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A Review on Optimization of Electrical Parameters of Cu_2O Solar Cells.

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Abstract

In this work, a review on how to improve the performance of Cu_2O-based solar cells is presented. Generally, electrical parameters of solar cells and their effects on the performance of the solar cells are reviewed. Various factors that affect these parameters are presented. Some literatures that reported works on the determination of the electrical parameters of Cu_2O-based solar cells are analyzed and more information on factors affecting the parameters are obtained. Solutions on how to obtained better Cu_2O-based solar cell electrical parameters, for improved efficiency of the cells, are proffered

Keywords: Cu_2O solar cells, electrical parameters, factors affecting the electrical parameters.

1.0 Introduction

Direct conversion of solar energy to electricity using PV solar cells serves as an alternative source of power to the long existing conventional non-renewable sources. The conventional energy sources, mainly fossil fuels, are faced with ever increasing demand and thus are not expected to last long. Besides being non-renewable, these sources, mainly of fossil nature, contribute tremendously to the increase in the average measured temperature of the earth near the surface, leading to global warming. The present heavy dependence on fossil fuels makes these energy sources not reliable; as they face depletion problem. These energy sources have been predicted that some time in life they will be completely exhausted. Solar cells are more promising since their source of power being the sun has longer life span. The sun is predicted to have a reasonable life-time, with a projected constant radiative energy output of over 10 billion (10^{10}) years [1]. Photovoltaic (PV) systems have several advantages; they are cost effective alternatives in areas where extending utility power line is very expensive; they have no moving parts and require little maintenance; and they produce electricity without polluting the environment. There are presently few PV cells that are widely used in commercial quantities. These are silicon pn-junction solar cells, cadmium sulphide/copper sulphide (CdS/Cu_2S), gallium arsenide (GaAs) and amorphous silicon (a-Si) solar cells. But their future development is predictably going to be lowered by high cost of material and fabrication methods. For large scale power generation using these cells, there should be a drastic reduction in the cost of the cells. One of the cheapest solar cells now being investigated world wide are the Cu_2O-based solar cells due to the availability of the starting material which is copper, the material being non-toxic and simple and cheap fabrication methods. Although the highest electrical power conversion efficiency of the Cu_2O-based solar cells is 3.83% [2] with heterojunction structure, efforts are being made to improve on this efficiency. This review work is part of the efforts towards enhancing the performance of the Cu_2O-based solar cells. The work is aimed at gaining more understanding of the electrical parameters of the Cu_2O-based solar cells which eventually determine the performance of the cells, and identifying problems affecting them that up to now their efficiencies are very low. Finally, solutions would be proffered on how to optimize the values of the electrical parameters for improved efficiencies of these solar cells.

1.1 Solar Cell Electrical Parameters

The main electrical parameters that could be used to characterize the performance of a solar cell are the open-circuit voltage, V_{oc}, short circuit current, I_{sc}, and the fill factor, FF. These parameters provide the output performance of a cell [3, 4]. There are other electrical parameters of the solar cell that directly impact on the stated three parameters, theses are; the shunt resistance, R_{SH}, the series resistance, R_s, non-ideality factor, A, and the dark saturation current density, J_o. These parameters collectively determine the efficiency, η of the solar cell.

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1.2 The Open-Circuit Voltage, V_{oc}

The voltage measured across the device when its terminals are open is called the open-circuit voltage, V_{oc}.

From the equivalent circuit, Fig. 1, the current density, J produced by the solar cell is then written as:

$$J = J_L - J_D - J_{SH} \text{...} (1)$$

where

J = output current (in Am^{-2})

J_L = photogenerated current (in Am^{-2})

J_D = diode current (in Am^{-2})

J_{SH} = shunt current (in Am^{-2})

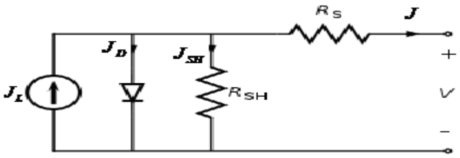

Fig. 1. The equivalent circuit of a non-ideal solar cell.

