

Optical and electrical properties of fabricated dye sensitized solar cells based on extract from bush tea (*hyptis suaveolens*).

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Abstract

Dye sensitized solar cells were successfully fabricated using deionized water and ethanol to extract natural dye from Bush tea (*Hyptis Suaveolens*). Nanocrystalline titanium (iv) oxide (TiO_2) (solaonix SA) was deposited on the working electrode by Dr. Blade method and Platinum catalyst was deposited on the counter electrodes using screen printing method. The optical properties of the solar cells were investigated using Ava Spec-2048 UV/Visible Spectrophotometer. Electrical properties of solar cells were characterized using Oriol Class A Solar Simulator. The I-V characterization of the cells was measured in dark and illumination intensity and the illumination intensity used was at 100 mW/cm^2 . Under illumination intensity the open circuit voltage (V_{oc}) was 0.520 V, short circuit voltage (I_{sc}) was 0.287 mA, fill factor was 0.629%, and maximum power point is 0.092 mW with a conversion efficiency of 0.092. Under dark intensity (no halogen lamp), the open circuit voltage (V_{oc}) was -4.24×10^{-1} V, short circuit voltage (I_{sc}) was -0.0016 mA, the fill factor was -6.846%, maximum power point was 0.003 mW with an efficiency of 0.003.

Keywords: dye sensitized, solar cells, Nanocrystalline Titanium

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I. Introduction

One of the greatest problems in the developing countries is the challenge in energy supply. This is as a result of rapid increase in human population, improved living standards, vandalisation of high voltage power lines, inadequate and poor equipment (Grid line), lack of maintenance and facilities. In order to eliminate these challenges, a steady source of energy supply has to be generated. There are two sources of energy: Nonrenewable and renewable energy (O'Regan and Grätzel, 1991).

Nonrenewable source of energy is generated from fossil fuel (coal, oil and natural gas). However, there are concerns on maintaining the usage of fossil fuels as the main source of energy. This energy from fossil fuels has some numerous disadvantages; first being the limitation of resources, Secondly, the emission of toxic gases such as carbon monoxide (CO) and sulfur dioxide SO_2 , which contribute to acid rain and global warming (O'Regan and Grätzel, 1991).

According to Grätzel (2009), the worldwide power consumption is expected to double within the next 30 years. The availability of energy is not only necessary for people in their daily life activities; it is also among the major driving forces of the global economy (Lewis *et al.*, 2006).

Renewable energy is energy that is harvested from renewable resources which can be used over and over again (Ellabban *et al.*, 2014). This energy resource includes solar, wind, geothermal energy, biomass and hydropower energy. They generate clean, noise free, affordable, and easy to produce energy.

Solar energy is one of the renewable energy, which is originated from the sun. In fact, several of the alternative energy sources used today is derived from solar energy (Boyle 1996). The solar radiation to the earth is approximately 100 000 TW which is almost 10 000 times more than the current energy consumption (Grätzel 2007). The practical global solar potential is about 600 TW (Hagfeldt *et al.*, 2010). This abundance of solar energy makes it very attractive for electricity production.

Photovoltaics (PV) is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors that exhibit the photovoltaic effect. Materials presently used for photovoltaics include monocrystalline silicon, polycrystalline silicon, amorphous silicon, cadmium telluride, and copper indium gallium selenide/sulfide (Jacobson, 2009). Due to the expensive nature of silicon and other materials for the production of solar cells, O'Regan and Grätzel, 1991 developed an unconventional photovoltaic system a process similar to photosynthesis to produce electrical energy has been adopted. This process is known as Dye-Sensitized Solar Cell (DSSC, DSC or DYSC). The interesting features of this Dye Sensitized solar cell include; low cost, toxic free, noise free, it is flexible, it's easy to manufacture and requires little maintenance.

II. Experimental Detail

2.1 Chemicals and materials

The materials used in this research, for the fabrication of dye sensitized solar cells are as follows;

Fluorine doped tin oxide (FTO), Transparent Conductive Oxide (TCO 10-10), soda lime glass (SLG), Bush tea (*Hyptis Suaveolens*), DT 9205A digital multimeter, diamond glass cutter, nose mask, hot air blower, electric hot plate, scotch/masking tape, petri dish, beaker, ceramic mortar and pestle, squeegee, substrate holder, stirring glass rod, hand glove (latex), Carbolite 201 tubular furnace, wooden clamp, film cupboard, de-ionized water, ethanol, zinc oxide, platinum catalyst, hydrogen peroxide, ammonia solution, acetone, methanol, Titanium tetrachloride (TiCl_4), electrolyte, epoxy sealant and separator, con HCl, diluted HCl.

