction. (Arnulf, 2011).

Copper Indium Gallium Di Selenide (CIGS) is one of the most promising materials for thin-film photovoltaic devices because of its appropriate band gap and high absorption coefficient for solar radiation (Green *et al.*, 2003). CIGS 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.(Kessler and Rudmann, 2004).

In this work, the code of simulation SCAPS-1D was used to examine the performances of the solar cells containing Copper indium gallium (di) selenide (CIGS). A series of studies of the parameters of the cells according to the thickness of the absorbing layer and buffer layer to improve them was carried out.

II. THEORETICAL BACKGROUND

The parameters used to characterize the output of solar cells for given irradiance and temperature are short circuit current (I_{sc}), short circuit current density (J_{sc}), open-circuit voltage (V_{oc}), maximum power point (P_{max}), current at maximum power point (I_{max}), voltage at maximum power point (V_{max}), fill factor (FF), conversion efficiency (ŋ), series resistance (R_s), and shunt resistance (R_{sh}) and can be obtained from I-V characteristic measurement.

The short circuit current (I_{sc}) is the current through the solar cell when the voltage across the solar cell is zero. The open-circuit voltage (V_{oc}) is the voltage across the solar cell when the current through the solar cell is zero. The maximum power point (P_{max}) is the condition under which the solar cell generates its maximum power; the current and voltage are defined as $I_{max}$and $V_{max,}$ respectively. The fill factor (FF) is defined as the ratio of P_{max} divided by the product of $V_{oc}$and I_{sc}. The conversion efficiency is defined as the ratio of P_{max} to the product of the input light irradiance (E) and the surface area of the solar cell (A).

$$I = I_o\left(1 - e^{\frac{qV}{KT}}\right) + I_L \tag{1}$$

$$V_{oc} = \frac{KT}{q}\left(In\frac{I_{sc}}{I_0}\right) \tag{2}$$

$$FF = \frac{P_{max}}{V_{oc} \times I_{sc}} = \frac{V_{max} \times I_{max}}{V_{oc} \times I_{sc}} \tag{3}$$

$$\eta = \frac{P_{max}}{P_{in}} = \frac{V_{max} \times I_{max}}{E \times A} = \frac{V_{oc} \times I_{sc} \times FF}{E \times A} \tag{4}$$

2.1. Governing equations of SCAPS

SCAPS-1D version 3.3.06 is a one-dimensional solar cell device simulator, developed at Electronics and Information Systems (ELIS), University of Gent, Belgium. SCAPS is freely available to the PV research community. The user can describe a solar cell as a stack of up to seven layers with different properties, such as thickness, optical absorption, doping, defect densities, and defect distribution. It is then pissible to simulate a number of common measurements: I-V, C-V, C-f, QE (Mandadapu*et al.*, 2017).

SCAPS is capable of solving the basic semiconductor equations, the Poisson equation and the continuity equations for electrons and holes:

$$\frac{d^2}{dx^2}\Psi(x) = \frac{e}{\varepsilon_0\varepsilon_r}\left(p(x) - n(x) + N_D - N_A + \rho_P - \rho_n\right) \tag{5}$$

Where Ψ is electrostatic potential, e is an electrical charge, ε_r is relative, and ε_0 is the vacuum permittivity, p and n are hole and electron concentrations, N_D is charged impurities of donor and N_A is acceptor type, $\rho_{p,}$ and ρ_n are holes and electrons distribution, respectively. The continuity equations for electrons and holes are:

$$\frac{dj_n}{dx} = G - R \tag{6}$$

$$\frac{dj_p}{dx} = G - R \tag{7}$$

where, j_n=Electron Current Density, j_p=Hole Current Density, G=Recombination Rate, R= Generation Rate. Carrier transport in semiconductors occurs by drift and diffusion and can be expressed by the equations:

$$J_n = D_n\frac{d_n}{dx} + \mu_n n\frac{d\emptyset}{dx} \tag{8}$$

$$J_p = D_p\frac{d_p}{dx} + \mu_p p\frac{d\emptyset}{dx} \tag{9}$$

SCAPS calculates the solution of the basic semi-conductor equations in one dimension and in steady-state conditions (Ouedraogo*et al.*, 2013).

The parameters used for simulations of a standard CIGS-based solar cell are summarized in table1.

Table 1: The parameters for the CIGS-based solar cell at 300K.

Parameters	CIGS[Mostefaouni et al,2015]	nZnO:Al [Oubda et al,2015]	ZnO [Asaduzzaman et al,2017]
E_g(eV)	1.5	3.3	3.3
ε_r	13.6	9	10
$\chi(eV)$	4.5	4.65	4.6
μ_n($cm^2V^{-1}s^{-1}$)	100	100	100
μ_p($cm^2V^{-1}s^{-1}$)	25	25	30
N_C(cm^{-3})	2.2e18	2.2e18	1.5e18
N_V(cm^{-3})	1.8e19	1.8e19	1.8e19
Vt(cm/s)	1e7	1e7	1e7
Vt(cm/s)	1e7	1e7	1e7

III. Procedure

Figure 1 explains the simulation process.

