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Improvement The Efficiency Of Thin Film CIGS Solar Cells By Changing The ZnO Layers using Silvaco Software

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Abstract

In this study the function of solar cells with the structure of $CuIn_{1-x}Ga_xS_{e2}$ is examined. CIGS solar cell consists of layers of ZnO (Layer TCO), Cd_S (buffer layer), CIGS (absorbent layer), and Layer MO (substrate), which Cd_S and CIGS layers form a PN Junction. Later using SILVACO software CIGS solar cell is simulated. Then, CIGS solar cell is simulated using Silvaco software. Later by changing the ZnO layer thickness, its effect on cell function is discussed and examined. Important parameters of a solar cell that will be discussed here, include open circuit voltage (VOC), short circuit current (ISC), maximum power (Pmax), filling factor (FF) and efficiency (η). After it was that conducted simulations, ZnO layer has significant impact on cell function and it leads to change in efficiency, open circuit voltage, and short circuit current and cell power.

Keywords: Efficiency, Solar Cell, Photon, open circuit voltage, thickness

Introduction

When the cell is illuminated, the photons having energy which is greater or equal to the energy of the band gap semiconductor may be absorbed by the bound electrons and cause the formation of an electron-hole pair, which is immediately separated due to the internal electrostatic field. A solar cell cannot convert the entire amount of solar radiation received on its surface into electrical energy. Some part of the radiation is reflected from the surface of the cell and is diffused back into the environment. Also, of radiation that penetrates the semiconductor, those photons having energy that is smaller than the energy of the band gap cannot be absorbed. For these photons, the cell behaves like a transparent body. This pattern is shown in Figure 1. [1]

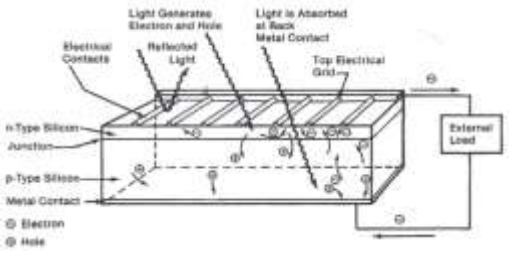


Figure1. Light incident on a cell

Shorting the terminals of the device, the extra electrons of the n-region move through the external circuit To counteract the additional holes in the p-region. The current due to this flow of excited carriers is called photocurrent I_L, (where L stands for light) depicted in Figure 2. [1]

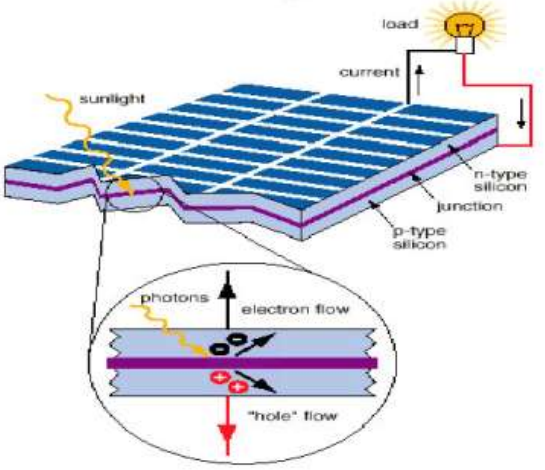


Figure2. The PV effect in a solar cell

SOLAR CELL I-V CHARACTERISTICS (BASELINE PARAMETERS)

In an ideal PV cell under illumination, the short - circuit current I_{SC} is equal to the produced photocurrent since the load resistance R is zero, causing the voltage to be also equal to zero. If a load resistance is connected to the circuit, the photocurrent causes the creation of a voltage V in the cell, which forward-biases the p–n junction and reduces its potential as well as the infusion of minority carriers and their diffusion, just as would happen in a normal diode. Therefore, due to the forward-bias voltage, a forward-bias current I_F, which opposes the photocurrent, will be present This is given by[2].

$$I_F = I_0 \left(e^{eV/\eta kT} - 1\right) \qquad (1)$$

Where I_0 is the reverse saturation current and η the quality factor which ranges from one to two. The resulting net p-n junction current I is

$$I = I_L - I_F = I_{SC} - I_0 \left(e^{eV/\eta kT} - 1\right) \qquad (2)$$

Much can be learned about solar cell operation by examining the basic form of Equation (2). Using the equality of the two produced currents in the open-circuit state, we have the resulting open-circuit voltage

$$Voc = Vt \ln\left(1 + \frac{IL}{Is}\right) \qquad (3)$$

Where is I_s the reverse saturation current, and V_t is the thermal voltage.

