Effect of the Graphite Dispersed Titanium Dioxide Solid Solar Cell Composition on the Generated Potential (V_{OC})

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Abstract

Energy is globally recognized as one of the most fundamental inputs for social and economic development. Most energy sources are serious environmental pollutants. To overcome this challenge, presence of abundant sunshine was exploited through use of photovoltaic cells. However most photovoltaic cells are silicon based hence expensive. This study reports on the fabrication of a cost effective and environment friendly solar cell by use of TiO_2 and I_2/ KI (dispersed in graphite-Cx) layers in their solid form to provide an alternative source of clean energy. TiO_2 has a high photo generation ability when excited with radiation and is chemically inert over a wide pH range. The photo generated electrons were replenished by iodine complex and graphite facilitated their migration. The mixtures at varying ratios were made into pellets and their electrical properties investigated. The optimum electricity generation was observed at the ratio of TiO_2/ C_x: I_2: KI as 0.4: 0.3: 0.17: 0.01 g respectively. The optimal thicknesses of the photo active layer and that of the electronegative layer were found to be 2.00 and 1.00 mm respectively. An open circuit voltage (Voc) of 0.979V and a short circuit current density (Jsc/cm²) of 12.037µA was observed, giving efficiency (η) of 0.006% and a Fill factor (FF) of 0.64. The cell did not suffer from corrosion effects as it was used in a dry solid state making it suitable for photovoltaic application.

Keywords: Graphite Dispersed Titanium Dioxide, Solid Solar Cell Composition, Generated Potential.

Introduction

Energy is recognized universally as one of the most fundamental inputs for social and economic development. Modern consumption patterns and energy production contribute significantly to climate change and air pollution. Substantive emissions reductions over the next few decades can reduce climate risks in the 21st century and

increase prospects for effective adaptation, reduce the costs and challenges of mitigation in the longer term for sustainable development and reduced threats to human and environmental health across the world (IPCC, 2014). In the recent past, use of renewable energy as an alternative source of energy has increased considerably. The feasibility of photovoltaic solar energy as an alternative source of energy has become real. However, solar PV systems are still compounded with low efficiencies and their dependency on weather conditions still offer room for improvement of the technology to extract higher outputs for different environmental conditions. Therefore, the current study proposes a low cost method of fabricating a renewable source of energy void of greenhouse gas emissions.

Air pollution and climate change influence each other through complex interactions in the atmosphere. High levels of GHGs alter the energy balance between the atmosphere and the Earth's surface, which lead to temperature changes that change the chemical composition of the atmosphere. These changes in temperature result in reduced water reservoir on the earth surface which in turn leads to reduced amount of hydro electric energy generated. There are technological solutions which address concerns of switching off from fossil fuels to renewable forms of energy that cuts down on air pollution emissions(Monasterolo & Raberto, 2018).This study sought to develop a photo cell which will reduce use of fossil fuels and in turn reduce on air pollution and climate change.

Literature Review

Titanium dioxide is a non-toxic inorganic chemical of industrial importance widely used aswhite pigments because of its brightness and high refractive index (Wang et al., 2017). Sellappan (2013) noted that TiO_2 generate electrons and holes when illuminated with UV radiation of wavelength domain 10nm to 400nm. Similar observations have been reported by Liu et al. (2018). A study by Hecht (2018) reported that with a suitable conductor, the discharged electrons have the ability to migrate in a specified direction leading to some conductivity. The conductivity can be improved by adding (doping)

traces of elements that effectively add or remove electrons from the light illuminated titanium dioxide (Adler, 2011). This photo activity of TiO_2 makes it a preferred semiconductor material which is stable and chemically inert over a wide pH range under irradiation, and its relatively favourable deposition of band edges (Wang et al.,2017). Hebling (2010) reported that titanium dioxide has been utilized in photo cells in a wet chemical process. However, that application is associated with a lot of corrosion.

Similar studies used transparent single crystals or thin films which have a high refractive index as a conductor in contact with the TiO_2 material in multi-layers composition to monitor optical and electrical characteristics of the resulting cell (Colin, 2011). Other applications of the electron hole splitting enabled by TiO_2 are widely used for photo catalysis such as water treatment by oxidation (Kanakaraju, et al, 2014). The TiO_2 photo active material used in electro chromic devices and dye-sensitized solar cells show promising results but it is affected by corrosion (Caitian *et al.*, 2014). Since exposure of TiO_2 to solar radiation generates electricity, this study explored options of developing a solar cell using this material. The solar cell fabricated was based on the use of TiO_2 in its solid form and graphite (C_X) which was used as a medium of electron migration. This was done by fabricating layer structured cells with external conductors which enables electrons to migrate and fill the deficient holes that exist upon illumination. The fabricated involved two layered solar cell of TiO_2 and I_2/ KI dispersed in graphite.