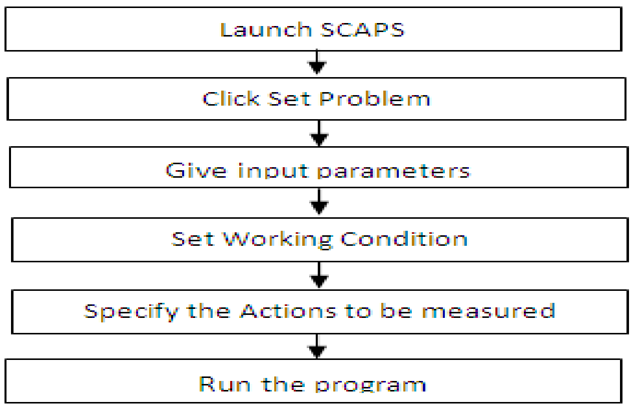


Figure 1. SCAPS working procedure

SCAPS has been designed to simulate CIGS and CdTe-based thin-film solar cell devices. The user can calculate results in the form of following characteristics: I-V, C-V, C-f, Q(λ), band diagrams, electric field, carrier densities, partial recombination currents. The user can set parameters of materials and an operating point: temperature, voltage, and frequency and illumination condition. The device is represented as a stack of layers, up to 7 semiconductor layers with specified properties, separate entries for interface parameters and two additional layers for front and back contacts. All layers are characterized by the numerical description of parameters (Burgelman et al., 2016)

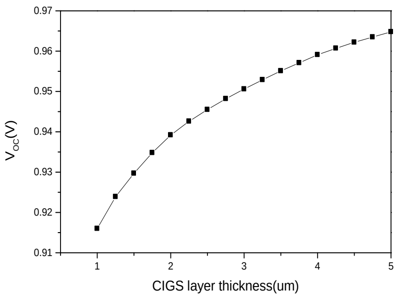
A typical CIGS-based solar cell structure consists of a p-type wide-bandgap absorber layer,a back contact glass substrate. An n-type buffer layer made of and window layer made of n-ZnO:Al

The TCO window layer that is used in this simulation is aluminum-doped zinc oxide (ZnO:Al) deposited on the top of Zinc Oxide as a buffer layer. The absorber layer is the CIGS that is a compound and direct band gap semiconductor material, while the material for the back contact is molybdenum (Mo). Each layer has its own special electrical and optical properties, which should be specified inside the SCAPS software as inputs before executing. The electro-optical properties of materials used for the specific layers are extracted from known and reliable numerical models and experimental studies.

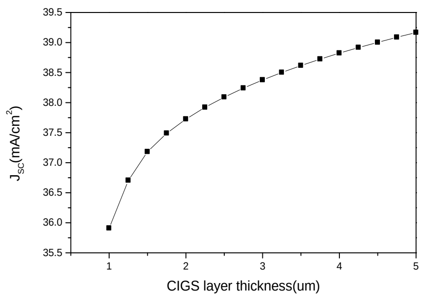
The simulations are conducted by specifying the materiel parameters in each defined layer of the device structures as the input parameters. Within the reasonable ranges, the material parameters selected from the reported literature for all the layers are shown in Table 1. In order to study the effects of thickness on the performances of the CIGS solar cells, we have proceeded layer by layer in such a way that the thickness of two layers are kept unchanged and those of the third layer are varied. This has allowed us to attain solar cells with high efficiencies. The J-V characteristic was simulated with the AM1.5 illumination conditions (100mW/cm2). The simulation started by changing the thickness of the absorber layer from 1 to 5µm, and the thickness buffer layer was changed from 0.01µm to 0.10µm, and the variation of the cell performance has been reviewed. The open-circuit voltage (V_{oc}), short circuit current density (J_{sc}), fill factor (FF), efficiency (η) is calculated by the software.

IV. RESULTS AND DISCUSSION

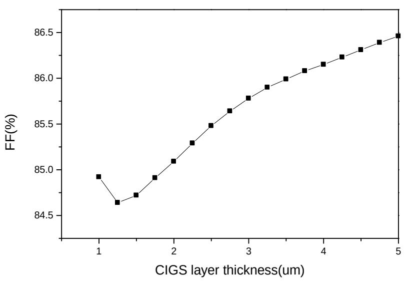
4.1 Effect of Absorber Layer Thickness with ZnO as Buffer Layer



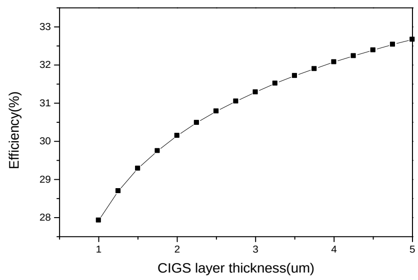
(a)



(b)



(c)

