Science and Technology for Energy Transition **78**, 26 (2023)

https://doi.org/10.2516/stet/2023024

Available online at:
stet-review.org

REGULAR ARTICLE OPEN ACCESS

Titanium dioxide Ag NP enhanced solid solar cell electrodes for favourable efficiency

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Received: 15 February 2023 / Accepted: 29 August 2023

Abstract. Population growth leads to a heightened demand for working potential to support modern commercial and residential evolutions. Available conventional energy sources, however, cause environmental pollution and severe health problems like global warming. The current energy sources also face challenges due to factors like global warming that make hydro-generated energy production even more difficult due to droughts. Therefore, alternative energy options need to be explored. The study in question aimed to find a cost-effective and environmentally friendly energy source by fabricating a solar cell that uses titanium dioxide and potassium iodate (mixed in carbon) layers in a solidified structure. TiO_2 was chosen due to its photo-generating properties and synthetic steadiness over a spread acidity/basicity neutrality. The iodine/iodide complex was used to replenish the photo-excited electrons while graphite facilitated their migration. The researchers varied the ingredients capacities for the separate electrodes keeping the rest unvaried for improved (I-V) terminal parameters. Deduction from the research established that the (0.4:0.3:0.17:0.01) TiO_2/C_X:I_2:KI proportions resulted in the optimum charge range generation. The inclusion of potassium iodate (KI) improved iodine solvability and facilitated even dispersal in graphite, which was maintained at 0.01 g in all cells. The absorber and receptive layer thicknesses of 2.00 mm and 1.00 mm respectively generated the best 0.979 V open-circuit voltage (V_{oc}) and 12.037 μA short-circuit current (Isc) results. Favorable (10.46%) efficiency (η) and (0.64) fill factor (FF) were derived. Conducting transparent glass was suggested for improving the linkage to the external circuit and models of reducing air pockets in the solid TiO_2 photovoltaic devices could further enhance their performance.

Keywords: Titanium dioxide (TiO_2).

1 Background information

Population growth leads to a heightened demand for working potential to support modern commercial and residential evolutions. However, most current energy sources cause environmental pollution, including global warming and serious health issues. The situation is compounded by problems such as droughts that affect hydro-generated energy sources. Therefore, alternative energy solutions must be explored. This study aimed to create a non-corrosive and environmentally friendly solar cell that does not emit harmful fumes, providing a clean source of energy.

1.1 Responses to the solid TiO_2 solar cell layer variations

Varied cross-sections of the solid TiO_2 solar cell layer have a significant impact on its optical properties (Naqvi, 2013). Modifying the thickness of the electrodes affects the effective band gap edges of the TiO_2 sandwiched material, potentially improving charged particle generation. A research Kavita (2011) reported that uniform realignment of charged particles in photovoltaic devices resulted from the absorbed energy dynamics and film electric tensions. Samples of three different cross sections had similar responses with Kavita inferring that thicker layers interface affecting diffusion of photon energy, leading to lower potential (Kavita, 2011; Zhang, 2013).

Grätzel (2009) highlighted the significance of coating graphite onto the conductive side of Dye-Sensitized Solar Cells (DSSC) as a crucial step in its fabrication. The researcher sought to examine the relationship between the receptive layer cross-section and the parameters generated by the DSSC. Grätzel (2003) observed that the graphite-based receptive layer could have a significant impact on the output parameters of the solar cell. The research first involved designing a blank solar cell as a control experiment to establish the effect of graphite layer void as a receptive side. This was used as a comparison to the complete graphite layer. The thickness of the carbon-based receptive

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electrode was varied with proportionate regulation of the waxed rush light sourced duration ensuring minimum random error by using a candle with minimal light fluctuation. The disparity in the different cross-sectional areas of the moderated carbon electrode could be confirmed by their varying coloring complexion. However, it was noted that an iodine-moderated carbon electrode was necessitated for the dye-sensitized solar cell to generate potential while overboard cross sections had dismal cell performance.

The initial Titanium dioxide solar cells were fabricated by O'Regan and Grätzel (1991) using liquid TiO_2 solutions. Exaggerated TiO_2 cross-sectional area electrodes reduce the cell's output by impeding radiation penetration (Ahmad and Mohamad, 2010). This advancement paved the way for the alternative to silicon-based photovoltaic cells. The TiO_2 liquid-based cell popularly referred to as DSSC, is a low-cost simple manufacturing process with a 12% reported overall conversion efficiency (Wasiu, 2017). However, it is susceptible to corrosion from oxygen and the aqueous environment. The current study aims to address this issue by exploring the principles of the dye-sensitized solar cell while avoiding the use of aqueous media to minimize corrosion.

