



Simulative analysis of Copper Indium Gallium Selenide (CIGS) Thin Film Solar Cell

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Abstract

This research aims to study the performances of Copper Indium Gallium Selenide (CIGS) Solar Cells. The Photovoltaic parameters of different buffer layer materials such as InS, ZnO, ZnS, ZnSe and CdS was simulated in solar cell capacitance simulator (SCAPS). The main idea behind this analysis is the investigation of effect of different buffer layer; absorber layer thickness; and effect of temperature of CIGS Solar Cell. Various thicknesses of CIGS absorber layer ranging from 1 to 5 μm was used to determine the efficiency and fill factor. The thickness of the absorber layer affects the current density, efficiency, fill factor and open circuit voltage. The optimum value of absorber thickness is chosen to be 4.5 μm . Temperature also had a direct effect on solar cell performance as with an increase in temperature overall efficiency decreased. This happens because with the increase in temperature diode reverse saturation current increases that in turn affects the open circuit voltage of the solar cell. So, with a decrease in open circuit voltage other function parameters of solar cell also reduced.

Keywords: Solar Cell, Thin film, CIGS, SCAPS-1D.

1. Introduction

Solar energy is becoming one of the primary sources of energy replacing fossil fuels due to its abundance (Yuan, 2019). Semiconductor devices play a significant role in commercial applications and can be widely used in power generation in the form of photovoltaic. Photovoltaic cells absorb the radiation of sunlight and convert it into electrical energy (Baig, 2019). One of the free gifts of nature as an alternative energy source is solar energy. (Baig, 2019). Thin film solar cells are those using active semiconductor materials with a thickness of less than 10 micrometers, such as CIGS absorber materials solar cells. (Wang et al., 2019), Materials for thin film solar cells are currently the subject of multiple researches in order to reach the highest ratio efficiency. This reduces the cost of the solar cells and retains an acceptable performance compared to cells based on silicon which requires an absorber layer with a thickness of 200 μm . Polycrystalline chalcopyrite Cu(In,Ga)Se₂ (CIGS) is a very promising material for thin film Photovoltaic and offers a number of interesting advantages compared to the bulk silicon devices (Baig, 2019).

Among thin film technologies successful are copper–indium–gallium–selenide (CIGS) cells that have achieved record efficiencies close to 20% (Efaz *et al.*, 2021). There is also a need to protect our health and environmental benign PV technology; instead of the conventional fossil fuels which produce environmental harmful greenhouse gases. Promising PV potential above has increased research interest and concerns on the sustainability and use of PV system in solving global energy deficiencies (Beck, 2019).

2. Related Works

(Wang et al., 2019) The Cu(In, Ga)S₂ (CIGS) Thin film solar which has demonstrated 23.4% efficiency but that is well behind the Shockley–Queisser. The CIGS solar cell efficiency of 22.6% set a world record as the highest of any thin-film technology, and is even higher than that of multicrystalline silicon (21.9%) (Michael, 2019). Advances in Cost-Efficient Thin-Film Photovoltaics Based on Cu(In,Ga)Se₂ Who explain efficiency improvements translate directly into a reduction of electricity generation costs, the CIGS technology will only become more attractive as these developments are realized. CIGS-based PV technology is also attractive for applications in aesthetic building integration and for curved surfaces with a flexible product.

Abhinav, et al., (2020) Performance analysis of thin film CIGS solar cell at different values of thickness, bandgap and temperature through numerical simulation. The structure is numerically simulated using the SCAPS-1D code. The investigate how the photovoltaic parameters of the solar cell such as V_{oc}, J_{sc}, FF, and η are affected by varying the thickness of the absorber layer ranging from 1m to 2μm and bandgap value from 1 eV to 1.7 eV. They Further demonstrate how the performance of this chalcopyrite material based solar cell varies with the increase in the temperature ranging from 300- 360K. By detailed understanding, that an efficient CIGS solar cell can be developed in the future.