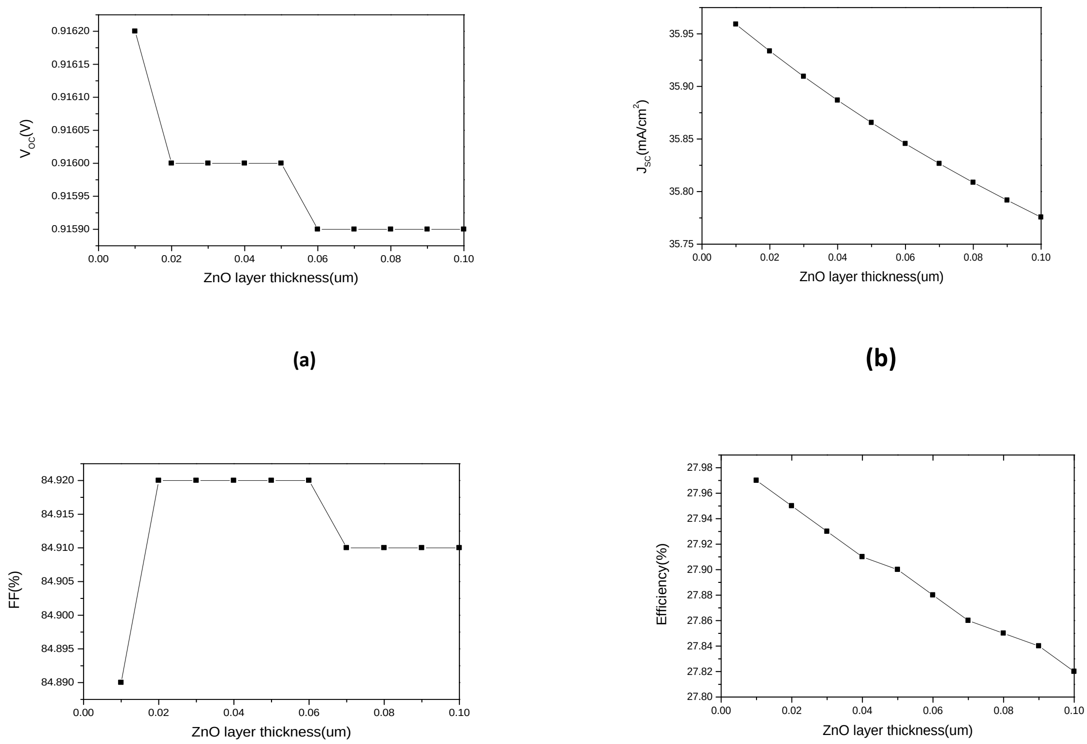


(d)

Figure 2. Variation of (a) Voc (b) Jsc (c) FF and (d) Efficiency as a function of CIGS layer thickness.

The simulation results show that the general performance of the cell increases while the thickness of the absorber layer is increased. The entire measured parameters, including Voc, Jsc, the Fill factor (FF%) and efficiency almost follow the same pattern. Figure 2 shows the variation of the cell performance due to the absorber thickness changes. The photovoltaic cell parameters for various thicknesses of CIGS, ranging from 1 to 5µm are shown in Figure 2. It was observed that as the thickness of CIGS is increased both Voc and Jsc of CIGS solar cells are increased as well. In fact, this allows the collection of lightening wavelengths, which contribute to the generation of the electron-hole pairs (Chelvanathan et al., 2010) and results in the increase of the Voc and Jsc. It is generally agreed that the values of Voc and Jsc will be reduced if the thickness of the absorber layer is reduced. This may be caused by the recombination process at the back contact of the solar cell. Figure 2d shows the variation of the electric efficiency versus the thickness of the CIGS absorber layer,but over 2.25µm, the efficiency variation seems to be very slow. The efficiencies was recorded as 30.49%. Note that as the thickness of CIGS increases the efficiency increases monotonically. On the other hand, the fill factor of the solar cell increases as well with the increase of the thickness of the absorber layer. This is in good agreement with the previous results reported by Heriche et al., 2016 and Chelvanathan et al., 2010.

4.2 Effect of Buffer Layer (ZnO) Thickness



(a) (b)

(c) (d)

Figure 3. Variation of (a) Voc (b) Jsc (c) FF and (d) Efficiency as a function of CIGS layer thickness.

From Figure 3, it was found that the open-circuit voltage of device decreases with the increase of the buffer layer thickness, but the short circuit current density decreases considerably, particularly for larger thickness. The efficiency decreases monotonically with the increase of buffer layer thickness, as shown in Figure 3c. The larger the thickness of the buffer layer, the higher the number of absorbed photons that transport energy in the layer. This results in the loss of these photons leading to the decrease of the number of photons reaching the absorber layer.the optimum thickness was found to be 0.02µm.

V. Conclusion

The cell performance was simulated and analyzed by the function of the buffer layer and absorber layer thickness. The optimum thickness of CIGS absorber layer and ZnObuffer of a CIGS thin film solar cell were found to be 2.25µm and 0.02µm respectively. There is a compromise between having a thin and a minimum recombination current density in these layer thickness. Although these results can help us to fabricate a desired CIGS thin film solar cell, there are some other effective parameters which can affect the cell performance and need to be investigated in further studies.

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