TiO_2 particles have nanocrystalline electronic junctions network, which are interconnected to allow for electronic conduction to take place and they present comparable band gap values and conduction band position as well as higher electron mobility (Chergui *et al.*, 2011). Tse et *al.* (2018) reported thatTiO_2 has a higher dielectric constant which provides effective capacitance that can be obtained with thicker layers of other materials and therefore used to provide high dielectric constant for storage of potential. According to Hussein *et al.* (2018),TiO_2 has been used as passivation layers on other cells and as photo-anode in solar cells in its solid state. When the energy band gap of TiO_2 particles are reduced, lower energy photons are absorbed by the TiO_2 catalyst

and the photo activity of the catalyst are increased proportionally to the increase in the absorbed solar radiation (Ola & Maroto-valer, 2015).

Statement of the Problem

Hydro-electric source of lighting have been affected by the changing weather patterns resulting to reduced precipitation hence diminishing water levels due to global warming. This has reduced the amount of electricity generated. The use of fossil fuel has contributed to pollution of environment which has disastrous health effects (Perera, 2018). 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). Their source of lighting comprises ordinary tin lamps to other form of lamps that use paraffin. Upon combustion of that fuel, toxic fumes result to respiratory ailments. That being the case, alternative sources of energy is required and solar power offers such 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. The study at hand 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 day light.

