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Yumbo Tumtum as a Photosensitizer in the Fabrication of a Dye-Sensitized Solar Cell

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Abstract
A dye-sensitized solar cell (DSSC) was fabricated using a natural dye Yombo-tumtum (YT) as the photosensitizer. The solar cell configuration include a transparent conducting oxide (TCO) (Fluorine-doped tin oxide coated glass or FTO/glass) substrate as the transparent electrode, Zinc oxide (ZnO) as anode, YT as the sensitizer, iodide/triiodide (I^-/I_3^-) as the electrolyte, and platinum coated FTO/glass as counter electrode (cathode). The absorption spectrum of the dye (YT) was investigated by uv/vis spectroscopy, and it revealed high absorbance property within the visible region (400 - 700 nm). Fourier transform infrared (FTIR) spectroscopy carried out on the dye (YT) showed its infrared spectrum and revealed the functional group of the dye with major peaks at 3340.71, 2970.38, 1647.21, 1159.22 and 948.98 cm^{-1}. The photoelectric values obtained under illumination was 31.5mV and 7.5 μA which dropped to17.6 mV and 2.0 μA when the cell was partially covered, indicating the photosensitivity of the device. The current - voltage characteristic values were obtained for the cell fabricated using the dye and the fill factor and the efficiency obtained were 0.5473 and 4.7 x 10^{-3}%.

Keywords: DSSC, Yombo-Tumtum, Zinc oxide, Absorption spectrum, Efficiency

1. Introduction

Dye sensitized solar cell (DSSC) fabrication research was pioneered by Regan and Gratzel (1991). It is an emerging solar energy conversion technology, promising, attractive, cost effective and with a viable conversion efficiency of over 10 % (Ito *et al*., 2007). Silicon based solar cell though have relatively high and large market share today, they are however expensive to process (Guangchao *et al*., 2014). DSSC is a photoelectrochemical system, based on wide band gap nanocrystalline semiconductor oxide (e.g. TiO_2, ZnO, SnO_2, Nb_2O_5,

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etc.) porous film electrode (deposited on a transparent conducting oxide (TCO)), dye sensitizer, electrolyte and a counter electrode (Suri *et al*., 2007).

In DSSC, the light absorption and the separation of the electrical charges happens in different processes. The light absorption process is performed by the dte molecules and the separation of the electrical charges is done by the nanocrystal inorganic semiconductor (Maheswari and Venkatachalam, 2013). The photoexcited electrons in the dye sensitizer are injected into the conduction band of the nanocrystalline semiconductor. The performance of the DSSC depends on a factor such as the absorption efficiency of the dye sensitizer for the visible light range (El-Shishtawy 2016). Yombo-Tumtum (YT) is a rock-like black mineral and natural dye which can be obtained from a local market in Ilorin, Nigeria whose original source was traced to the coastal region of Ghana (Adebayo et al, 2006). One of the fundamental characteristics of an effective photosensitizer (dye) is that its absorption spectrum should cover the whole visible region and even the part of the near-infrared (NIR) and the photosensitizer should have anchoring groups (carboxylate (-COOH), phosphonate (-H_2PO_3) or hydroxamate (-SO_3H)) to strongly adsorb/bind the dye onto semiconductor surface (Grätzel 2003).

Ruthenium Polypyridyl complexes are very effective sensitizer because of their strong charge transfer absorption in the visible region. However, they have environmental shortcomings and their preparation is complicated and not cost effective. Therefore, a natural dye, which is rightly available, cheap and effective such as Yombo-Tumtum is considered an alternative to ruthenium polypyridyl complexes in this work.

The use of YT as a photosensitizer in the fabrication of DSSC in this work was attributed to its UV-Visible absorption spectrum (Figure 3), which has high absorbance values in the visible region (400 - 700 nm) as well as the FTIR spectrum (Figure 4) which reveals the presence of needed anchoring groups.

2. Materials and Methods

The substrate (FTO/glass) was washed with detergent, rinsed thoroughly with distilled water and was ultrasonically agitated in isopropyl alcohol (IPA) for 15 minutes and then dried in air. 30mL of IPA and distilled water (15mL each) solution was added into 50mL beaker and 4% by mass of the solution volume was used to measure the mass of zinc oxide which was added to the solution. The resulting mixture was stirred for 40 minutes on a magnetic stirrer and was then heated at 90°C on a hotplate, until the mixture turned milky.

