EFFECT OF VARYING THICKNESS ON PERFORMANCE OF TITANIUM DIOXIDE SOLAR CELL

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ABSTRACT

The need for energy to drive economic development has increased tremendously yet most energy sources lead to environmental pollution with consequences such as global warming and serious health complications. Global warming for instance exacerbate problems of some energy source like hydro-generated energy due to climate variability. Alternative options have thus to be investigated. This study assessed the effects of varying solar cell thickness on its output. The study used a TiO_2 (the photo active layer) and the electronegative material layers on current-voltage output of the fabricated solar cell. Various ratios of titanium dioxide: graphite /iodine/KI mixtures were prepared in each respective layer. Optimization involved varying the mass of the constituents of each layer while maintaining other constants to obtain the highest current-voltage outputs. The mixtures at varying ratios were made into pellets and their electrical properties investigated. The presence of KI enabled solubility of iodine enhancing it to disperse evenly in graphite whose mass was constant at 0.01g in all the cells fabricated. The optimal thicknesses were found to be 2.00 and 1.00 mm respectively. The optimum electricity generation was observed at the ratio of TiO_2/ C_x: I_2: KI as 0.4: 0.3: 0.17: 0.01g, respectively. The highest open circuit voltage (Voc) of 0.979V and a short circuit current density (Jsc/cm^2) of 12.037μA was observed, giving efficiency (η) of 0.006% and a Fill factor (FF) of 0.64. The study concludes that thicker cells resulted to higher voltage and current output. However, this variation was dependent on the ratio of TiO_2/ C_x: I_2: KI. Industrial and scholarly recommendations are presented.

Keywords: Varying Thickness, Performance, Titanium Dioxide Solar Cell

INTRODUCTION

The need for energy to drive industrial, domestic and other social economic projects increases with the population growth. Currently, most energy sources result to environmental pollution with consequences such as global warming and serious health complications. Factors such as global warming exacerbate the problem of some energy source like hydro-generated energy due to drought. Due to such challenges, alternative options of energy sources have to be investigated. This study sought to fabricate a non-corrosive cell with no toxic emissions. Besides environmental friendliness, optimized solar cells can be used to bridge this energy gap.

ELECTRODE THICKNESS

Thickness of solar cell electrodes dominantly influence its optics (Naqavi, 2013). When the thickness of electrodes is modified, it exerts impacts on the conduction band edges of the semiconductor material and the electron excitation is potentially improved. According to Kavita (2011), ordered configuration of particles in solar cells is attributed to photon energy diffusion dynamics and strain in the film. With three different thicknesses, Kavita revealed that the characterized fabricated samples had identical film properties. Kavita concluded that photon diffusion was affected by thicker layer interface. Thicker layers affect diffusion of photon energy in thin films resulting to low potential (Kavita, 2011; Zhang, 2013).

Grätzel (2009) indicated that coating graphite onto the conductive side is one of the crucial steps for making the dye-sensitized solar cells (DSSC). Therefore, the study tested the dependence of the thickness of graphite layer with the performance of the cell. Grätzel (2003) noted that graphite layer has potential influence on the efficiency of the solar cell. Graphite layer is necessary for cell functioning properly (O’Regan & Grätzel, 1991) and is controlled by manipulating the time over the candle flame. Difference in thickness of graphite can be tracked by the colour of the layer (O’Regan & Grätzel, 1991). However, graphite layer was necessary for the DSSC to produce voltage and bulky thickness would not improve the efficiency of the solar cell (O’Regan & Grätzel, 1991).

O’Regan and Grätzel (1991) fabricated titanium dioxide solar cell through a wet chemical process. Thicker layers of titanium dioxide potentially decrease the output of the cell by blocking the photon transfer (Grätzel, 2003). The development of the cell brought about the possibility of having an alternative to silicon based photovoltaic cell (Sundaram, 2009). The Grätzel cell (DSSC) is inexpensive, easy to develop and has an overall conversion efficiency at 12%. However, the cell suffers from corrosion due to action of oxygen on the material used (Sundaram, 2009). The current study exploited the same principles of the DSSC but without the aqueous media to minimize effects of corrosion.