The following assumptions were made; that solar radiation was 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.
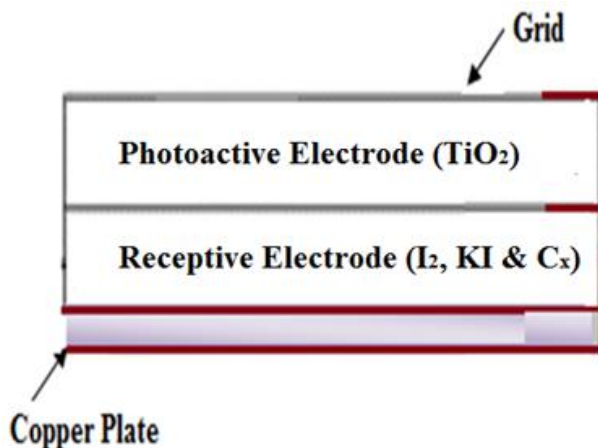
To provide the required dimensions, a copper plate was cut into 2.5 cm by 2.5 cm by the use of metal plate shears. An active cell of Ø 1.3 cm (A=1.327 cm^2) was prepared, laid on the copper plate and covered with a transparent raisin as a copper conductor in contact with the upper electrode was drawn 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 resultanting circular pellet 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 molding 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 molding 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 the 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.
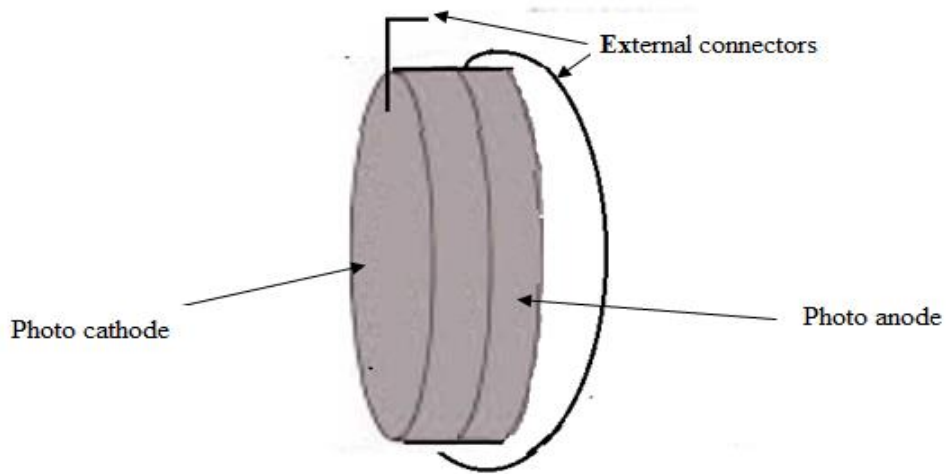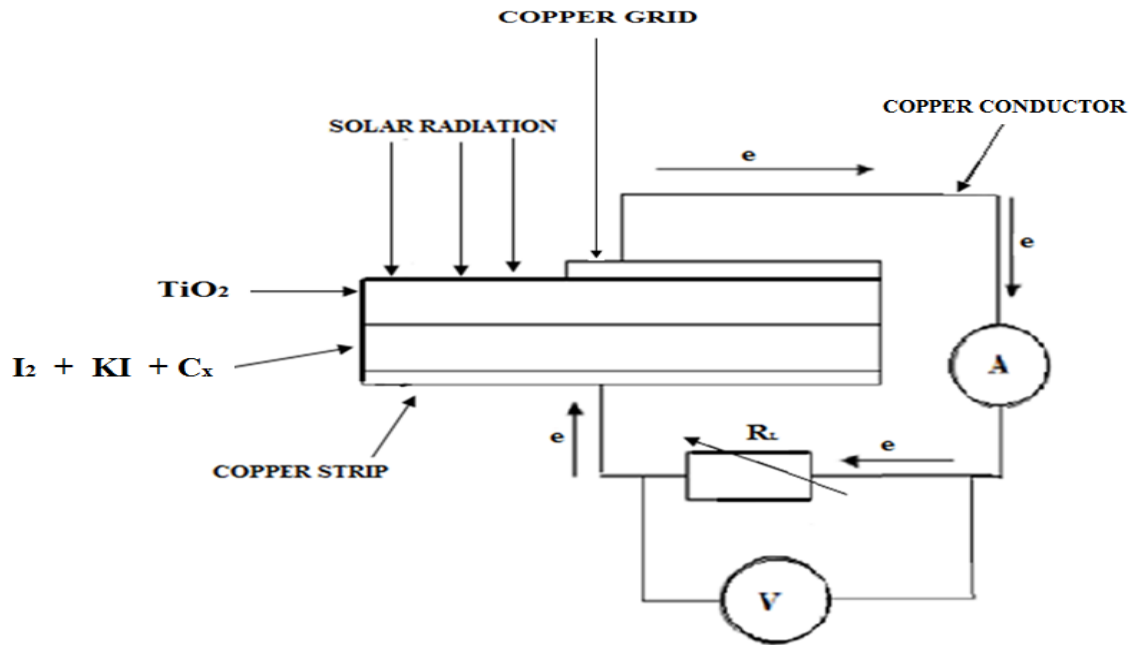

Figure 3: Assembly of the Circuit Diagram for the I-V Characterization

COPPER GRID

COPPER CONDUCTOR

SOLAR RADIATION

TiO₂

I₂ + KI + Cₓ

COPPER STRIP

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 cm²) 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}/cm²) 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 1cm² squared blocks while the cell in this study had a diameter of (Ø) 1.3 cm giving an area (A) of 1.327 cm²;

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

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

$$P_{MAX} = V_{MP} \times J_{MAX} \tag{3}$$

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

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

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

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

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

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

$$\text{Efficiency}\,\eta = \frac{J_{SC} \times FF \times V_{OC}}{p_{in} \times A} \tag{10}$$

'A' is the photoactive area of the cell; A= 1.327 cm²

In the study at hand, 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.

Nikhil (2013) defined the open circuit voltage (V_{OC}) as 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. Nikhil (2013) further noted 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 Discussion

Effect of Varying Iodine-Iodide Complex on (V_{OC})

Variation of the electron replenishing source was investigated by varying the amount of iodine at a constant mass of TiO_2 (0.6 g) and graphite -C_X (0.25 g) as presented in Table 1.

Table 1: Effect of variation of iodine masses of cells A, B and C on V_{OC}

Cell	Mass (g)				Voc (V)
	TiO₂	KI	C_X	I₂	V_{OC}
A	0.6	0.01	0.25	0.12	0.496
B	0.6	0.01	0.25	0.18	0.278
C	0.6	0.01	0.25	0.24	0.243

From the information recorded in Table 1 above, a graphical presentation of potential (Voc) against the masses of iodine was made as shown in Figure 4.