The graph between the output current and output voltage of a solar cell is called the I-V curve and describes its energy conversion capability at the existing conditions of irradiance and temperature. A representative I-V curve of a typical solar cell is plotted in Figure 3 [2].

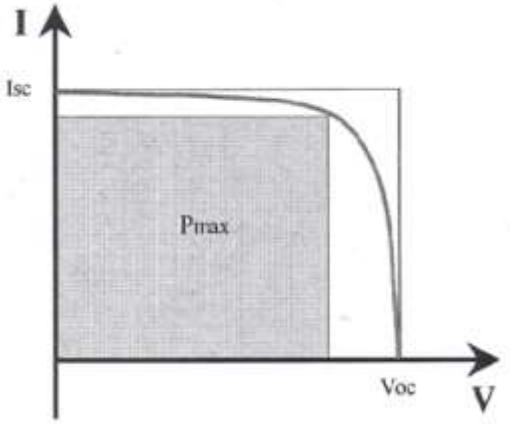


Figure3. I-V curve for a photovoltaic cell showing its maximum power rectangle

Referring to Figure 3, the span of the I-V curve ranges from the maximum possible current, where the voltage is zero, to zero current and the maximum possible voltage in the circuit. That is, the span is from the short - circuit current I_{SC} at zero volts to the open-circuit voltage V_{OC} at zero current. The calculation of these points is done by the intersection of the characteristic of the solar cell with the respective axes. The output power produced by a solar cell is given by [2].

$$P = VI \qquad (4)$$

The maximum output power point P_{max} is at the knee of the curve, resulting from the corresponding points of maximum current I_{max} and maximum voltage V_{max} and is equal to the area of the rectangle. The maximum current and maximum voltage can be calculated either by solving the equations of the solar cell characteristic and the load characteristic or graphically, by drawing vertical lines outward from these points to the corresponding axis [2].

The fill factor FF is an indication of how close the characteristic of the solar cell is to the ideal rectangular shape. The I-V curve is close to this shape, and the fill factor's value is close enough to one. But the properties of the p–n junction make this impossible; the normal value for the fill factor is between 0.70 and 0.85 depending on the material and structure of the device. Fill factor is defined as the quotient of the product of the voltage multiplied by the current for the point of maximum output power to the power that the open-circuit voltage and short-circuit current would make if they were multiplied together. The fill factor is given by [2].

$$FF = \frac{Pmax}{Voc\ Isc} \qquad (5)$$

Schematically, the fill factor arises from the I-V curve as the ratio of area bounded by the voltage and current values that maximize the power to the area, defined by the open-circuit voltage and short-circuit current [2].

The most basic parameters for evaluating the conduct and operation of a PV cell are the fill factor, the short-circuit current, and the open-circuit voltage. These parameters determine the efficiency of the cell, which equals the ratio of the maximum creditable power of the cell to the incident light power per unit area, which is the input power from the sun P_{in}. Thus, the efficiency is calculated from [2]

$$\eta = \frac{Pmax}{Pin} \qquad (6)$$

The input power from the sun is based on the air mass number where the cell is located in relation to the sun. The efficiency of a solar cell is sensitive to variations in both the power and spectrum of incident light. To facilitate an accurate comparison between solar cells measured at different times and locations, a standard spectrum and power density has been defined for radiations outside the earth's atmosphere and surface. The standard spectrum at the earth's surface is called AM1.5 to describe the dissipation of the energy put out by the sun due to atmospheric intercession, compared to the AM0 spectrum for space where we do not have any power losses. For this thesis, the light source used was the sun, and the solar cells were illuminated assuming an AM1.5 solar spectrum, which is used for terrestrial applications. The AM1.5 and AM0 spectrums are shown in Figure 4 [3].