STATEMENT OF THE PROBLEM

Climate change and variability has resulted to reduced precipitation hence affecting water levels and HEP production. Fossil fuel on the other hand has contributed to environmental pollution which has disastrous health effects (Herman, 2002). Domestic lighting is essential in many homesteads particularly in rural Kenya as most of them are not connected to the national grid (Ahmad & Mohammad, 2010) and use paraffin which on combustion results to respiratory ailments. Alternative sources of energy are therefore required and solar power offers the best alternative. The use of doped titanium dioxide activated by ordinary radiation and graphite as the conduit for the migration of electrons are suitable materials for making a solar cell (Ahmad &Mohammad, 2010). Due to the rising cost of energy, alternative options of generation of electricity necessitated this study to be carried out. This study endeavoured to fabricate a solid solar cell using titanium dioxide (TiO_2), and iodine (I_2) with potassium iodide (KI/I_2) dispersed in graphite (C_X) for solar cell application. This was intended to be an alternative green source of energy which is renewable and not easily degraded.

MATERIALS AND METHODS

The study adopted an experimental research design to investigate the performance of the fabricated solar cell. It was done by first obtaining the optimal values of the parameters under investigation. The best parameters were obtained by establishing the optimal values of each material constituent of the cell. These were TiO_2, which was the photoactive material, the graphite which was the conducting medium and the Iodine/Iodide mixture which replenished the electrons conducted away after photo excitation. This process employed varying the weights of the component parts, and finally characterization of the fabricated solar cells under constant radiation intensity in clear daylight.

In the study, the following assumptions were made: The solar radiation was assumed to be constant at 100 mW/cm^2 irradiance (Hagfeldt *et al*., 2010); the solar density on the solar cell was assumed to be uniform, and the voltage drop in the digital meter leads was assumed to be negligible. All reagents were of analytical grade and were sourced from Sigma Aldrich. The titanium dioxide (TiO_2), iodine (I_2), potassium iodide (KI) and graphite (C_X) in their powder form were used.

To fabricate the solar cell, different mass ratios of graphite (C_X) powder, titanium dioxide (TiO_2) powder, potassium iodide (KI) and iodine (I_2) were mixed and compressed to form a Solar Cell. Figure 1 below shows the schematic presentation of the fabricated cell.

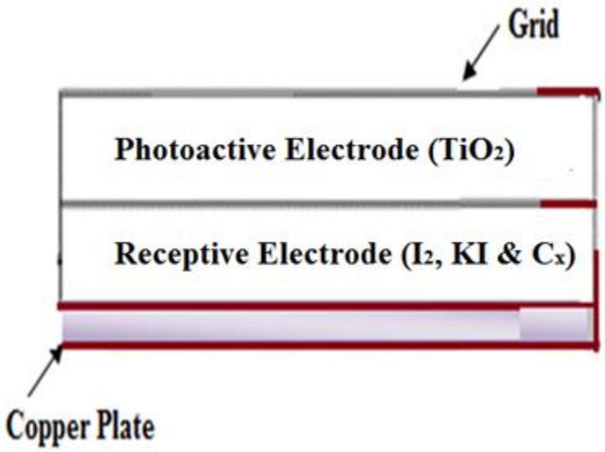

Figure 1: Schematic presentation of the fabricated solar cell

To provide the required dimensions, a copper plate was cut into 2.5 cm by 2.5 cm by the use of metal plate shears. An active cell of Ø 1.3 cm (A=1.327 cm^2) was prepared, laid on the copper plate and covered with a transparent raisin as a copper conductor in contact with the upper electrode was drawn through the raisin for external connection.

The first cell electrode was made by placing the photo active measured sample separately in a circular dice and compressed thoroughly. The second electrode was made by disposing the mixtures of mass ratios of (graphite: iodine: I_2/KI) over the initial layer and the pressing procedure followed. The resultant was a circular pellet which served as the photo active cell. I-V characteristics of each of the resulting cells were monitored. The photo active (cathode) was prepared by varying masses of powdered TiO_2 ranging from (0.2-1) g. These masses were inserted in a moulding dice and pressed into a disc form with a diameter of 1.3 cm to form a circular pellet.