2.2 Simulations

The following working conditions were considered in the simulations: Using the spectrum AM1.5G as an illumination incident on the device at room temperature

2.2.1 Effect of Buffer Layer

The band gap, electron concentration, and other parameters presented in table 1 were fixed for each layer of the solar cell. The AM1.5 illumination condition (100m W/cm²) was used to simulate the J-V characteristic for various buffer layers. The Cd-free buffer layer was simulated. The buffer layer optimization was carried out through simulations by replacing the CdS layer with a Cd-free buffer layer in order to investigate the potential of using different buffer layers such as InS, ZnO, ZnS, and CdS to improve the device's performance. The software calculates the open circuit voltage (V_{oc}), short circuit current density (J_{sc}), fill factor (FF), and efficiency (η).

2.2.2 Effect of Varying the Absorber Layer Thickness

All parameters of the absorber were kept constant in the simulations, except for the thickness of the absorber, so that only the effects of changes in thickness on the solar cell parameters could be investigated. The parameters in table 1 were still kept fixed and also the absorber layer thickness was set at 0.5μm simulated. The simulations results were represented graphically. The procedure was repeated by varying the thickness of the CIGS absorber layer from 0.5μm to 5μm at an interval of 0.25μm. The open circuit voltage (V_{oc}), short circuit current density (s), fill factor, efficiency (η), is calculated by the software.

2.2.3 Effect of Varying Temperature

All parameters except temperature were kept at constant in the simulations so only the impact of temperature changes on the solar cell parameters might be investigated. The temperature dependence of photovoltaic parameters of cell CIGS is studied for a solar cell in the range (280-400K) under a constant illumination (1000W/m)

Table 1. Simulation parameters for CIGS-based Solar Cell (Mohammadi et al., 2020)

| Parameters | CIG | InS | ZnO | ZnSe | CdS | ZnS |
|---|------|-----|------|------|------|-----|
| Bandgap, E _g (eV) | 2.42 | 3.3 | 1.5 | 2.5 | 3.3 | 2.7 |
| Dielectric permittivity, ε _r | 10 | 10 | 13.6 | 13.5 | 10 | 10 |
| Electron affinity, χ (eV) | 4.7 | 4.5 | 4.25 | 4.6 | 4.09 | 4.2 |

| Parameters | CIG | InS | ZnO | ZnSe | CdS | ZnS |
|---|--------|--------|--------|--------|--------|--------|
| Electron mobility, μ_n (cm ² /Vs) | 100 | 50 | 100 | 400 | 100 | 50 |
| Hole mobility, μ_p (cm ² /Vs) | 25 | 20 | 25 | 210 | 30 | 20 |
| Effective Density of states, NC (cm ⁻³) | 1.5e18 | 1.5e18 | 2.2e18 | 1.5e19 | 1.5e18 | 1.5e18 |
| Effective Density of states, NV | 1.8e19 | 1.8e19 | 1.8e19 | 1.8e19 | 1.8e19 | 1.8e19 |
| Electron and hole concentration, n, p (cm ⁻³) | 1e7 | 1e7 | 1e7 | 1e7 | 1e7 | 1e7 |