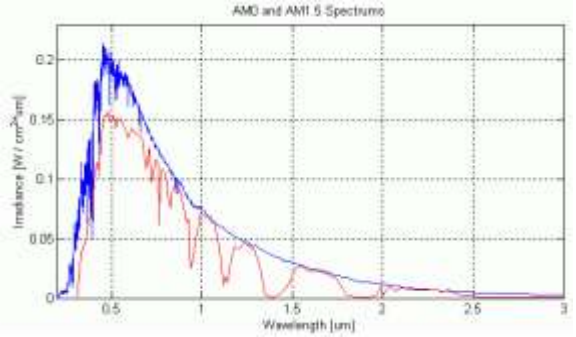


Figure4. AM0 (in blue) and AM1.5 (in red) spectrum

CIGS Solar Cells Structure

CIGS Solar cell (Copper-Indium-Gallium-Selenium) is a semiconductor I-IIIVI2 with a direct band gap and high absorption coefficient. The preceding is an alloy between CIS and CGS which is described by the chemical formula $CuIn_{1-x}Ga_xSe_2$, Where x is the ratio between Ga/(Ga+In). By changing x, the concentration of Gallium and Indium will change and as a result would alter the band gap. The value of band gaps change from 1.04ev for x= 0 for the CIS to 1.68ev for x=1, for the CGS, maximized for a Ga content with a value roughly 0.3, resulted in absorber energy band gap values of roughly 1.1–1.2 eV. [5]. In these cells, the lowest conduction band has been put against the maximum Capacity of the tape and has the highest efficiency compared to other solar cells.CIGS Solar cells as shown in Figure5 is composed of the following layers [6].

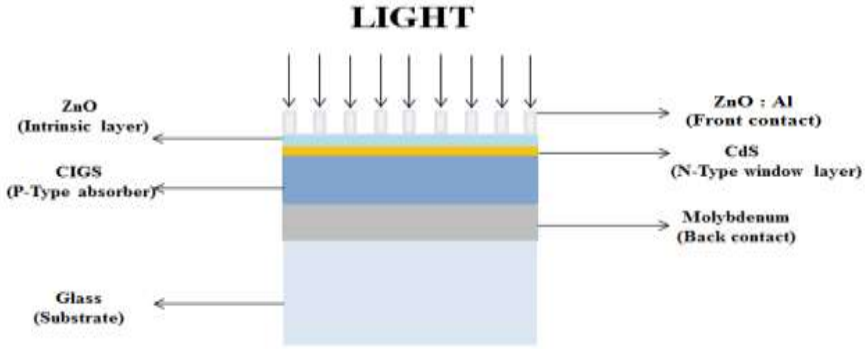


Figure5. CIGS structure

Layer 1) Impure aluminium with zinc oxide (ZnO: Al) whose duty it is to guide the photons received.
Layer 2) Layers of zinc oxide (ZnO: i) as layer TCO (Transparent Conductive Oxide) used. TCO layers have a large band gap to ensure maximum absorption of sunlight. It should be a transparent layer that can absorb maximum photons [7].
Layer 3) layers n-Cd_S (Sulphide Cadmium) that is n type semiconductor and acts as a buffer layer between CIGS and TCO layers .These layers will result in better performance of the solar cells [8].
Layer 4) of the CIGS absorber layer is the core and active layer of the solar cell and a p-type multi crystal semiconductor .It has a direct band gap and its absorption coefficient is about $105cm^{-1}$.This layer along with the buffer layer form a p-n junction [3].
Layer 5) (Mo) layer is a refractory metal which is used as a rear connection. Its role is to gather the carriers from the absorption layer and to present them to a foreign carrier. As a result, the resistance is low [9].
Layer 6) Solar cell Substrate, is made of a glass (soda) or plastic .This material is highly resistant against corrosion and its price is reasonable.

Simulation

Physical parameters used in the simulations Table1 have been identified. Are given in Table1 physical parameters used in the Simulation.

Table1. Physical Parameters Used In the Simulation [10]

	ZnO	C_dS	CIGS
εr	9	10	13.6
χ_e (eV)	4	3.75	3.89
μ_n (cm^2/Vs)	100	100	100
μ_p (cm^2/Vs)	25	25	25
N_A ($1/cm^3$)	0	0	2e+16
N_D ($1/cm^3$)	1e+18	1e+18	0
N_C ($1/cm^3$)	2.2e+18	2.2e+18	2.2e+18
N_V ($1/cm^3$)	1.8e+19	1.8e+19	1.8e+19
Band gap (eV)	3.3	2.4	1.15
Thickness (nm)	Variable	200	1700

The basic model structure of simulated CIGS solar cells is shown in Figure 6.

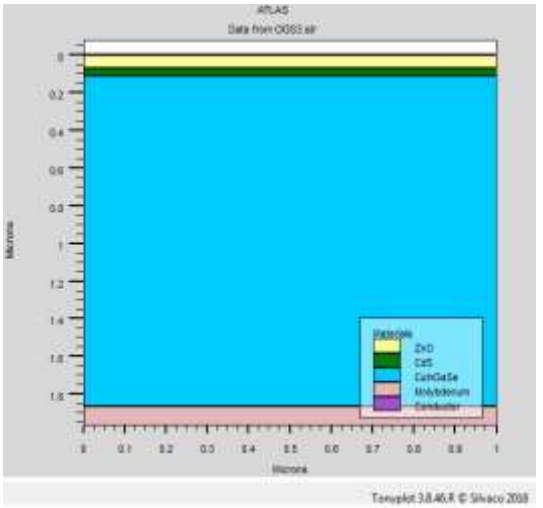


Figure 6. Simulated CIGS Structure

Changing the thickness of ZnO layer

Simulation is performed for CIGS solar cell will the thickness of ZnO layer of 200nm, 75nm and 40nm respectively. The efficiencies of these solar cells were determined by their I-V curve and are shown in figure7.