The receptive layer (anode) was prepared by varying masses of finely divided mixtures of mass ratios (graphite: I_2: I_2/KI) ranging from (0.1: 0.1: 0.01) g to (0.6: 0.3: 0.01) g. These mixtures of mass ratios were then inserted in a moulding dice and pressed into a disc form with a diameter of 1.3 cm to form a circular pellet similar in size to the photoactive layer. The receptive layer (anode) was then placed on photo active (cathode) and pressed further to form a complete assembly of the solar cell. External conductors were then connected to the cell for I-V characterization. Figure 2 shows the schematic cell presentation of the solar cell.

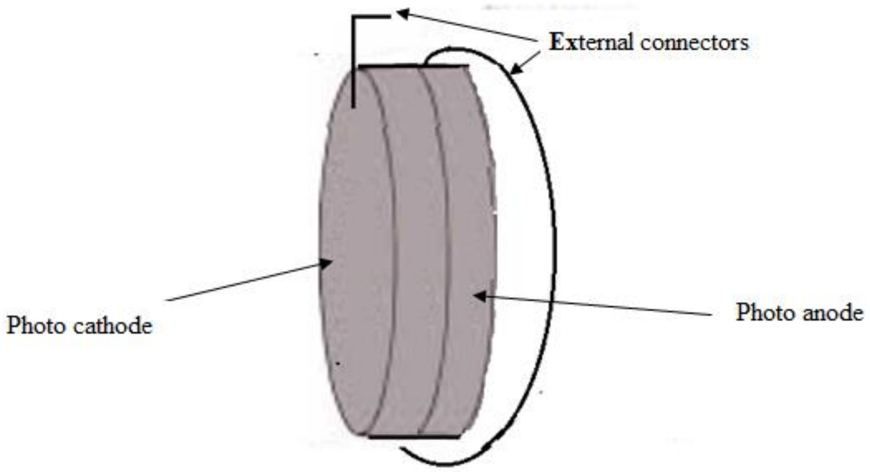

Figure 2: Photo voltaic cell scheme

The optimum I-V characteristics were established using the circuit diagram of Figure 3.