3. Results

3.1 Effect of Buffer Layer Performance on CIGS Solar Cell

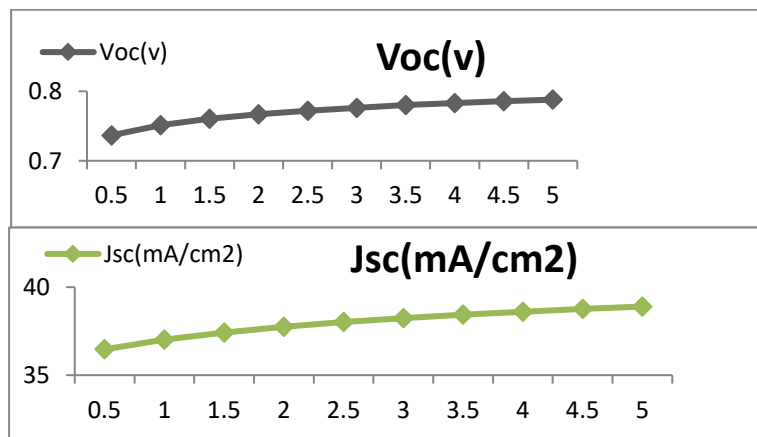
Device characteristics were observed under illumination condition. The photovoltaic cell's function is to convert light energy into electricity. When the photovoltaic cell is exposed to light, it starts to work and current flows due to charge carriers formed by incident photons. The photovoltaic process begins when photons strike the cell; these photons generate charge carriers, which are produced after the cell is exposed to 1 Sun (Air Mass 1.5) for varied buffer layers. Table 2 includes all photovoltaic parameters (I_{sc} , V_{oc} , η and FF) of CIGS solar cell. From the table 2 it is obvious that when compared to InS, ZnS, ZnSe, and CdS, the CIGS solar cell with ZnO as a buffer layer has a higher conversion efficiency, but the solar cell with ZnSe as a buffer layer has the least power conversion efficiency.

Table 2. Photovoltaic parameters for the CIGS Solar cell for different buffer layer

| Parameters | CdS | ZnO | ZnS | ZnSe | InS |
|--------------------------------|--------|--------|--------|--------|--------|
| V_{oc} (v) | 1.041 | 1.059 | 1.0580 | 0.893 | 1.051 |
| J_{sc} (mA/cm ²) | 31.606 | 32.197 | 32.062 | 32.280 | 31.774 |
| FF(%) | 66.943 | 66.430 | 65.634 | 65.352 | 66.495 |
| η (%) | 22.036 | 22.597 | 22.266 | 21.743 | 22.209 |

3.2 CIGS absorber thickness effect on device performance with ZnO as buffer layer

CIGS absorber thickness effect on device performance is explained with the help of figure 1 the thickness of CIGS was changed from 0.5 μ m to 5 μ m. Figure 1 show that as the thickness of the CIGS absorber layers is increased, conversion efficiency increases with FF and V_{oc} . However, after attaining an optimum thickness, the fill factor decreases as the thickness increases, although conversion efficiency, J_{sc} , and V_{oc} remain nearly constant. The optimum thickness parameters for CIGS taken to give an efficient output from a solar cell were 4.5 μ m.