The current density flowing in the diode and the shunt resistance depend on the voltage across them, given as:

$V_j = V + JR_S$ ………………………………………….(2)

where V is the voltage across the output terminals

The approximate diode equation is given by Musa [4]:

$$J_D = J_O \left\{ \exp\left[\frac{qV_j}{AkT} \right] - 1 \right\} \text{..} (3)$$

where

J_o = reverse saturation current (in Am^{-2})

A = diode ideality factor (1 for an ideal diode)

q = elementary charge

k = Boltzmann's constant

T = absolute temperature

The current density passing through the shunt resistance is expressed as

$$J_{SH} = \frac{V_j}{R_{SH}} = \frac{V + JR_S}{R_{SH}} \text{..} (4)$$

where

R_{SH} = shunt resistance (Ωcm^2)

Now substituting equations (3) and (4) into equation (1) gives the characteristic equation of the solar cell. The equation is now written as:

$$J = J_L - J_O \left\{ \exp\left[\frac{q(V + JR_S)}{AkT} \right] - 1 \right\} - \frac{V + JR_S}{R_{SH}} \text{.....................................} (5)$$

Equation (5) relates the solar cell parameters to the output current and voltage.

For an ideal solar cell, $R_s \rightarrow 0$, and $R_{SH} \rightarrow \infty$, and the equation reduces to

$$J = J_L - J_o \left\{ \exp\left(\frac{qV}{AkT} \right) - 1 \right\},$$

and since $J_L \approx J_{sc}$

$$J = J_{SC} - J_o\left\{\exp\left(\frac{qV}{AkT}\right) - 1\right\}\text{...}(6)$$

It shows that the terminal current density through the device under open circuit condition is zero (J = 0) and the device equation becomes

$$J_L = J_{SC} = J_o\left\{\exp\left(\frac{qV_{OC}}{AKT}\right) - 1\right\}\text{...}(7)$$

$$V_{OC} = \frac{AKT}{q}\ln\left\{\frac{J_{SC}}{J_o} + 1\right\}\text{..}(8)$$

Or

Since $\frac{J_{SC}}{J_o} \rangle\rangle 1$

Then, $$V_{OC} = \frac{AKT}{q}\ln\left\{\frac{J_{SC}}{J_o}\right\}\text{..}(9)$$

Equation (9) above gives the ideal value of V_{oc}. The value of V_{oc} is determined by the properties of the semiconductor, by virtue of its dependence on J_o [3].

1.3 The Shot-Circuit Current Density, J_{sc}

This is the current that flows through the junction under illumination at zero applied bias. In the ideal case when all the effects of the parasitic elements are negligible, the short-circuit current is equal to the light generated current, I_L. The short circuit current is proportional to the illumination intensity. From eqn. (6)

$$J = J_L - J_o\left\{\exp\left(\frac{qV}{AKT}\right) - 1\right\}\text{...}(10)$$

For the short circuit condition, V = 0, and then equation (10) becomes

$$J_{SC} = J_L\text{...}(11)$$

The short-circuit current density, J_{SC} is affected by the series resistance, R_s

1.4 Fill Factor, Ff

Fill Factor is defined as the ratio of the maximum output power that can be extracted from the cell to the product of I_{sc} and V_{oc}. This is written as

$$FF = \frac{P_{\max}}{J_{SC}V_{OC}} = \frac{V_{\max}J_{\max}}{J_{SC}V_{OC}}\text{...}(12)$$

Fill Factor is a measure of how “square” the I-V characteristic curve is. For a solar cell of reasonable efficiency, it has a value in the range of 0.7 to 0.85 [3].

1.5 The Shunt Resistance, R_{sh}

The Shunt Resistance, R_{SH} is a parasitic element associated with practical solar cells, indicated in Fig.1. The shunt resistance is caused by leakage across the pn-junction around the edge of the cell in the presence of crystal defects and precipitates of foreign impurities in the junction region [3]. The shunt resistance reduces the Fill Factor [3, 5]. As the shunt resistance decreases, the flow of current diverted through the shunt resistor increases for a given level of junction voltage. This produces a slight reduction in V_{oc}.