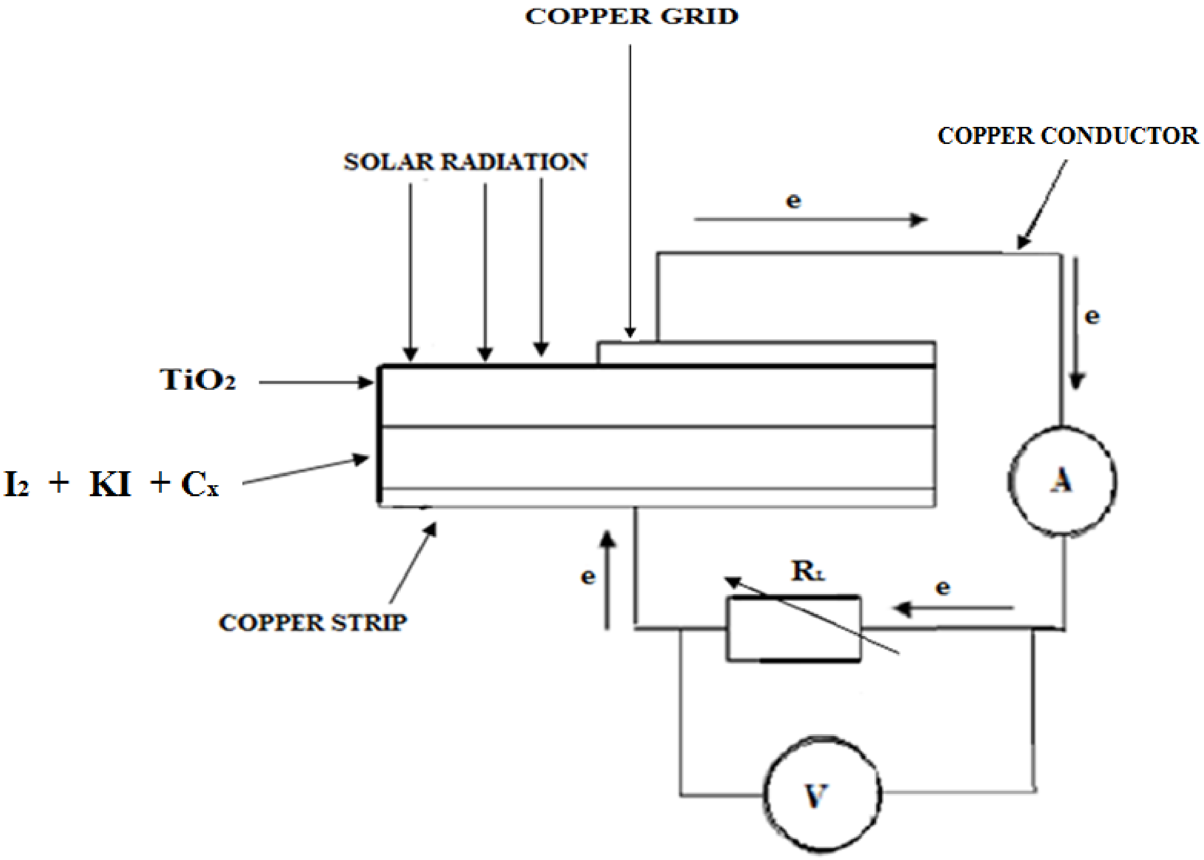

Figure 3: Assembly of the circuit diagram for the I-V characterization

A high resolution micro-Ammeter (0-100 μA) was connected in series with the fabricated Solar cell to measure the current density output (J_{MP}) resulting from the generated charge carriers which migrated from the photo active cathode layer of the cell through external conductors and back to the cell through the anode. A high resolution galvanometer (0-250 mV) was connected in parallel with the arrangement of the Ø 1.3 cm ($A=1.327\ cm^2$) active solar cell and the micro-Ammeter (0-100 μA) to measure the resulting open circuit voltage (V_{OC}) at the output terminals.

A high resolution graduated variable resistor (Ohmmeter) (0-34 Ω) was connected in series with the micro-Ammeter (μA) and in parallel with the galvanometer (0-250 mV). The variable resistor served the purpose of an external load and the ratio of the generated potential (V_{MP})to the measured resistance at any particular instant, confirmed the amount of the current density (J_{MP}) through the external circuit and this was recorded to determine the maximum power (P_{MAX}) of the solar cell. The short circuit current density (J_{SC}/cm^2) values were determined at zero applied voltage and the open circuit voltage (V_{OC}) values were determined at zero current under solar radiation. The current generated against their corresponding potential for various cells were collected and tabulated. The voltage output for maximum power output (P_{MAX}) were taken at 5 minutes intervals and tabulated for analysis.

The fabricated solar cell parameters were calculated using equations as applied by Adegbenro (2016) while calculating parameters of different shapes and states of solar cells. In his study, the cells were in $1cm^2$ squared blocks while the cell in this study had a diameter of (Ø) 1.3 cm giving an area (A) of 1.327 cm^2:

$$V_{MP} = \frac{V_{MAX}}{A}(\mathrm{mV\,cm^{-2}}) \quad (1)$$

$$J_{MP} = \frac{I_{MAX}}{A}(\mathrm{\mu A cm^{-2}}) \quad (2)$$

$$P_{MAX} = V_{MP} \times J_{MAX} \quad (3)$$

$$J_{SC} = \frac{I_{SC}}{A}(\mathrm{\mu A cm^{-2}}) \quad (4)$$

$$V_{OC}/cm^2 = \frac{V_{OC}}{A}(\mathrm{mV/\,cm^2}) \quad (5)$$

$$P_T = V_{OC}/cm^2 \times J_{SC}/cm^2 \quad (6)$$

$$\text{Fill Factor(FF)} = \frac{J_{MP}V_{MP}}{J_{SC}V_{OC}} \quad (7)$$

$$\text{Shunt Resistance}(R_{SH}) = \frac{\Delta Y}{\Delta X} \quad (8)$$

$$\text{Series Resistance }(R_S) = \frac{\Delta X}{\Delta Y} \quad (9)$$

$$\text{Efficiency } \eta = \frac{J_{SC} \times FF \times V_{OC}}{p_{in} \times A} \quad (10)$$

'A' is the photoactive area of the cell; A= 1.327 cm^2. In the study, the parameters were obtained by adopting expression 1-10 as applied by Adegbenro (2016) when he characterized different shapes and states of solar cells to obtain their parameter values.