1.2 Identified gap

Hydroelectric power sources have been impacted by global warming and climate-changing trends, leading to submerged rainfall and lower aqua lines, resulting in decreased electricity production. Furthermore, the use of fossil fuels has led to environmental pollution with negative health consequences. In rural areas of Kenya, where many homes lack high voltage power lines supply, the basic essential lighting is often sourced from through use of ordinary tin lamps or paraffin lamps. However, the combustion of these fuels releases toxic fumes causing respiratory issues. Solar power offers a viable alternative to these traditional sources of energy. Impurity-enriched TiO_2 stimulated by natural solar emissions and iodate-enhanced carbon for charge carriers dispersion conductors are appropriate substances for creating a sun radiation-dependent voltage-generating compartment. The challenges of elevated electricity prices motivated the researcher to explore alternative options for generating electricity. The study aimed to develop a TiO_2 powder potential generating compartment sandwiched with carbon/iodate complex for solar cell applications. This was intended to enrich the renewable energy devices void of chemical emissions and reduce downgraded properties.

2 Methodology and materials

Scientific experimentation was applied to evaluate the upgrading of the intended solar cell. The optimal values of the observed output characteristics were used to establish the best performing solar-dependent compartment: absorber layer substance, carbon enriched with iodate (for electrons replenishment) charge transmission channel. Masses of the constituent materials were varied, and the final solar cells were characterized under the normal daylight environment. The research undertook the underlined inferences:

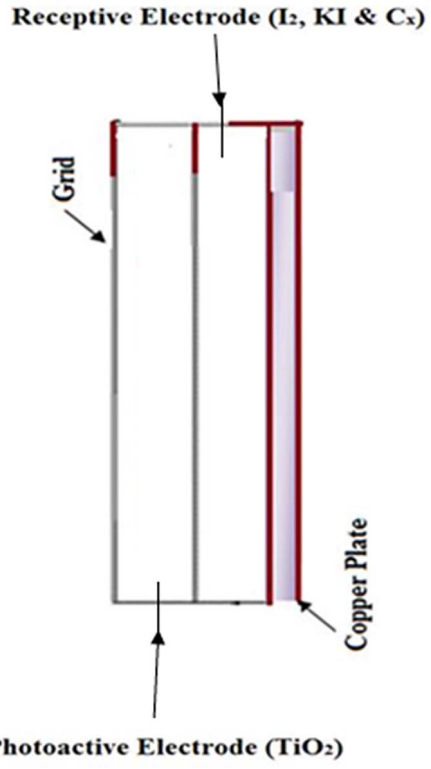

Fig. 1. Schematic presentation of the fabricated solar cell.

uniformly distributed sun energy at 1000 W/m^2, uniform solar density on the cell, and negligible voltage drop in digital meter leads. Empirically justifiable standard reagents were obtained from Sigma Aldrich. The (TiO_2) photo is active together with (I_2) for electron replenishing (KI) for solubility enhancement, and carbon materials were used in their miniaturized particles' solid states. The solar cell was made by mixing and compressing various weight proportions of carbon (C_X), photoactive material (TiO_2), solubility enhancement (KI), and electron replenishment (I_2) to form a solar cell. The fabrication is depicted in Figure 1.

A 2.5 cm × 2.5 cm copper plate was cut with metal plate shears for the required dimensions. An active cell with a diameter of 1.291 m ($A = 1.309$ cm^2) was mounted on the Cu plate and covered with a transparent past. A circular copper material was drawn through the transparent paste for external connection and made in contact with the upper electrode.

The process of creating the first electrode involved placing the photoactive material into a circular dice, which was then compressed. For the second electrode, a mixture of carbon and iodate was placed on top of the first formed electrode, which was then pressed to form a circular pellet serving as the photoactive cell. The performance of the cells was monitored using prepared *I-V* characteristics equipment. The fabricated light-sensitive layer was formed by using varying amounts of TiO_2 powder, between the limits of 0.21–0.9 g. The resulting compressed spherical-shaped cell had a radius of 0.65 cm.