2.2 Identification of conductive side of the fluorine doped tin oxide (FTO)

Transparent fluorine-doped tin oxide (FTO) and soda lime glass (SLG) were used as the substrate. The FTO glasses are only conductive on one side; this conductive side of the glass were determined or obtained with the aid of DT9205A digital multimeter. This was done by placing the cable probe on the surface of the FTO, and the conductive sides were determined by observing some displays or some readings on the digital multimeter.

2.3 Cleaning of the FTO | Soda Lime Glass

The FTO and Soda lime glass were first cut to a size, using a diamond glass cutter, and then cleaned carefully with detergent, water and distilled water in that order. All the substrates were washed with Deconex and a soft sponge to remove dirty particles and as well decrease the surface tension. Immediately after washing of the FTO, some were squint with ethanol while some were rinsed with deionized water to prevent contamination. All the substrates were blown- dry with a hot-air blower for faster drying and were kept in petri dish.

2.4 Dye Extraction

Bush tea (*Hyptis Suaveolens*), which is popularly known as mosquito repellent in Africa which is also used as a medicinal tea in Asia, food and source of essential oil in South America were blended using ceramic mortar and pestle. Some portions of the blended leaves were soaked with ethanol and deionized water respectively. And a sieve used to extract the pigment which forms our dye

2.5 Deposition of Blocking Layer

Fifty (50) millimoles of titanium tetrachloride (TiCl_4) was deposited on the FTO using spin coating technique. A hot air blower was used to dry the electrode for five (5) minutes, after which it was heated with an electric hot plate for 90-100°C. This deposited titanium tetrachloride (TiCl_4) is dense layer and the layer was transparent. This was done to ensure adsorption of TiO_2 film that is yet to be deposited and to reduce or block the recombination reactions.

2.6 Deposition of Titanium (iv) oxide Paste (TiO_2)

Nanocrystalline titanium (iv) oxide paste (TiO_2) was deposited on a plasma cleaned layer using Dr. Blade method. Prior to the deposition of titanium (iv) oxide paste, the active area of a 2.5 cm x 2.5 cm FTO was identified and covered on each of the two parallel edges with a double layer of masking tape to control the thickness of the TiO_2 film. The TiO_2 paste was applied at one of the edges of the FTO and was distributed with a squeegee sliding over the tape-covered edges (Ozuomba *et al.*, 2011). Immediately after the deposition, a hot air blower was used to gradually dry the electrode for 2-3 minutes and the scotch tape was gently removed. The edges were cleaned with ethanol. The electrode was heated to dry at 75°C on an electric hot plate (Ceramag Midi IKA[®]WORKS USA) for ten (10) minutes. The electrode was immediately sent into furnace (carbolite 201 tubular furnace) to heat for 400°C. This is to ensure complete combustion of organic additives and also ensure sintering of the materials which lasted for thirty (30) minutes. All these were done to enhance the electrical contact and mechanical adhesion on the glass. During the period of sintering, we observed some changes; at first, the white colour of the TiO_2 changed to brownish and brownish fumes were released, after some time the same electrode also changed to black colour and finally turned to its initial colour (white). This white colour indicated that the electrode is now ready to be soaked in the dye.

2.7 Deposition of Platinum Catalyst Using Screen Printing

The counter electrodes were fabricated from the same substrate material and had the same dimensions as the working electrode. The cleaning was also done as in the working electrode.

The deposition was done by dipping a clean stirring glass rod in 0.5 grams of platinum catalyst and was rolled on the conductive side of the FTO. The FTO was coated for five times while it was placed on an electric hot plate that was controlled at 90°C. While the platinum electrode was still on the electric hot plate, a hot air

blower was also used to enhance the drying process which lasted for ten (10) minutes. Thereafter, the platinum electrode was sent in a furnace (Carbolite 201 tubular) at 450⁰C for thirty (30) minutes for sintering. The electrode was left in the furnace to cool gradually.

2.8 Sensitization of Titanium Dioxide by Natural Dyes

The sensitizers used are natural dyes extracted from Bush tea (*hyptis Suaveolens*). All the electrodes were preheated at 400⁰C for ten (10) minutes. This process helps in the prevention of rehydration of TiO₂ surfaces or capillary condensation of water vapours from ambient air inside the nanopores of thin film. The presence of water in the pore decreases the injection efficiency of the dye.

In order to achieve a good result, it was ensured that;

- (i) The working electrodes were carefully put into the dye.
- (ii) All the working electrodes were faced up to avoid cracking.
- (iii) The impregnation process lasted for forty eight hours for the dye molecules to naturally adsorb onto the Titania particles.
- (iv) All the dye-coated films were rinsed in ethanol and deionized water to remove excess dye and dried with an electric hot blower for three minutes.
- (v) The dye-coated films were sealed with aluminum foil and were kept in a dark air tight case till the cell was assembled.
- (vi) All these were done at room temperature (300⁰K).