Jain (2013) defines the open circuit voltage (V_{OC}) is the voltage delivered by the solar cell when the electrodes are isolated and no current is sourced under infinite load resistance. This voltage represents the maximum potential energy stored to initiate the flow of electrons which are yet to be dissipated. Jain also notes that the voltage of a unit area (V_{OC}/cm^2) delivered by a solar cell when the electrodes are isolated represents the maximum potential energy stored to initiate the flow of electrons which are yet to be dissipated.

RESULTS AND DISCUSSIONS

Effect of the Cell Thickness on Potential (V_{OC}) and Efficiency (η%)

The influence of photoactive layer thickness on the photocurrent density was a parameter of concern. This is because thickness has effects on the penetration of radiation that reaches the photo active material and as a consequence influences the resistivity of the cell (Wasiu, 2017; Zhang, 2013). As such, an optimum value had to be established for optimal results. The effect of (1, 2, 3 and 4) mm thickness of the photo active material (TiO_2) on the open circuit voltage and the efficiency of the solar cell was investigated and the results obtained were as presented in Table 1 below.

Table 1: Effect of varying thickness of the optimized solar cells on V_{OC} (V) and η%

Layer	Thickness (mm) of TiO_2	V_{OC} (V)	Efficiency (η) %
One layer	1	0.833	0.0034
Two layers	2	0.979	0.0060
Three layers	3	0.562	0.0040
Four layers	4	0.497	0.0038

From the information recorded in Table 1, graphical presentations of potentials and efficiency (η%) against the thickness of the photo active material were made as presented in Figures 4 and 5.

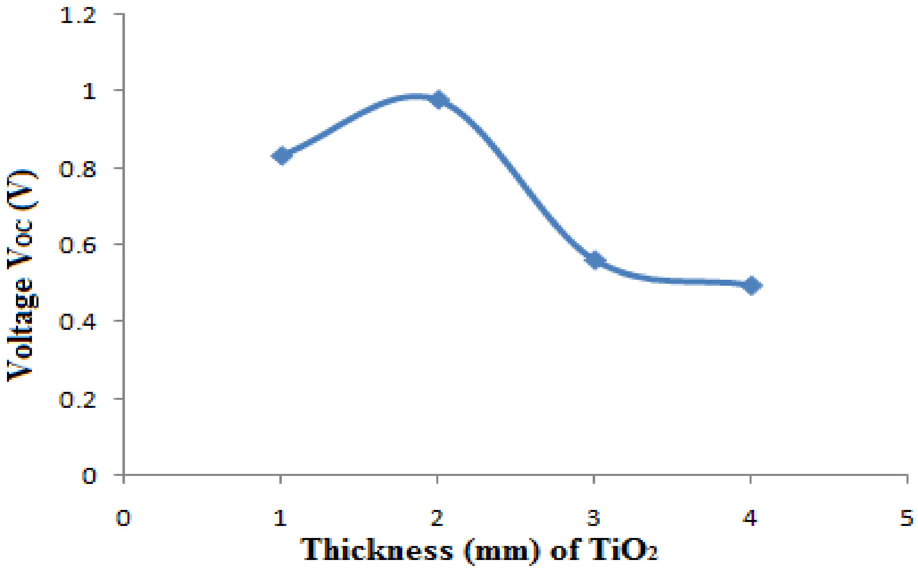

Figure 4: Variation of the cell thickness against V_{OC}

The results in Figure 4.11 show a gradual increase in potential until a thickness of 2.0 mm after which the optimal value of the photoactive cell yielded a potential of 0.979 V. A sudden decrease in potential was observed as the thickness of the photoactive material was increased. This can be concluded that thicker layers of titanium dioxide potentially decrease the output of the cell by blocking the photon transfer (Grätzel, 2003). Comparable observations were presented by Swapnil (2016) when he fabricated and characterized an organic solar cell. Another graphical presentation of efficiency (η%) against the thickness of the photo active material was made from the information recorded in Table 1, as presented in Figure 5. A similar profile to that of Figure 4 was observed confirming that the optimum thickness found for maximum potential was also the one for maximum efficiency.

