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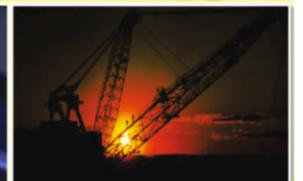
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## Improving the Efficiency of Titanium Dioxide Based Dye Sensitized Solar Cell (DSSC) using Silver Surface Counter Electrode

Charity, S.O.<sup>1</sup>, Ayodeji, O. A.<sup>2</sup>

1. Electrical Electronics Engineering Department, Federal University of Technology P. M. B 704 Akure Nigeria.
2. Department of Pure and Applied Physics, Ladoko Akintola University of Technology Ogbomoso Nigeria.

### A B S T R A C T

#### Keywords:

Sensitized, electrode, Counter electrode, Titanium dioxide, efficiency

*The high cost of processing crystalline silicon for solar cell has shifted research focus to cheaper materials for solar cell production. Although a variety of advanced approaches to solar cell are being investigated, dye sensitized solar cell (DSSC) is expected to offer one of the lowest manufacturing costs in the future because of its simplicity and use of cheap materials. However, the major challenge being faced in DSSC technology is its low efficiency. In an effort to improve the performance of DSSC, this work focused on the use of a silver surface glass for the counter electrode instead of the transparent glass which is normally used. Two solar cells were produced based on Gratzel method. In the first one, both the working electrode and the counter electrode were made of transparent conductive glass substrate. In the second cell, the titanium dioxide was coated on a transparent conductive glass electrode substrate to form the working electrode while a silver surface glass was used for the counter electrode. Teak extract was used as the organic dye sensitizer and potassium iodate as the electrolyte. The solar cell was then illuminated and tested. The results of the performance evaluations carried out show that the cell with silver surface counter electrode has an improved efficiency of about 400%. The result of the study therefore shows that the conductivity of the counter electrode material has effect on the performance of DSSC.*

### 1. Introduction

Different methods of generating electric energy include generating plants such as - thermal or steam generating plant, fossil-fueled plant, nuclear plant, and hydro-electric plants. Owing to population growth, these sources of energy which are non-renewable are being rapidly depleted (Shitta et al 2008). This is what led to the insufficient power supply to the national grid as being experienced especially in developing countries of the world. Therefore, there is a need for renewable energy which can sustain the rate of growth in the population of the world. Among all the renewable energy sources, solar energy is the most promising being the most abundant. Silicon solar cell which is presently the main source of solar to electric energy conversion is being faced with the challenge of high cost of production. Hence dye sensitized

solar cell since its discovery in 1972, has drawn the attention of researchers mainly due to its cheap and available material components (EIA 2016). In the investigations into the photovoltaic properties of some African dyes, researchers observed that there are natural dyes of African origin which have potential for use as sensitizers in DSSC (Shitta et al 2008). DSSCs were made in 2014 where the photoelectrodes were sensitized with coffee natural dye extract. Although there were promising results but the efficiencies were generally low (Moe et al 2014). The major challenge facing DSSC technology to date is the problem of low efficiency.

Dye sensitized solar cell operates by absorption of photon from the sun. This type of cell is classed as photo-electrochemical cell. The dye-sensitized semiconducting oxide on a transparent conductive glass substrate is the photo-anode or working electrode while the return path for the electrons flowing through the load is the counter electrode (Awodugba and Olabisi 2013). It is projected to be

a low-cost third generation photovoltaic cell whose principles of operation depend on the semiconductor formed between a photo-sensitized anode and an electrolyte (Pablo et al 2014). In DSSC, the liberated electrons flow through the conductive photo anode substrate to the load and return through the counter electrode and the cycle continues (Christies 2001) and (Sitta et al 2008)

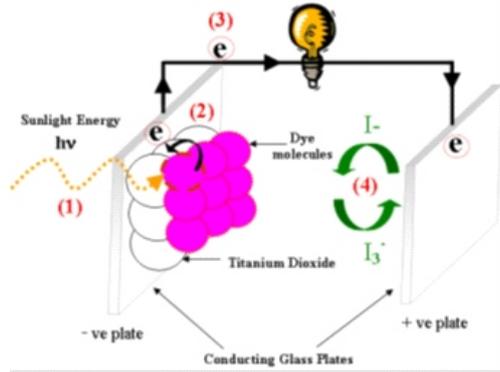


Figure 1. Principle of operation of Dye Sensitized Solar Cell, (Christies 2001)