2.9 Solar Cell Assembly

Before we assembled the dye-sensitized solar cell, we prepared a liquid electrolyte with I-/I³ redox couple by dissolving 0.5 M potassium iodide (KI) and 0.05 M iodide (I²) into acetonitrile and anhydrous ethanol.

The cells were assembled since the working electrode, counter electrode, and electrolyte are ready.

The procedures for the assembling are as follows;

1. Permanent laminating films (Solaronix SX 1170-25PF) were cleaned with ethanol and were used to connect the working electrode and the counter electrode together and to avoid bridging.
2. The electrodes were kept in a way such that there will be room (gap) for the electrical connections on both electrodes.
3. They were heated under the pressure from two clips at 80⁰C for 1 minute on a hot plate and allowed to cool for some minutes. The thickness of the laminating film was about 127 μm which decreased to 60 μm after heating.
4. Electrolyte (Iodolyte R-150 Solaronix SA) was introduced drop by drop at the gap between the two electrodes by capillary action.
5. Immediately after the introduction of the electrolyte, the edges of the electrodes were cleaned with acetonitrile and were sealed with Amoxil 4R sealant (BN011008SN, Solaronix SA).
6. Electrical contacts were made by applying silver paint on the conductive side of each electrode for optimal electrical connections.

All the assembled solar cells were kept in air tight container for proper characterization.

III. Results And Discussion

Figures 1, 2, 3, and 4 shows comparative studies of the optical properties of the fabricated dye sensitized solar cells which were extract from bush tea using deionized water and ethanol as solvent. The optical properties of the solar cells were investigated using Ava Spec-2048 UV/Visible Spectrophotometer.

Figure 1 displayed a high absorption rate in the visible region of the electromagnetic spectrum for ethanol dye extract. This reveals that ethanol based DSSC absorbs more photon energy than the water based cell. Hence, ethanol based solar cell is more efficient.

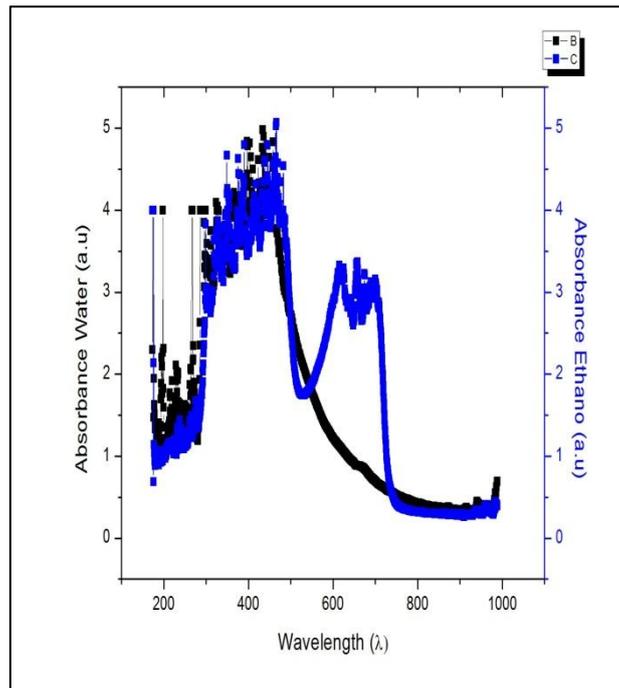


Figure 1. Absorption Spectra of Bush tea (*Hyptis Suaveolens*)DSSCs extracted using deionized water and ethanol

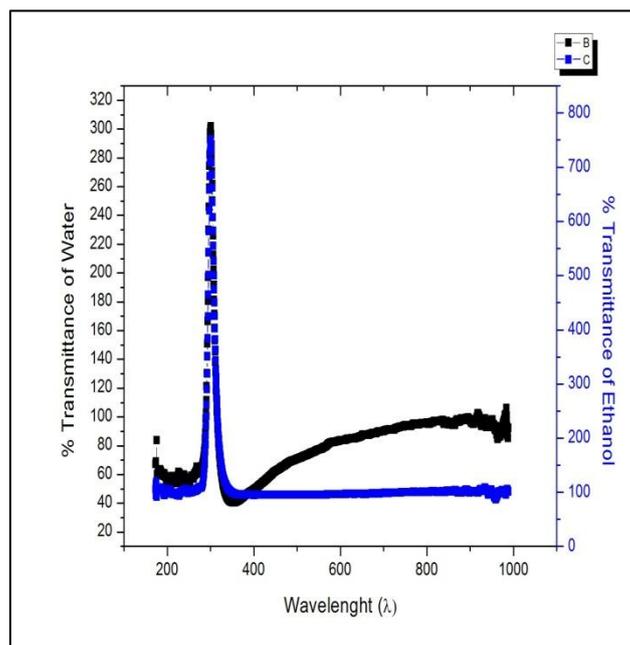


Figure 2. Transmittance Spectra of Bush tea (*Hyptis Suaveolens*)DSSCs extracted using deionized water and ethanol

Figure 2 Showed that both solar cells (ethanol and deionized water based solar cells) are highly transmitting at ultra violet region of the electromagnetic spectrum, with outstanding peaks at 299.70nm at 297.51a.u for water and 738.96a.u for both ethanol and water based cells, while poor transmittance was recorded at the visible regions of the electromagnetic spectrum for ethanol based cell. Thus water based solar cell is highly transmitted in UV region with a very low transmittance in higher wavelength, indicating that ethanol based cell is more efficient than the water based cell.

