CIGS based Solar Cells - A Scaps 1D Study

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Abstract: ***In the current article, the effect of absorber layer thickness on various solar cell parameters such as open circuit voltage (V_{oc}), short circuit current (J_{sc}), fill factor (FF) and solar cell efficiency (η) has been studied using the Scaps-1D software. It is found that initially efficiency increases and is maximum for 0.3 µm thickness of absorber layer (CIGS). After 0.3 µm, the efficiency is found to be decreased on increasing the absorber layer (CIGS) thickness.***

Keywords: Thin film solar cell, CIGS, absorber layer, efficiency, Scaps-1D

1. Introduction

Now a days, one of the main objectives of the researchers around the world is the development of renewable and eco-friendly energy sources to overcome the detrimental effects of CO_2 emissions generated by the usage of unconventional fuels. Solar energy is being considered as an important source for the replacement of fossil fuel since it is abundant, eco-friendly, and renewable[1]. A device called a photovoltaic (PV) cell is utilized to transform the solar energy into electrical power, which is a plentiful, efficient, and affordable source of electricity. From last several years, PV power has been growing at an approximate rate of 8.3% annually[2]. Thin film solar cells (TFSCs) are becoming increasingly popular as they offer a cost effective alternative to traditional solar cells, resulting in their widespread adoption in various applications. Despite their potential, these thin film solar cells are also notorious for their instability. The Copper indium gallium (di) selenide Cu(In, Ga)Se2 (CIGS) TFSCs are currently in high demand because of their long-term stability, impressive cost effectiveness and exceptional PCE [3,4].

CIGS is a direct bandgap, p-type semiconductor, composed of copper, indium, gallium, and selenium, which has a high absorption coefficient. Polycrystalline CIGS absorber layers based thin film solar-cells can provide a good alternative to wafer based amorphous or crystalline silicon solar cells, which currently constitute the major share of worldwide photovoltaics. The high cost of indium and gallium constituents is the limiting factor in the commercialization of CIGS solar cells. In order to overcome this short coming, researchers are focussing on decreasing the thickness of CIGS absorber layer leading to the reduction in the use of indium and gallium. Vermang et. al [5] reported an efficiency of 13.5% in ultra-thin Cu(In, Ga)Se_2 solar cells using a CIGS absorber layer with a thickness of 0.385 µm. This efficiency still remains smaller than those of conventional CIGS solar cells with an absorber layer thickness lying in the range 2.5 - 4 µm[6]. Based on numerical modelling and using 1 mm of CIGS absorber layer thickness, Amin et al. [7] have achieved an efficiency of 17.26%.

In this work, a numerical study of the thin film CIGS-based solar cells with SCAPS, has been carried out to calculate the photovoltaic parameters (V_{oc}, J_{sc}, FF and PCE) under standard illumination (AM1.5G, 100 mW/cm^2, 300K). The influence of CIGS absorber layer thickness on various parameters has been studied to examine the performance of solar cells.

2. Device structure and simulation methodology

In this study, SCAPS-1D simulation software has been used to model the heterojunction thin film solar cells' device properties. At the Electronics and Information Systems (EIS) Department at the University of Gent in Belgium, the "Solar Cell Capacitance Simulator One Dimensional" (SCAPS-1D) application was developed to model solar cells. The continuity equation and Poisson's equation are given for the free electrons and holes in the conduction and valence bands [8–10]. The electron and hole continuity equations are as follows

$$-\frac{1}{q}\frac{dj_n}{dx} = [G - R]$$
$$-\frac{1}{q}\frac{dj_p}{dx} = [G - R]$$

where G and R are the generation rates and recombination rates, respectively. J_n and J_p are the current densities for electrons and holes, respectively. The Poisson formula is as follows:

$$\frac{d^2}{dx^2}\psi(x) = -\frac{q}{\epsilon_0\epsilon_r}\left[p(x) - n(x) + N_D - N_A + \rho_p - \rho_n\right]$$

where q is the electrical charge, ε_r is the relative, ε_0 is the vacuum permittivity, ψ is the electrostatic potential, p and n are the concentrations of holes and electrons, respectively, N_A and N_D are the charge impurities of the acceptor and donor types, respectively, and ρ_p and ρ_n are the distributions of holes and electrons, respectively. SCAPS-1D solves the above equations while considering boundary conditions using the steady-state response of the fundamental semiconductor equations in one dimension. CIGS based thin film solar cell structure is shown schematically in Figure 1(a). The reference parameters of the CIGS, CdS and ZnO layers which have been used to execute numerical calculations are listed in Table 1. The metal contacts are assumed to make ohmic contacts with ZnO and CIGS.