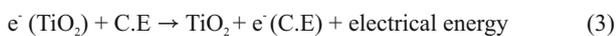
Generally, the operational steps of DSSC usually involved four stages. In the first stage, there is absorption of photons into the dye molecules from the light source. In the second stage, the dye molecule becomes excited and released an electron into the conduction band of the semiconductor. Hence, the dye becomes oxidized and the electron flows to the conductive surface of the working electrode substrate. In the third stage, the electron flow through the load to the counter electrode. In the fourth stage, which is the final stage, the oxidized dye molecule regains back its lost electron from the graphite coated counter electrode with the help of an electrolyte and the cycle continues, (Moe et al. 2014).

In working on ways of improving the performance of a dye sensitized solar cell, the mechanism of dye sensitized solar cell operation was studied. Efforts were made to understand the role played by each of the components of the cell as shown in Figure 1. The electron ejected from the dye as a result of photon absorption is replenished through the iodide ion in the electrolyte. The dye having been oxidized regains its loss electron at the graphite coated counter electrode. This process is represented in Equations (1) to (5), Lung-Chien et al. (2014) & ICE (2007):

If C.E = Counter Electrode

S = Dye

S\* = Excited Dye



This mode of operation of a dye sensitized solar cell as shown both in Figure 1 and in equations (1) to (5) reveal that the counter electrode does not harvest photons but serves as a return path for the electrons to come back in to the cell and the dye to be regenerated. Therefore the necessary feature of a good counter electrode for dye sensitized solar cell is not transparency but good conductivity which is a result of the movement of electrically charged particles. Study shows that among known metals, silver has the highest conductivity  $\sigma$  of  $6.30 \times 10^7$  (S/m) at room temperature (Luttrel et al 2014) and (ECT (2014).

Considering the electrical conductivity of materials, silver shows more prospect than most materials because it has the highest electrical conductivity. Therefore two dye sensitized solar cells were designed and fabricated with different materials as substrate for the counter electrode. The first has its counter electrode made of transparent tin dioxide coated glass slide just as the working electrode. The second cell was made of a Silver coated glass slide as the counter electrode.

## 2. Materials and Method

In carrying out the study, Gratzel method was adopted. The method was modified to achieve a better result. The working electrode substrate used was a transparent conductive glass plate made of fluorine-doped tin dioxide ( $\text{SnO}_2:\text{F}$ ). The transparency is necessary for photon collection while a conductive surface is required to transport the electrons released as a result of the incident photons. The counter electrode is the return path for the electrons flowing from the load back to be regenerated. Two different types of counter electrodes were used for the two solar cells. The first type is the one made of transparent  $\text{SnO}_2$  while the second is made of a silver coated glass. The silver coated glass was obtained by removing the paint covering of a plain mirror leaving a silvery surface. The dye sensitizer was extracted from dry Teak plant. Another important component of the DSSC is the electrolyte. The electrolyte is dissolved in an appropriate solvent and attracted into the intra-electrode space by capillary action; for this work potassium iodate  $\text{KIO}_3$  was used.

About 6.0 g of nanoparticle titanium dioxide was mixed with 9 ml of acetic acid in a mortar while grinding with pestle to break the  $\text{TiO}_2$  aggregates that may have been formed because of the packaging. A drop of surfactant like colourless detergent in 1ml of distill water was added and ground gently. This helps to produce a uniform and lump-free suspension. The conductive side of the

working electrode was cleansed with ethanol and two third coated with the Titanium dioxide paste by doctor blade technique (Simon 2014), (Padlo et al 2014). After coating, the set up was sintered at about 450°C for 30 minutes in an electric furnace to produce the electrode. The electrode was then placed faced down in a filtered dye solution and allowed to soak the Titanium dioxide surface for about five minutes.

The conductive side of the counter-electrode (the silver surface glass) was cleansed with ethanol and coated with graphite. This is gently placed face down on the Titanium dioxide coated part of the working electrode so as to offset leaving about one third of the conductive surface exposed on both the electrode and the counter electrode. The electrode and the counter electrode are then held firmly together with two alligator clips as shown in Figure 3. One or two drops of the electrolyte was introduced at one edge of the slides and was allowed to spread by capillary action, after which the edges were cleansed and waxed to prevent excess air infiltration. The assemblage was then tested with the non-conductive side of the working electrode facing the light source for photons collection. The conductive side of the working electrode was the positive terminal while that of the counter electrode was the negative terminal. This process is represented in the block diagram shown in Figure 2. The images of the two solar cells are as shown in Figure 3.