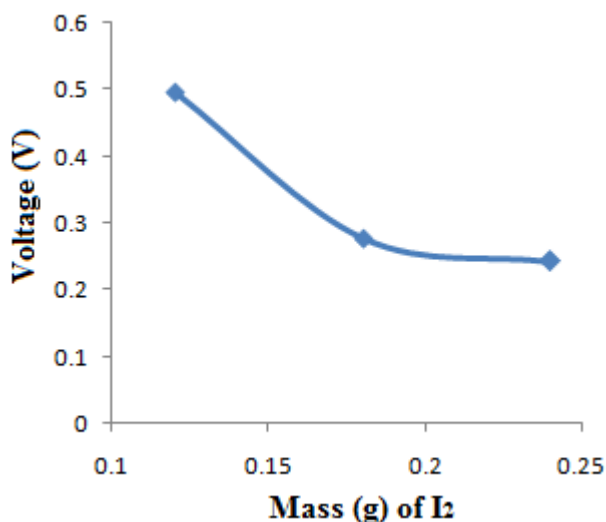**Figure 4: Variation of Iodine Mass against Potential of Cells A, B and C**

Figure 4 shows a general profile of decrease in potential as the mass of I_2 increases. The composition of TiO_2: graphite: I_2 of cells A, B and C were varied in the mass ratios (0.6: 0.25: 0.12), (0.6: 0.25: 0.18) and (0.6: 0.25: 0.24), respectively.

It is observed that between the mass of (0.18 and 0.24) g the generated voltage was almost constant. This can be explained by the fact that when the iodine ions surpassed the number of the electrons released from the photo active material, there was an increase in resistance which restricted the migration of the photo excited electrons on the photo active electrode to the external circuit (Jessica, 2018). Increasing the mass of I_2 beyond 0.24 g would decrease the potential difference because extra I_2 ions inhibited migration of the generated photo excited electrons.

The mass of TiO_2 and graphite (C_X) was then increased to (0.7 and 0.28) g respectively and a similar procedure was followed to characterize the resulting cells. The change in potential against the mass of iodine was monitored and the results were recorded as shown in Table 2.

Table 2: Effect of Variation of Iodine Masses of Cells D, E and F at Constant TiO_2 on V_{OC}

	Mass (g)				Voltage(V)	Short CCT Current Density ($\mu A\ cm^{-2}$)
Cell	TiO_2	KI	C_X	I_2	V_{OC}	J_{SC}
D	0.7	0.01	0.28	0.15	0.956	6.474
E	0.7	0.01	0.28	0.2	0.295	2.000
F	0.7	0.01	0.28	0.28	0.2	1.353

From the information recorded in Table 4, a graphical presentation of potential (Voc) against the masses of iodine was made as shown in Figure 5.

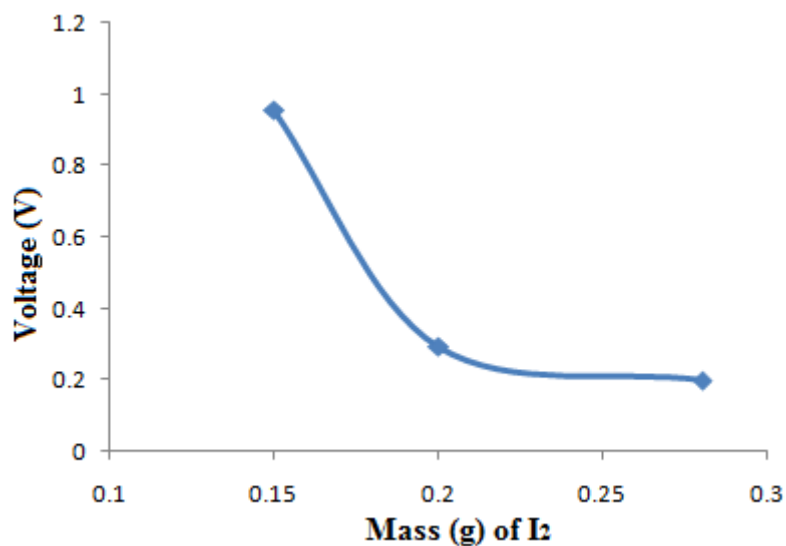**Figure 5: Variation of Iodine Mass Against Potential of Cells D, E and F**

Figure 5 shows a general profile of a decrease in potential as the mass of I_2 was increased. However, the values of the potential generated were higher as compared to those found in Figure 4. This could be attributed to the ratios of iodine ions nearing the optimization value with respect to the other cell constituents which in turn increased the rate at which the iodine ions replenished the electron deficient holes (Khan, 2013).