The ZnO paste was deposited on the conducting surface FTO/glass substrates by doctor-blading. This process involved the use of cello tape to hold down the substrate's two opposite edges on a flat surface while glass slide is used to spread and blend evenly the milky ZnO paste on the exposed substrate surface to thickness level of the cello tape, thus removing excess ZnO paste. The as-deposited ZnO film was heated on the hotplate at 100°C for 1 hour, and was thereafter annealed in an oven/furnace at 500°C for 1 hour. The as-deposited ZnO film was allowed to cool down to room temperature before it was removed from the oven/furnace (Amal Al – Kahlout, 2015)

The mineral dye (Yombo-Tumtum) was dissolved in an isopropyl alcohol to form a solution shown in figure1, in which the as-deposited ZnO film was immersed and left to soak for 24 hours, the dye is anchored and adsorbed on the large band semiconductor (Hao *et al*., 2006).

Figure 1: Yombo-Tumtum prepared using Isopropynl Alcohol

Assembly of the Yombo-Tumtum based Dye Sensitized Solar Cell

The as-deposited ZnO film on the FTO/glass substrate photosensitized by YT (serving as the photo electrode), and the platinum coated FTO/glass substrate (serving as the counter electrode) were clamped together and the electrolyte (iodide/tri-iodide) was injected in between them using a syringe. The DSSC assembly is as shown in Figure 2.

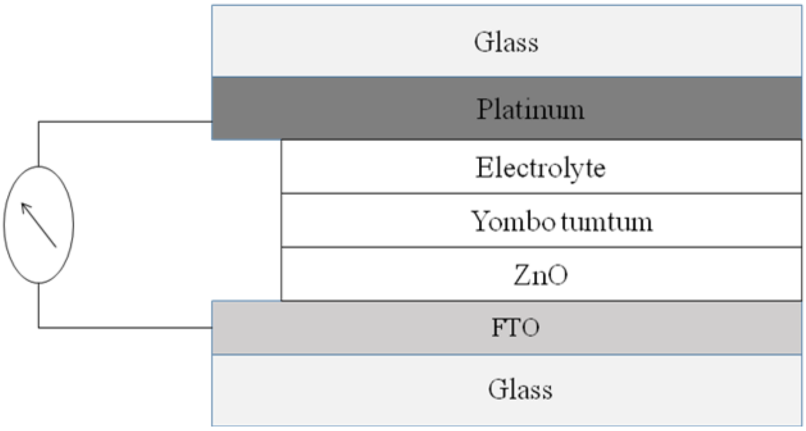

Figure 2: Assembly of the dye-sensitizer solar cell (DSSC)

3. Results and Discussion

3.1 Optical Analysis of the Dye

The optical properties of the dye (YT) was investigated using UV-Visible spectrophotometer.