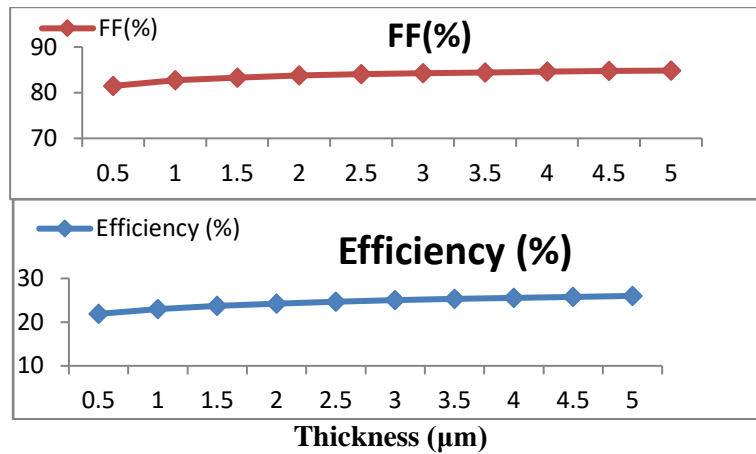


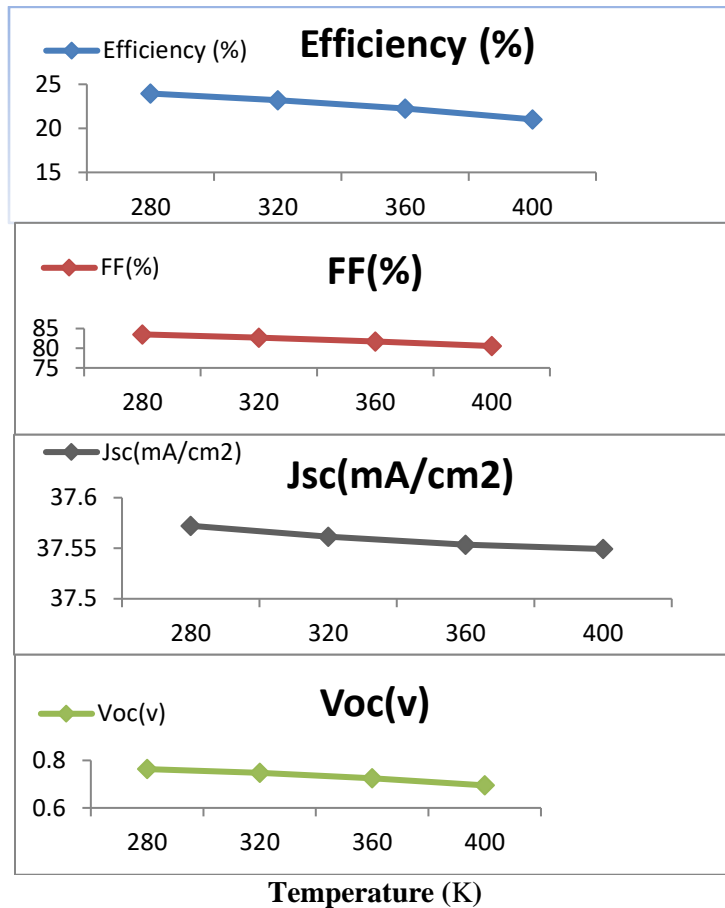
Figure 1. CIGS absorber thickness effect on device performance with ZnO as buffer layer

3.3: Temperature effect on cell performance with ZnO as buffer layer

The working temperature of a device has a significant impact on its performance. The photovoltaics are set up outside in the open. We took the temperature in a range from 280K to 400K to investigate the performance of a cell. Figure 2 shows the simulation findings. The performance of cells decreases as the temperature rises. It is evident that when the temperature rises, the current voltage decreases. The results also reveal that as the temperature rises, these characteristics decrease in general. The material carrier concentration, band gaps, electron, and hole mobilities are all influenced by the greater temperature, resulting in a decreased conversion efficiency from a cell. As the temperature rises, the conversion efficiency drops, as seen in Figure 2. Along with the decrease in FF, there's also a decrease in Voc.

Table: 3 Temperature effect on cell performance with ZnO as buffer layer

| Temp.(k) | Voc(v) | Jsc(mA/cm) | FF(%) | Efficiency(%) |
|----------|--------|------------|---------|---------------|
| 280 | 0.7633 | 37.572 | 83.5122 | 23.9521 |
| 320 | 0.7472 | 37.561 | 82.6709 | 23.208 |
| 360 | 0.7253 | 37.549 | 81.6955 | 22.2543 |
| 400 | 0.694 | 37.549 | 80.5529 | 21.0203 |



4.0 Discussion

The physical operating characteristics of thin film solar cells are described differently by different software. A detailed analysis of a solar cell was performed using SCAPS-1D software in this study to achieve a better knowledge of solar cell behavior. A CIGS/CdS/ZnO/ZnS/ZnSe/InS structured photovoltaic solar cell's performance was simulated and investigated using SCAPS simulator software. The buffer layer thicknesses were varied from 0.01m to 0.1m, and it was found that the optimum thickness of the buffer layers was between 0.04m and 0.05m, however the absorber layer thickness was always 4.5m. The working temperature of a device has a considerable impact on its performance, as shown by the analysis of the performance of a cell that took the temperature in a range (280K to 400K).

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