This shows that even if the thickness of the cell is enhanced thus to increase more charge carriers, there has to be agreement in the generated free electrons and the resistivity of the cell to enable the migration of the current (Calado *et al*., 2016).

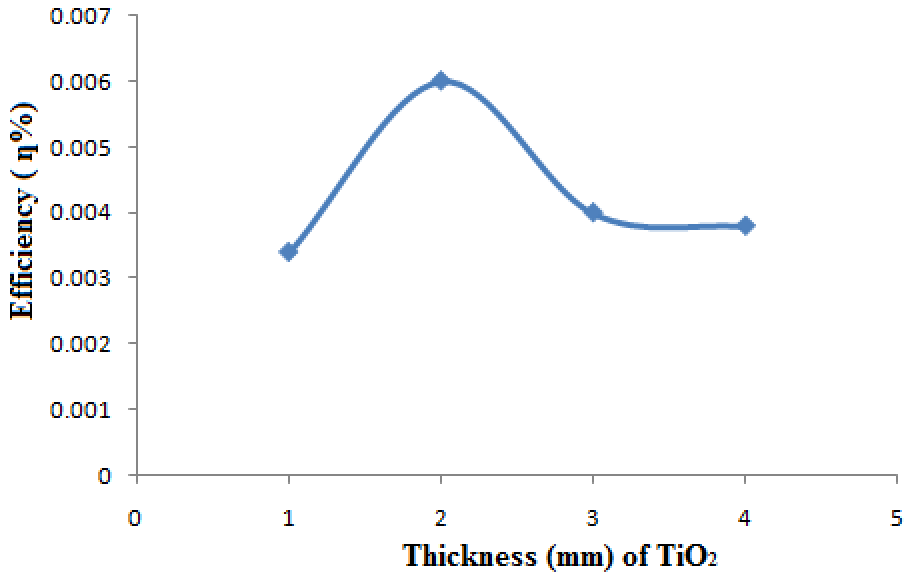

Figure 5: Variation of the cell thickness against efficiency η %

From Figure 5 above, it is observed that an increase in the number of TiO_2 layers from one layer to two layers raised the efficiency by 0.0026%. However, an increase from two layers to three layers contributed to a decrease in the efficiency by 0.002%. This change indicates that the thickness of TiO_2 photo anode layer made in this study has influence on the performance of the solar cell due to effects on the cell internal resistance (Imran, 2013). An increase in the thickness of both the conducting graphite medium – (C_X) and that the photo active material (TiO_2) contributed to a longer path for the photo-generated electrons to reach the working electrode thus delaying the electron recombination process. The thickness of the photoactive material was found to have a direct impact on the cell efficiency. The thickness of the cell made from a combination of the mass ratio of (0.4: 0.3: 0.17) of TiO_2: graphite: I_2 respectively was observed to give an open circuit voltage (V_{oc}) of 0.979 V as presented in Figure 4.

CONCLUSION AND RECOMMENDATIONS

Based on the above findings, our study adopted the values for the optimized thickness of the photo active layer as 2 mm for the fabrication of solar cells for I-V characterization. Certain thickness of the photo active material (TiO_2) and graphite (C_X) were observed to affect the cells output since variation of TiO_2 generated varied potentials. A thickness of 2 mm and 1 mm of TiO_2 and graphite respectively yielded the highest potential of 0.979

V. This study concludes that thickness affects penetration of radiation and also increases the parasitic resistance to the migrating electrons. It is therefore recommended that further research work be done using TCO (transparent conducting oxide) as the cathode in addition to employing technologies that can reduce air packets in the solar cell.

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