1.6 Series Resistance, R_s

The series resistance is, generally, a parasitic element associated with practical solar cells, indicated in the equivalent circuit, Fig. 1. There are several physical mechanisms responsible for the series resistance. The major contributors to the series resistance are the bulk resistance of the semiconductor material making up the cell, the bulk resistance of the metallic contacts and interconnections, and the contact resistance between the metallic contacts and the semiconductor [3]. Very high values of R_s will produce a significant reduction in J_{sc}.

1.7 Non-Ideality Factor, A

The diode non-ideality factor, A is also called the junction perfection factor. For a perfect junction A=1 and the open circuit voltage, V_{oc} attains its maximum value, while for higher values of A, J_o is larger such that V_{oc} is reduced. The later tend to erode the cell output.

1.8 Dark Saturation Current Density, J_o

The dark saturation current density, J_o is the sum of the thermally generated current in the n and p materials in the dark. It is obtained when a large negative voltage is applied across the solar cell in the dark. The dark saturation current is usually opposite in direction to the photocurrent and it therefore, tends to short the device; it is therefore desirable that J_o be as small as possible for a good solar cell.

1.9 Electrical Power Conversion Efficiency, H

The electrical power conversion efficiency, η of a solar cell is the ratio of the power output, P_{out} to the total power input, P_{in} of the light incident on the cell. This is expressed as:

$$\eta = \frac{P_{out}}{P_{in}} x100\% = \frac{FF\ J_{SC}V_{OC}}{P_{in}} x100\% \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(13)$$

2.0 Experimental Factors Affecting the Electrical Parameters of Cu_2o-Based Solar Cells

There are several factors affecting the electrical parameters of Cu_2O-based solar cells, the common ones include: the material deposition method used, annealing and doping.

2.1 Material Deposition Method

It has been established that good quality Cu_2O films result in better photovoltaic response. Production of good quality Cu_2O films ensures the removal of defects, lower dislocation density and stacking faults probability in the Cu_2O crystal lattice. This improves the quality of the films and results in Cu_2O films with higher grain size and lower resistivity. Therefore, the possibility of obtaining good quality Cu_2O layers depends on the material deposition method employed.

Electrochemical deposition of p-n homojunction Cu_2O solar cells was reported [6]. A disappointing result was obtained, which showed an efficiency of 0.1%. The low efficiency was as a result of the high resistivity of the p and n layers deposited using this method. The resistivity of the p-type Cu_2O layer varied from $3.2x10^5\Omega$cm to $2.0x10^8\Omega$cm while that of the n-type Cu_2O layer from $2.5x10^7\Omega$cm to $8.0x10^8\Omega$cm, depending on the deposition conditions.

Other researchers [7] reported the electro-deposition of Cu_2O film with various grain sizes. They obtained the largest grain size of 55nm at an optimum deposition potential of -0.555V and pH 9.0. But in galvanostatic deposition of Cu_2O films [8], good quality films were obtained in the pH range 8-11.

Cuprous oxide was produced using thermal oxidation [9]. The thermal oxidation method is also accompanied by the existence of crystal defects. The grain size obtained using this method is on the average 0.66 μm for the as-deposited layer.

Larger grain size of Cu_2O material was reported [10] using electro-deposition. The grains were of the order of 2-5μm.

Cu_2O sheets were also prepared by infrared light irradiation [11]. This involves a two-step oxidation with controlled temperature and oxygen pressure by heating with infrared radiation. The cell electrical parameters (for $1cm^2$ sample) obtained using the Cu_2O produced are: $R_s = 2.9\Omega$, $R_{sh} = 52\Omega$, $I_o = 3.0mA$, $A = 4.6$ and $\rho = 120\Omega cm$.

There is another report [12] on using Pulsed Laser Deposition (PLD) to produce TCO-Cu_2O solar cells. Various TCOs were used which include In_2O_3, ZnO, In_2O_3:Sn (ITO), ZnO:Al (AZO) and AZO-ITO (AZITO) were used. AZO-Cu_2O has electrical parameters as: $V_{oc} = 0.4V$, $J_{sc} = 7.1mA$, ff = 0.4 and η = 1.2% measured under AM2 solar illumination.