Another set of cells were made with the mass of TiO_2 held constant at 0.8 g and that of iodine was varied from (0.15 to 0.30) g. The change in the potential against the mass of iodine at constant radiation was monitored and recorded as shown in Table 3.

Table 3: Effect of Variation of Iodine Masses of Cells G, H, I & J on V_{OC}

Cell	Mass (g)				Potential (V)
	TiO_2	KI	C_X	I_2	V_{OC}
G	0.8	0.01	0.32	0.15	0.24
H	0.8	0.01	0.32	0.2	0.304
I	0.8	0.01	0.32	0.25	0.284
J	0.8	0.01	0.32	0.30	0.248

A graphical presentation of potential (Voc) against the masses of iodine was made as shown in Figure 3. The mass of the composition of TiO_2: graphite (C_X): I_2 were varied in the ratio of (0.8: 0.32: 0.15), (0.8: 0.32: 0.2), (0.8: 0.32: 0.25) and (0.8: 0.32: 0.30), respectively.

Figure 6: Variation of G, H, I Iodine Mass Against Potential of Cells and J
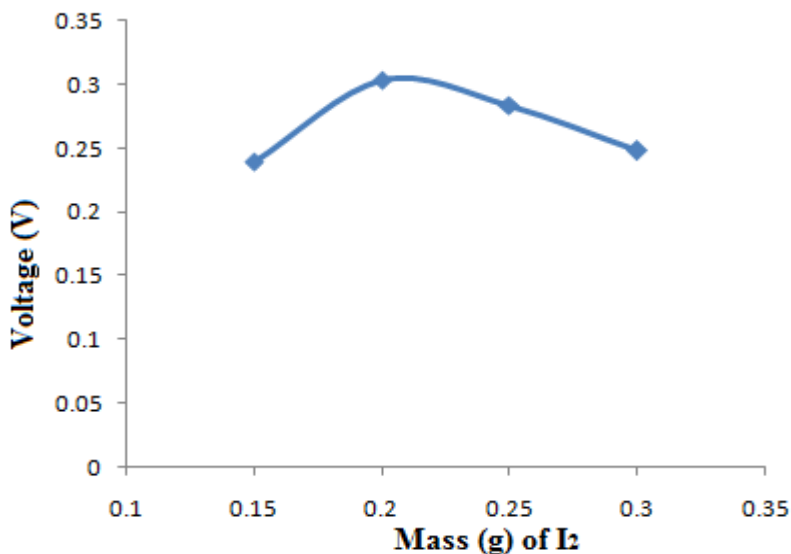
The result shown on Figure 6 is a general profile with increase in potential up to 0.304 V at a mass of 0.2 g. The voltage then decreased uniformly to 0.248 V when the iodine content was varied to 0.3 g. This showed that these ratios were nearing the optimum values of ratios which almost produced a uniform plateau with very small deviations. From the profile of figure 4.3, the resistance of the cell seems to have reduced drastically to indicate that the constituent ratio of the cell components enabled the migration of the charged species to generate almost a uniform open circuit voltage.

These results shows that there is an increase in potential with increase in the mass of iodine up to 0.2 g after which there was a drop in potential with further increase in the mass of iodine. Higher amounts of photo active material increase the charge density of TiO_2 which in turn increased the rate at which the electrons reached a recombination site (Martin, 2012). This observation was attributed to the increased quantity of TiO_2 which

on irradiation, a higher number of charge carriers were generated and migrated through the external circuit.

Further investigations were done on cells K, L and M made with mass cells ratios of iodine (I_2) varied as presented in Table 4. The mass ratios of the photo active material (TiO_2) and graphite-C_X were held constant at (0.9 g) and (0.36 g) respectively, as the composition of TiO_2: graphite (C_X): I_2 of the cells were varied in the mass ratios of (0.9: 0.36: 0.1), (0.9: 0.36: 0.2) and (0.9: 0.36: 0.3), respectively.