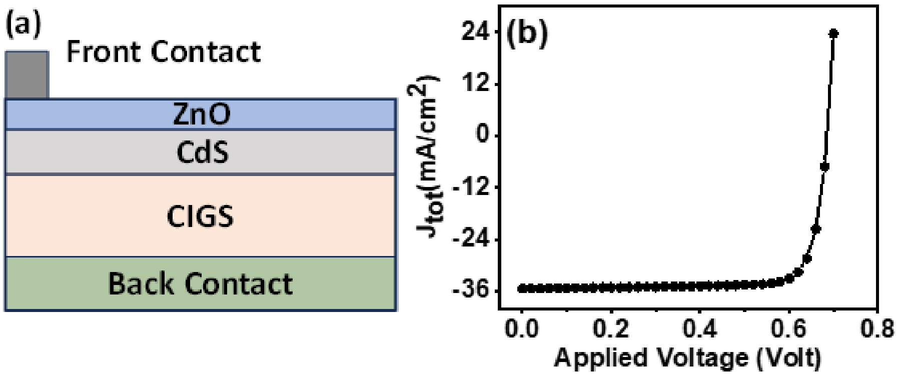

Figure 1: (a) schematic diagram and (b) I-V characteristic curve of the (metal/CIGS/CdS/ ZnO/metal) solar cell.

Table 1: Material parameters used in SCAPS-1D simulator

Parameter	ZnO	CdS	CIGS
Thickness (nm)	30	50	100-2000
Bandgap (eV)	3.3	2.4	1.2
Electron affinity (eV)	3.9	4.1	4.5
Dielectric permittivity	10	10	13.5
Conduction band DOS (cm^{-3})	$2.2x10^{18}$	$2.2x10^{18}$	$2.2x10^{18}$
Valence band DOS (cm^{-3})	$1.8x10^{19}$	$1.9x10^{19}$	$1.8x10^{19}$
Electron thermal velocity (cm/s)	107	107	$3.9x10^{7}$
Hole thermal velocity (cm/s)	107	107	$1.4x10^{7}$
Electron mobility (cm^2/Vs)	100	100	100
Hole mobility (cm^2/Vs)	25	25	25
Donor density N_D (cm^{-3})	1017	1018	0
Acceptor density N_A (cm^{-3})	0	0	1015

3. Results and Discussion

To make a cost-effective PV cell, the absorber layer should be tuned to the optimal thickness to absorb the maximum photons and produce electron-hole pairs. To study the effect of CIGS absorber layer thickness and the different solar cell parameters V_{oc}, J_{sc}, fill factor and power conversion efficiency (η), the thickness of the CIGS absorber layer is varied from 0.1μm -to 2.0μm, while keeping the all-other parameters fixed as represented in Table 1. A typical I-V Curve of the present solar cell structure for the CIGS thickness of 0.3μm is shown in Figure 1(b). It can be seen that the open-circuit voltage $V_{oc} \approx 0.65$ V, and the maximum current J_m and voltage V_m are found to be -35 mA/cm^2 and 0.72 V, respectively. The variation of V_{oc} and J_{sc} on increasing the CIGS absorber layer thickness is shown in Figure 2.

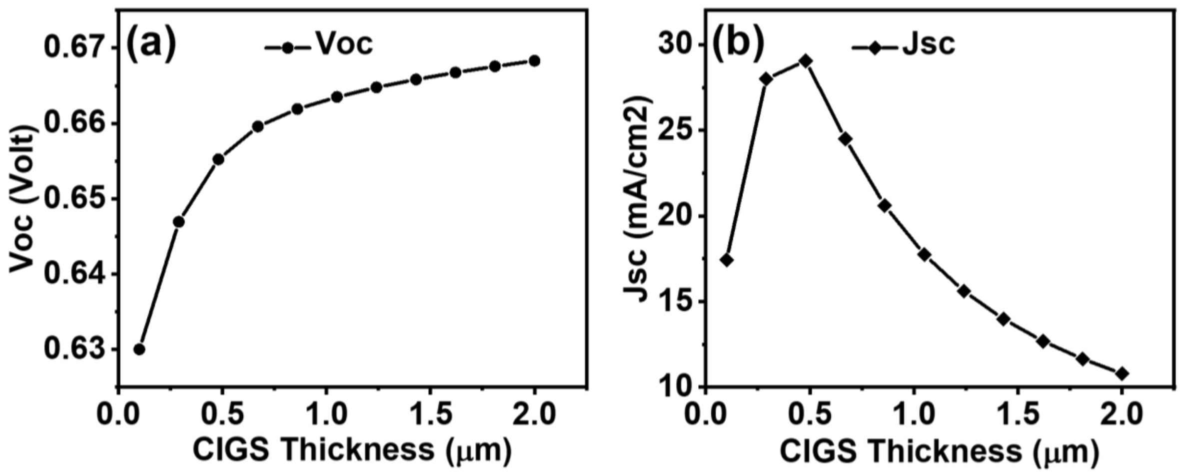

Figure 2: (a) Variation of Voc and (b) Jsc on varying the CIGS absorber layer thickness in (metal/CIGS/ CdS/ ZnO/metal) solar cell