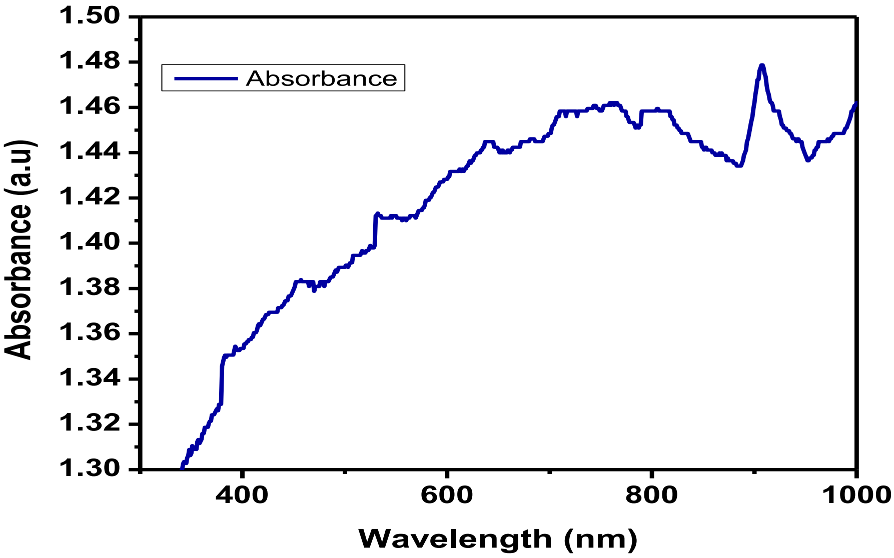

Figure 3: Absorption Spectrum of Yombo-tumtum

The absorption spectrum of YT using Isopropyl alcohol is as shown in Figure 3. It can be seen that the YT has high absorbance property in the visible region (400 - 700 nm), even tending towards the infrared region (above 700nm), making it a suitable photosensitizer for DSSC. This indicates that the solar energy will be well trapped by the dye, which is expected to enhance the performance of the cell, making the mineral dye YT a suitable dye for the DSSC fabrication. This is comparable to one of the ruthenium-based molecular dye ([Ru(4,40-dicarboxy-2,20-bipyridine)2(NCS)2] or N3 dye) (Kong et al., 2007).

3.2 Functional Group Analysis of the Dye

The FTIR spectrum of YT (Figure 4) obtained from the FTIR spectroscopy showed characteristic peaks at 3340.71, 2970.38, 1647.21, 1159.22 and 948.98 cm^{-1} which confirm the presence of certain functional groups. A broad absorption band at 3340.71 cm^{-1} is due to the O-H stretching frequency of absorbed water. The band at 2970.38 cm^{-1} is the C-H stretching vibration which indicates the presence of alkane (sp^3) stretching vibration functional group. The absorption band at 1647.21 cm^{-1} is assigned to the bending mode of H_2O molecules.

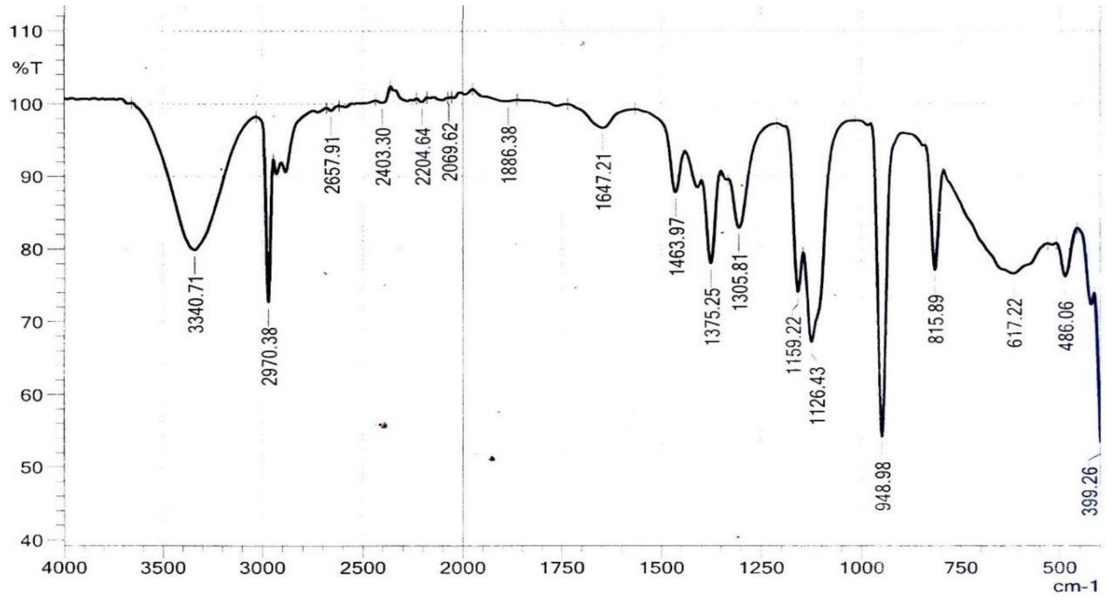

Figure 4: FTIR Spectrum of Yombo-Tumtum.

The band at 1159.22 cm^{-1} corresponds to the C-H bend of the alphatic functional group. The general range of 3100 – 3600 cm^{-1} may be assigned to anti – symmetric and symmetric O-H bonding stretching vibration modes of water of hydration. These functional groups will contribute immensely to the effectiveness of Yombo-tumtum, both in the absorption strength of the dye and its adherence to the semiconductor.

3.3 Photoelectric Values of the DSSC

3.3.1 Direct Measurement of the Electrical Output from the Cell

The photovoltage and the photocurrent of the DSSC were measured with a digital multimeter and a galvanometer respectively. Figure 3 shows the photovoltage and the photocurrent readings of the DSSC under partial covering and under illumination and are listed in Table 1.