A heterojunction solar cell of Cu_2O having ITO/ZnO/Cu_2O was reported [13]. The Cu_2O layer was prepared by thermal oxidation and the ITO and ZnO were both prepared by ion beam sputtering (IBS) at room temperature. The electrical parameters of the cell are V_{oc} =595mV, $J_{sc} = 6.78\ mAcm^{-2}$, ff of 0.50 and electrical power conversion efficiency of 2%.

A better cuprous oxide heterojunction solar cell was fabricated in 2011 [2]. The cell has AZO/ZO/Cu_2O structure, with the AZO and ZO thin films prepared by pulsed laser deposition (PLD) and the Cu_2O were obtained by thermal oxidation. The electrical parameters of the cell are $V_{oc} = 0.69V$, $J_{sc} = 10.1\ mAcm^{-2}$ and an ff of 0.55. The electrical power conversion efficiency of 3.83% was achieved for the cell.

2.2 Annealing

Annealing process involves heating the Cu_2O samples at a low temperature for a given time. The annealing process is performed in order to heal defects created during the material deposition and to improve on the grain size of the crystals so as to lower the resistivity of the layers.

It was reported that annealing of Cu_2O at a temperature range 150-450^oC showed increase in grain size. An optimum temperature of 350^oC produced the largest grain size of 100nm [7]. The same literature indicated that the electrical energy conversion efficiencies for the Photo-Electro-Chemical (PEC) cell of the material improved from 0.05% to 0.2% for the as-deposited and annealed samples. It was reported that as-deposited Cu_2O obtained by galvanostatic deposition method has resistivity of $5x10^7\Omega cm$ which after annealing improved to $3x10^4\Omega cm$.

Grain size of the Cu_2O produced by thermal oxidation [9] changed, after annealing, from 0.66-0.83 µm and a corresponding annihilation of crystal defects such as vacancies and dislocations. The resistivity of the material was found to have decreased from $3.7x10^3\Omega cm$ to $5.6x10^2\Omega cm$ for the unannealed and annealed samples, respectively. The researchers reported mobility increase also, from $75cm^2V^{-1}s^{-1}$ to $130cm^2V^{-1}s^{-1}$ for the unannealed and annealed samples, after chlorine doping.

2.3 Doping

Doping is the addition or introduction of foreign atoms into a material with the aim of influencing conductivity of the material (n-type or p-type). Some of the atoms used to dope Cu_2O material are F, p, N, Cl, In, Mg, etc. None of these doping agents changed the Cu_2O from p-type to n-type. Chlorine is the only successful doping impurity which enhances the p-type conductivity of Cu_2O.

A group of researchers [13] reported a reduction in the resistivity value of chlorine-doped Cu_2O material from 22,000Ωcm to about 1000Ωcm for the undoped and doped Cu_2O, respectively.

Thermally oxidized Cu_2O samples doped with chlorine were reported to have their resistivity value reduced from$5.6x10^2\Omega cm$ to $2.5x10^2\Omega cm$ for undoped annealed sample to doped annealed sample [9].

3.0 Conclusion

The outcome of this work suggests that, to obtain optimum values of the electrical parameters of the Cu_2O-based solar cells three problems should be tackled as follows:

1. The various methods used in the production of the Cu_2O layers resulted in Cu_2O layers of poor quality, with exception of a few: to overcome this problem, the method of thermal oxidation should be improved further. The thermally produced Cu_2O was observed to give a heterojunction Cu_2O solar cell of highest efficiency of 3.83%.
2. The existence of defects in the Cu_2O semiconducting material is expected to impede the flow of charge carriers and hence the mobility. The grain size also affects the quality of the Cu_2O films: having observed that charge carrier mobility was lower for the unannealed Cu_2O samples while it is higher for the annealed samples and crystals defects are minimized after the annealing; annealing of the Cu_2O sample is recommended always. Optimum annealing temperature should be explored and made standard for the thermally produced sample.
3. Doping was observed to enhance p-type conductivity instead of producing n-type Cu_2O layer so as to form p-n homojunction, which is widely believed would make better solar cells: in the absence of a viable n-dopant, the method of electro-deposition of p-n homojunction [6] should be investigated further to be able to improve on the resistivity of the p and n layers.

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