It can be seen that as the thickness of the CIGS absorber layer varies from 0.1 to 2.0 μm, the V_{oc} rises from 0.63 V to 0.67 V, which clearly indicate that, after 0.1 μm, the V_{oc} is not changing much and is approximately constant throughout the thickness range of 0.1 μm to 2 μm. This constant value of V_{oc} on increasing the CIGS thickness means that even 0.1 μm thickness of CIGS is sufficient to absorb the incident light. It is also clear from Fig. 2b that the J_{sc} initially grows rapidly from 17 mA/cm^2 to 29 mA/cm^2 on increasing the CIGS thickness from 0.1 μm to 0.3 μm and then peaks at 30 mA/cm^2 corresponding to 0.5 μm. On further increasing the CIGS thickness, J_{sc} shows a decreasing trend. The reduced values of J_{sc} may be due to the increased recombination of electron hole pairs on increasing the CIGS absorber layer thickness.

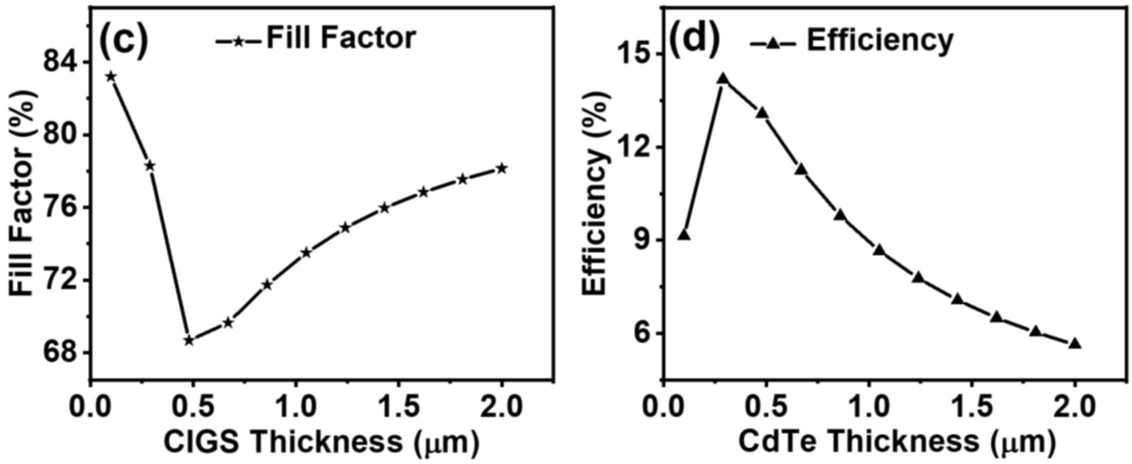

Figure 3: (a) Variation of Fill Factor and (b) Power Conversion Efficiency on varying the CIGS absorber layer thickness in (metal/CIGS/ CdS/ ZnO/metal) solar cell

The variation of fill factor (FF) and the power conversion efficiency (η) on increasing the CIGS layer thickness is shown in Figure3. As shown in Figure 3 (a), Initially the value of fill factor (FF) decreases from 83.2 % to 68.7 % to om increasing the CIGS Thickness from 0.1 µm to 0.48µm. On further increasing the CIGS thickness, FF again increases and attains a value of 78.1 % at 2µm. The increased serial resistance and inside power loss on increasing the thickness of the absorber layer may be responsible for the increased value of FF on increasing the CIGS thickness. As shown in Figure 3 (b), the value of efficiency increases from 9.1 % to 14.2 % om increasing the CIGS Thickness from 0.1 µm to 0.3µm. On further increasing the thickness, the efficiency decreases and reaches to 5.6 % at 2µm. The power conversion efficiency depends on the product of V_{oc}, J_{sc} and FF. The value of V_{oc} remains nearly constant on increasing the CIGS thickness. FF increases while J_{sc} decreases on increasing the CIGS absorber layer thickness. The rate of increase in FF is less in comparison to the rate of decrease in J_{sc} on increasing the CIGS thickness. Due to the dominance of decrease in Jsc, the efficiency also follows the downward trend on increasing the CIGS thickness.

4. Conclusion

It is found that above a certain thickness V_{oc} does not change much while J_{sc} and efficiency (η) decrease on further increasing the thickness beyond 0.3µm. The FF shows an opposite behaviour in comparison to Jsc and power conversion efficiency. The peak of power conversion efficiency at 0.3µm suggests that it is worthless to use a CIGS absorber thickness greater than 0.3 µm from the perspective of reducing the cost of the solar cell.

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