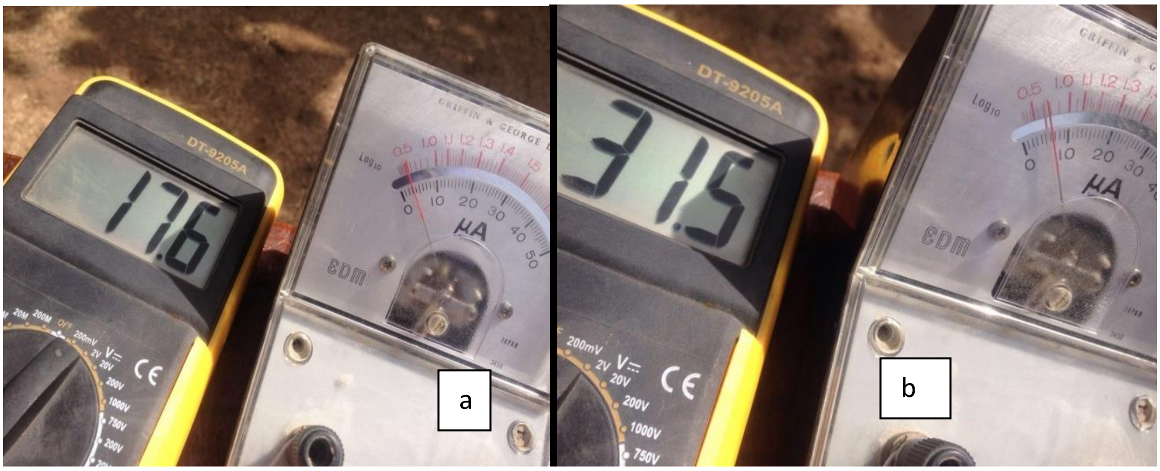

Figure 5: Photoelectric values (a) Under partial covering and (b) Under illumination respectively.

Table 1: Photoelectric values of the DSSC

	Photocurrent (μA)	Photovoltage (mV)
Under Partial covering	2.0	17.6
Under Illumination	7.5	31.5

3.3.2 Measurement of the Electrical Output of the Cell when Voltage is applied

Voltage was applied to the cell under illumination by a sun simulator and the electrical output was measured. The short circuit photocurrent (I_{sc}) was obtained at the point where the graph crosses the current axis and the open circuit photovoltage (V_{oc}) obtained at the point where graph crosses the voltage axis.

The overall energy conversion efficiency (η) is defined as: $\eta = \frac{I_{sc} \times V_{oc} \times FF}{P_{in}}$

Where P_{in} is the power of incident light and FF which is the fill factor is given as: $FF = \frac{I_{max} \times V_{max}}{I_{sc} \times V_{oc}}$

The fill factor of the DSSC was obtained, hence the energy conversion efficiency.