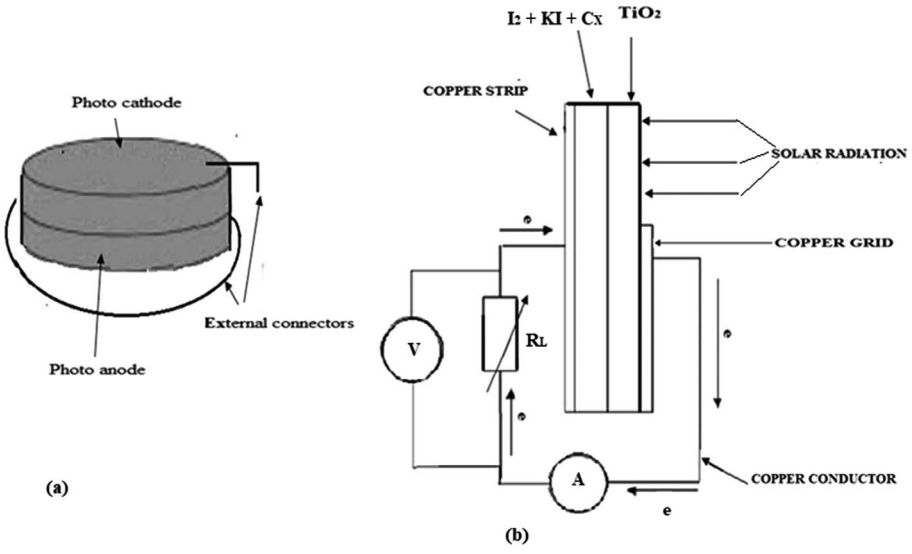

Fig. 2. (a) Spherical shaped cell. (b) Assembly of the *I-V* characterization circuit.

Preparation of the receptive layer involved differing carbon iodate mass ratios mixtures in stepping of 0.1 g and 0.01 g to 0.6 g, 0.3 g, and 0.01 g respectively. These mixtures were molded into discs of 0.65 cm radius with spherical shape pellets. The resulting receptive electrode together with the photoactive electrode was compressed using molding dice to form the entire light-responsive cell. Figures 2a and 2b show a sketch of the fabricated solar cell and the external conductors connection for optimum current-voltage measurement.

The (0–10) A scale high-resolution digital multimeter was used to record the generated charge carrier density output migrating from the light-sensitive layer to the receptive electrode of the fabricated solar cell. A similar (0–250) V was terminated across a potential in series with the cell and was used to confirm the potential (V_{OC}) due to the absorbed solar radiation. The high resolution (0–2.73 KΩ) potential connected in the cell *I-V* characterization circuit generated the data applied to determine the P_{MAX} and fill factor (FF) of the solar cell. The short-circuit current and open-circuit voltage were observed at a 4-minute time constant to derive the power conversion efficiency (η) cell parameter.

Table 1 shows the parameters derived from the 0.65 cm radius cell *I-V* characteristic properties as applied by Adegbenro (2016), who explored a 0.5 cm radius spherical solar cell.

The photoactive area of the cell in the study was 1.327 cm^2. The parameters were calculated using the expressions from Adegbenro (2016) who characterized different shapes and states of solar cells.

The potential observed in the absence of an external load indicated the highest potential (V_{OC}) generated by the solar cells when its terminals are isolated at negligible charge carrier migration (Herman, 2002; Jain, 2013). In such instances, the circuit resistance is at its maximum. That indicated the light-dependent accumulated potential readily available for initiating charge migration (Hagfeldt *et al.*, 2010). A study by Jain (2013) reported that the potential in a defined unit area of a solar cell in similar environments indicated a potential energy limit to necessitate the commencement of charge carrier migration.

Table 1. Derive parameters of the TiO_2 Solid solar cell.