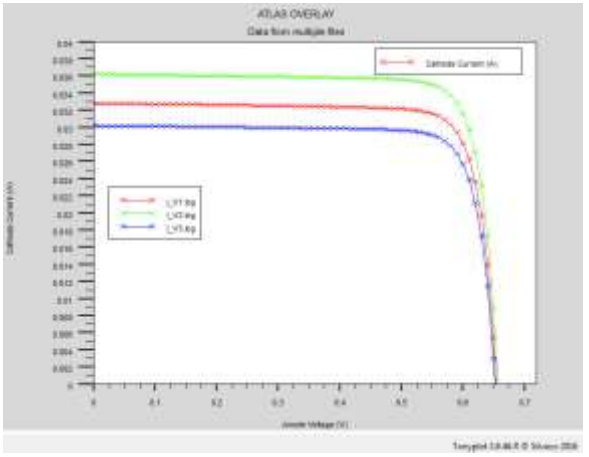


Figure7. I-V curves for changing the ZnO layer

Figure8 and a Figure9 respectively show curves efficiencies and Power

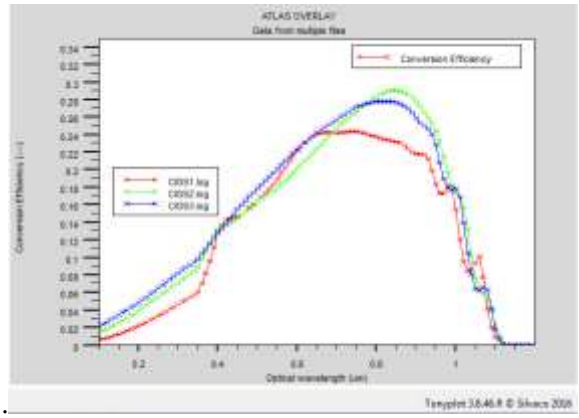


Figure8. efficiency curves for changing the thickness ZnO layer

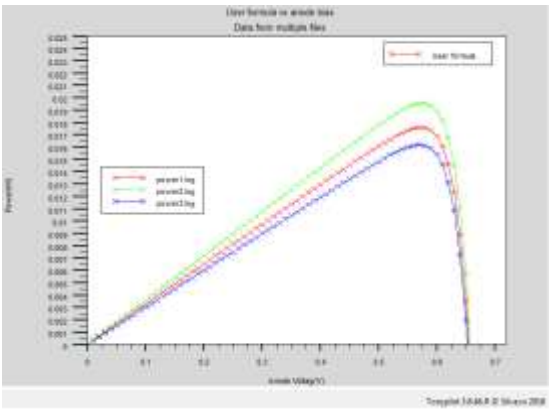


Figure9. Power curves for changing the thickness ZnO layer

As shown in the charts of power and voltage-current, when ZnO layer is selected not too large or not too small, it would have high power, open circuit voltage (V_{OC}), and short circuit current (I_{sc}). As is seen in the efficiency curve, Increase or decrease excessive ZnO layer cause Efficiency is coming down because If this layer be too thick Less photons Go to cell absorbent layer And cause The efficiency be low, also If The thickness of this layer Too thin Because of reflection Less photons Entered the cells and thus cell efficiency decrease.

Results

The exact results of studies conducted in connection with the change the thickness ZnO layer in Table2.

Table2. Results thickness change the ZnO layer

	CIGS1	CIGS2	CIGS3
ZnO Thickness (nm)	200	75	40
Voc (V)	0.653	0.655	0.652
Isc (mA/cm^2)	32.8	36.2	30.2
Pmax (W/cm^2)	17.6	19.6	16.2
FF(%)	82.1	82.6	82.2
Efficiency (%)	24.4	29.08	27.84

Conclusion

In this paper, by comparing three solar cells of CIGS that were equal in all aspects, except for ZnO layer, we found that too much increase and too much decrease in the thickness of this layer cause decrease in efficiency, open circuit voltage, short circuit current, and cell power. As a result, by accurately selection of ZnO layer thickness, we can improve the efficiency and power of the CIGS solar cell.

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