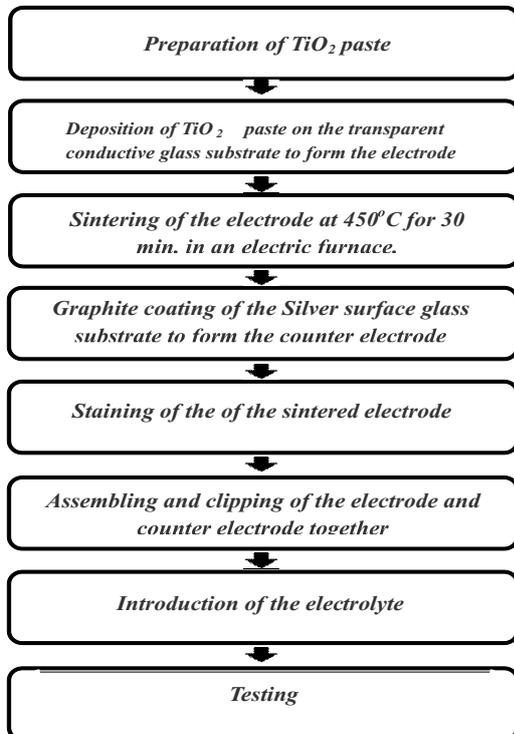


Figure 2. The block diagram of the production of the dye sensitized solar cell (DSSC)

### 3. Results and Discussion

After coupling, the two solar cells were tested under the same condition. A highly sensitive Fluke digital multi-meter was used in measuring the electrical parameters - open-circuit voltage ( $V_{oc}$ ) and short-circuit current ( $I_{sc}$ ). A light intensity of 100mW/cm<sup>2</sup> representing A.M 1.5 solar radiation illuminated the solar cells. In addition, the efficiency and the fill factor of the solar cells were computed as given in the Equations (6) and (7) Mehood et al (2014) and presented in Table 1

$$n = \frac{V_{oc} \times I_{sc} \times ff}{P_{in}} \times 100\% \quad (6)$$

where  $P_{in}$  = incident light power

$$\text{Fill factor, } ff, \text{ is: } ff = \frac{V_{max} \times I_{max}}{V_{oc} \times I_{sc}} \quad (7)$$

where  $V_{max}$  and  $I_{max}$  represent the voltage and the current at the maximum output power point respectively.

The two solar cells were fabricated by the same method and tested under the same illumination. The current-voltage relationship of the two DSSCs as shown in Figure 4 compares the output of the two cells. The open circuit voltage increased from 36 mV obtained from the DSSC with the transparent conductive glass counter electrode to 660 mV in the DSSC with silver surface counter electrode. Likewise the maximum short circuit current obtained in the DSSC with the conventional (transparent glass) counter electrode was 0.18 mA whereas, the short circuit current of up to 0.38 mA was recorded when a silver surface glass was used for the counter electrode.

The light conversion efficiencies of the solar cells were computed as shown in Table 1. The results shown in Table 1 and Figure 4 have revealed clearly that the counter electrode is a major determinant of the efficiency of a DSSC. It has also been shown that silver surface glass performs better as counter electrode substrate than the fluorine doped tin oxide transparent glass. This study has equally revealed that the choice of the material for counter electrode substrate should be based on the conductivity and not transparency in other to improve DSSC efficiency.

### 4. Conclusion

This study has shown that the efficiency of DSSC has been improved by using a silver surface glass for the counter electrode instead of the fluorine doped tin oxide transparent glass. The solar cell parameters like the open circuit voltage and the short circuit current increased considerably leading to a wide improvement in the efficiency from 0.06 % to 2.6 %. This represents over 400 % improvement in the efficiency.