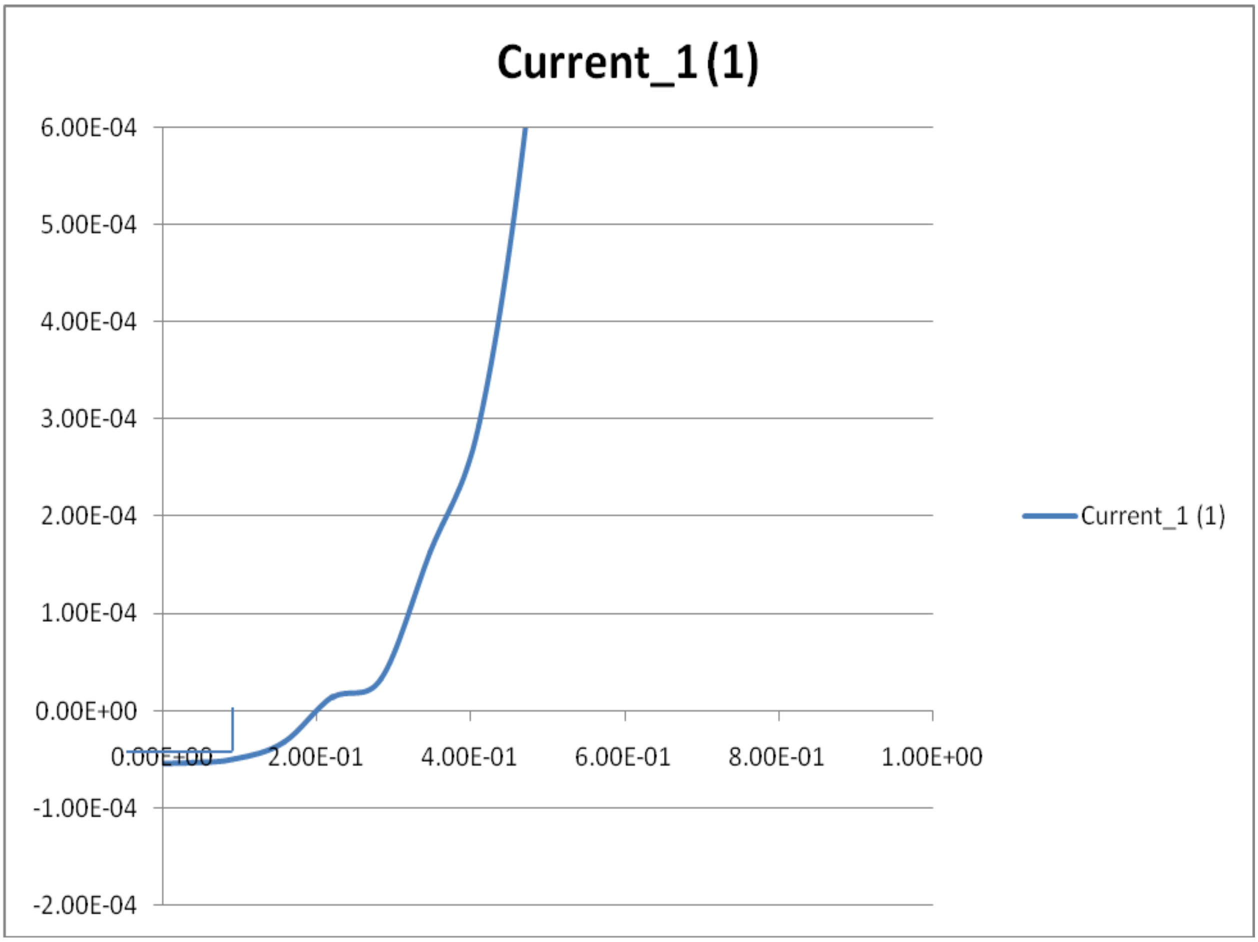

Figure 6: I-V Characteristics of Titanium oxide (TiO_2) based DSSC using Yombo Tum-Tum as the sensitizer

$V_m = 9.46 \times 10^{-2} V$, $I_m = -5.00 \times 10^{-5} A$

$V_{oc} = 1.58 \times 10^{-1} V$, $I_{sc} = -5.47 \times 10^{-5} A$

$FF = \frac{V_m \times I_m}{V_{oc} \times I_{sc}}$, $FF = \frac{9.46 \times 10^{-2} \times (-5.00 \times 10^{-5})}{1.58 \times 10^{-1} \times (-5.47 \times 10^{-5})}$, $FF = 0.5473$

The overall energy conversion efficiency is:

$$\eta = \frac{V_{oc} \times I_{sc}}{P_{in}} \times FF \times 100\%$$

$$\eta = \frac{1.58 \times 10^{-1} \times 5.47 \times 10^{-5}}{100 \times 10^{-3}} \times 0.5473 \times 100\% , \quad \eta = 4.7 \times 10^{-3}\%$$

The conversion efficiency when Yombo Tum Tum was used as the dye for this particular cell is 4.7×10^{-3} %.

4. Conclusion

In this work, a dye-sensitized solar cell (DSSC) photosensitized by Yombo-tumtum (YT), a natural dye, has been successfully fabricated. The absorption spectrum of the dye (YT) revealed its high absorbance property in the visible region and even to the infrared region, and its FTIR spectrum revealed the presence of carbonyl, hydroxyl and amines (important functional groups required for the adsorption of the dye on the semiconductor) making YT a suitable photosensitizer for the fabrication of DSSC. The photoelectric values of the DSSC under partial covering and illumination were obtained to be (2 µA, 17.6 mV) and (7.5 µA, 31.5 mV) using a digital multimeter (DMM) and a galvanometer giving definitive evidence to the use of YT as a photosensitizer in DSSC. I-V characteristic values were obtained for the cell fabricated using the dye and the fill factor and the efficiency obtained were 0.5473 and 4.7×10^{-3}%.

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