S/No	Parameters derived
1	$V_{MP} = \frac{V_{MAX}}{A}$ (V/cm^2)
2	$J_{MP} = \frac{I_{MAX}}{A}$ (μ/cm^2)
3	$P_{MAX} = V_{MP} \times J_{MP}$
4	$J_{SC} = \frac{I_{SC}}{A}$ (μ/cm^2)
5	$V_{OC}/cm^2 = \frac{V_{OC}}{A}$ (V/cm^2)
6	Fill Factor (FF) $\frac{J_{MP} \times V_{MP}}{J_{SC} \times V_{OC}}$
7	Efficiency (η) $= \frac{V_{OC} \times FF \times I_{SC}}{100} \times 100\%$

3 Results and discussion

3.1 Contribution of cell cross section variation output parameters and power conversion efficiency (η%)

Consequential responses of the light-sensitive electrode varied cross-section area on charge carrier concentration was of crucial consideration (Swapnil, 2016). The proportionate effect of radiation penetration and the cell's resistivity necessitated the study. To achieve optimal results, the optimal thickness had to be determined. The effect of different thicknesses (1, 2, 3, and 4 mm) of TiO_2 in the photoactive layer was observed, and derived parameters were interrogated. Table 2 shows the generated potential (V_{OC}) and power conversion efficiency (η%) resulting from the solar cell.

The results of Table 2 were plotted in Figure 3a and 3b to show their responses in potentials (V_{OC}) against

Table 2. Effect of varying thickness of the optimized solar cells on V_{OC} (V) and η (%).

Electrode (investigated)	Cross-section area (photoactive layer) (mm)	Potential (V_{OC}) (V)	Power conversion efficiency (η%)
Layer four	4	0.497	0.696
Layer three	3	0.562	1.913
Layer two	2	0.979	10.458
Layer one	1	0.833	6.029

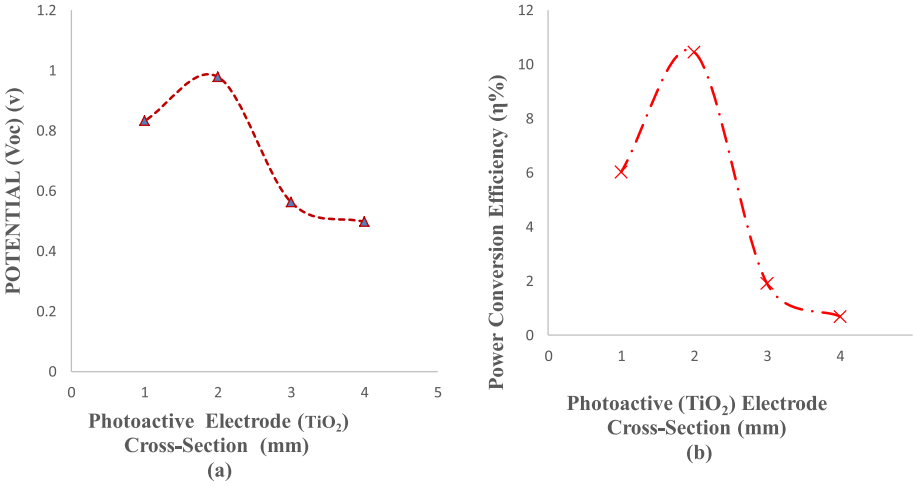

Fig. 3. Photoactive electrode cross section varied against. (a) Generated potential (V_{OC}) V; (b) efficiency (η%).

efficiency (η%) relative to the cells light-sensitive electrodes cross-section area.

The results of Figure 3a indicate a gradual (0.833–0.979) V potential build due to (1.00–2.00) cm varying cell thickness as observed after 4 min in clear daylight. The potential surge was detected to assume a (0.979–0.562) V declining trend with a (2.00–3.00) mm thickness bulge with 0.065 V negligible negative change. That suggested that thicker layers of TiO_2 decrease output by blocking photon transfer. Figure 3b presents efficiency against thickness, with a similar trend to that of potential. The 2.00 mm presented the most improved 10.458% as the thickest 4.00 mm had 0.696% power conversion efficiency (η). A study by Sundaram (2009) indicated that the effect of thickness variation had a consequential proportionality of the potential for efficiency response of the cell. That implied that to achieve improved potential and efficiency, there must be a balance between light penetration and cross-sectional area to moderate charge carriers' excitation (Imran, 2013). A study by Jain (2013) reported that a cell's resistance to radiation had a congruential response to thickness with a proportionate current flow.

4 Conclusion and recommendations

The thickness of 2.00 mm (photoactive layer) for the development of solid TiO_2 solar cells due to radiation penetration. A thickness 1 mm photoactive layer was also preferred for moderately better (0.833) V potential and power conversion efficiency. Further research is recommended using TCO as a cathode and reducing air pockets in the cell.

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