Table 4: Effect of Variation of Iodine Masses of Cells K, L and M on V_{OC}

Cell	Mass (g)				Voltage (V)
	TiO_2	KI	C_X	I_2	V_{OC}
K	0.9	0.01	0.36	0.1	0.2
L	0.9	0.01	0.36	0.2	0.6
M	0.9	0.01	0.36	0.3	0.3

From the information recorded in Table 4 a graphical presentation of potentials (Voc) against the masses of iodine was made as shown in Figure 7.

Figure 7: Variation of Iodine Mass Against Potential of Cells K, L and M
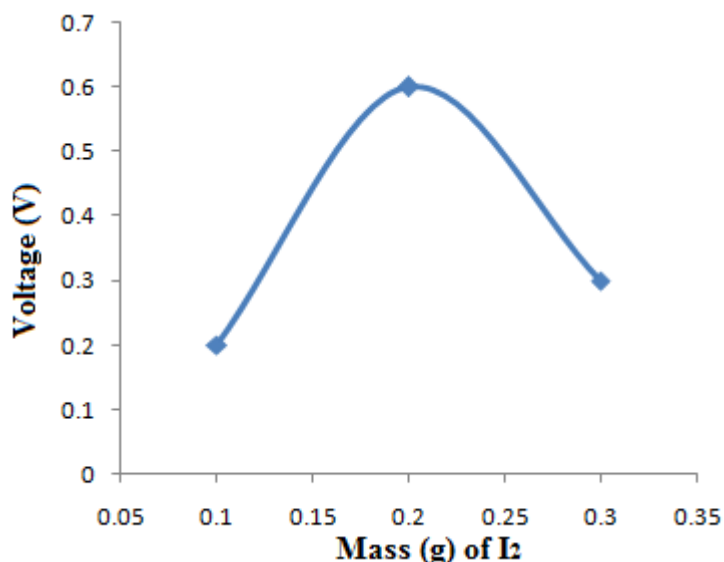
Figure 7 shows a gradual increase in potential with the mass of iodine varied from 0.1g to 0.2g producing the highest open circuit voltage of 0.6 V. The voltage then decreased gradually to 0.3V when the iodine content was varied to a mass of 0.3 g. The mass ratio (0.9: 0.36: 0.2) of TiO_2: graphite: I_2 was thought to exert impact on the conduction band edge (CB) of the TiO_2 and also on the electron recombination, therefore resulting in a higher photovoltaic.

Yordanov (2012) reported that higher iodine concentration leads to extra electron recombination between the injected photoelectron with the I^{3-} ion. This ion replenishes the electrons lost upon absorption of radiation (Yordanov, 2012). However, excess of the I_3^- ion contribute to losses of the photovoltaic performance in the iodine based photocell particularly on the short-circuit photo current density (Gorlov & Mikhil, 2010). Our conclusion based on the results, was that the highest optimization ratios of TiO_2: graphite: iodine which yielded the highest voltage was between (0.7: 0.28: 0.15) with a V_{oc} = 0.956 V to (0.9: 0.36: 0.2) with V_{oc}= 0.6 V. With higher mass ratios of iodine, limitation is less significant, while lower iodine concentration is favorable. The mass ratio of TiO_2: graphite: I_2 (0.8: 0.36: 0.2) generated a potential of 0.304 V. This implies that a mass ratio (0.7: 0.28: 0.15) of TiO_2: graphite: iodine gives a reasonably high output.

Conclusion and Recommendations

A solar cell was successfully fabricated using TiO_2 which is a non-toxic, chemically inert and stable material. The resulting cell was characterized in clear day light. The variation of current generated against its corresponding potential for the various cells was collected and the results obtained indicated that there is potential in the development of the photocell using TiO_2 graphite and I_2 materials in the mass ratios (0.4: 0.3: 0.17) for application at the point of use. These ratios yielded the best results of (V_{OC} = 0.979V, and J_{SC} = 12.037μAcm^{-2}, P_{MAX} = 7.55μW, fill factor (FF) = 0.64 and efficiency (η) = 0.006%). The general trend observed was that increase in the ratio of the photo active material generated higher potential which drastically reduced after the optimized ratio was reached, and the generation of potential reduced considerably. Considerable potential was generated with some ratio of iodine-iodide complex indicating that its presence contributed to generation and subsequent increase in voltage. The highest potential (V_{OC}) of 0.956V was generated with I_2 mass of 0.15 g. There is need to investigate the use of transparent conducting oxide (TCO) as the cathode electrode.

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