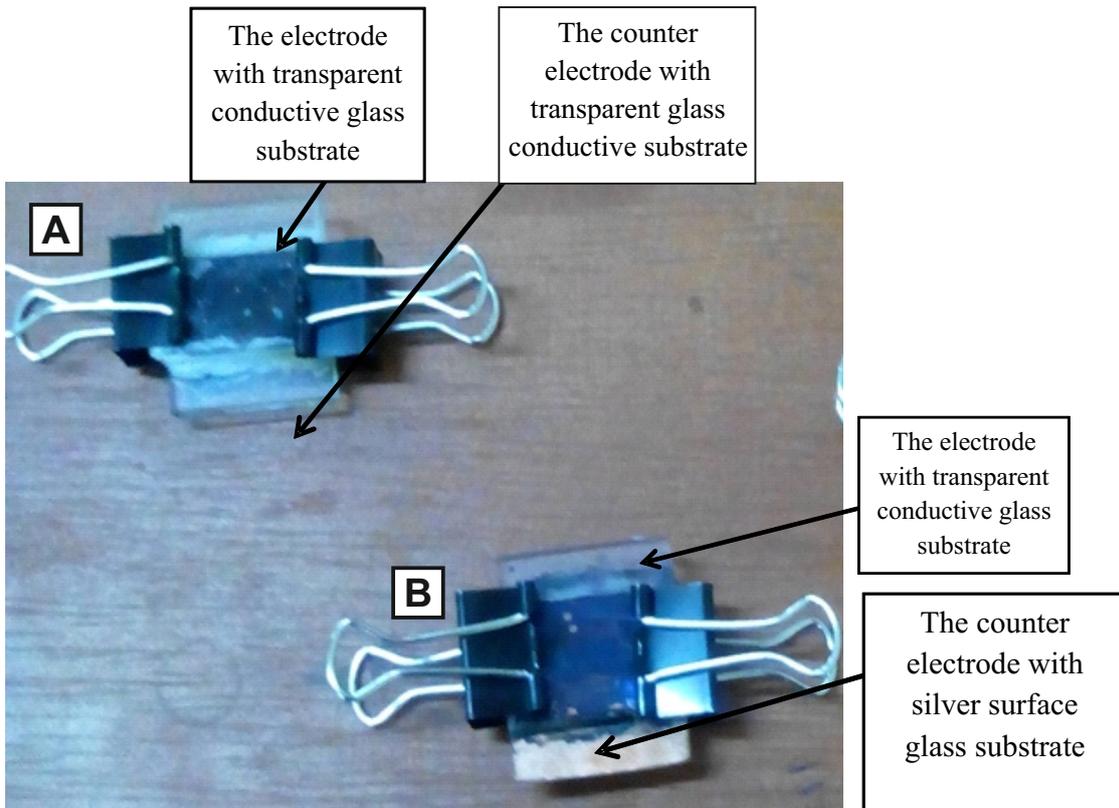


Figure 3. The two solar cells after production:  
 A - The DSSC with transparent conductive glass counter electrode  
 B - The DSSC with silver surface glass counter electrode

Table 1. The summary of the solar cell parameters obtained from the two cells.

Type of Counter Electrode	Dye	Sintering Temp. (°C)	Light Intensity (mW/cm <sup>2</sup> )	V <sub>oc</sub> (mV)	I <sub>sc</sub> (mA)	FF	Efficiency (%)
Transparent SnO <sub>2</sub> coated glass	Teak	450	100	36.00	0.18	0.99	0.06
Silver coated glass	Teak	450	100	660.00	0.38	1.04	2.60

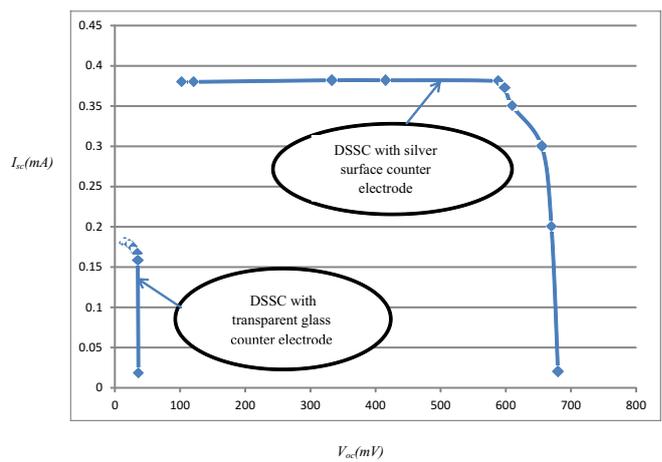


Figure 4: Current – voltage relationship for the two solar cells

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