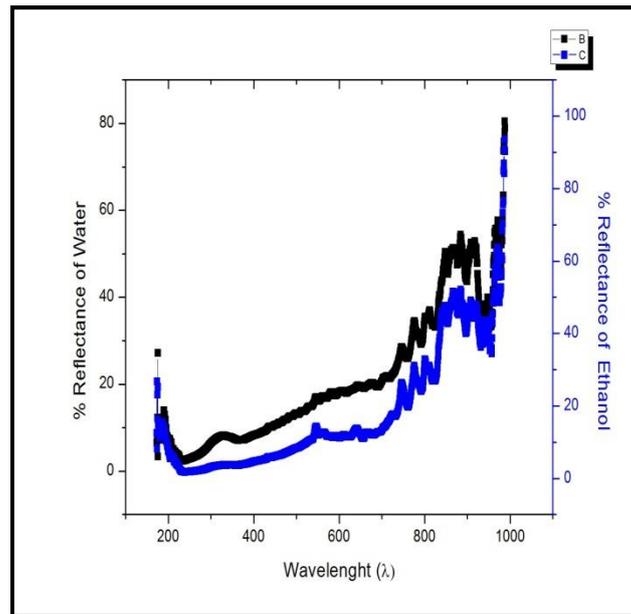


Figure 3 Reflectance Spectra of Bush tea (*Hyptis Suaveolens*)DSSCs extracted using deionized water and ethanol

In figure 3, the reflectance gradually increased with a highest peak of 987.68nm and this is at the region where very poor absorption was obtained.

However, in comparison, the water based DSSC depicts higher reflectance in higher region of the electromagnetic spectrum which implies that as the wavelength increases, the reflectance also increases. This is in line with ethanol based DSSC being more efficient than the water based cells because the ethanol DSSC absorbs more photon energy in the visible region of the electromagnetic spectrum.

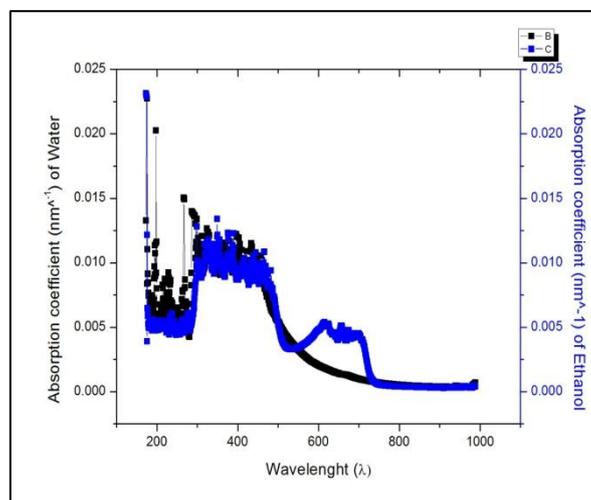


Figure 4 Absorption coefficient (nm^{-1}) of Bush tea (*Hyptis Suaveolens*)DSSCs extracted using deionized water and ethanol

Figure 4 displayed the graph absorption coefficient. This reveals the quantity of the light that is been absorbed per unit nanometer. It was observed that the rate of absorption was very little because the unit of absorption coefficient is per unit nanometer. Nevertheless, the ethanol based DSSC possess high absorption coefficient than the deionized water based DSSC in all the wavelength regions of the electromagnetic spectrum that was plotted in this work.

The current and power response to external voltage was carried out on ethanol based DSSC due its high efficiency. The I-V characterizations of the cell were measured under illumination intensity and dark (without halogen lamp) as indicated in figures 5 and 6 with an aid of Oriel Class A Solar Simulator. The illumination

intensity used was at 100 mW/cm². Comparative studies of current density and power as a function of voltage were carried out at 100 mW/cm² and at dark. The photovoltaic parameters were calculated using;

$$FF = \frac{V_{mp} \times J_{mp}}{V_{oc} \times J_{sc}} = \frac{P_m}{V_{oc} \times J_{sc}} \text{ or } \frac{V_{mp} \times I_{mp}}{V_{sc} \times J_{oc}}$$

The photoelectric conversion efficiency was also calculated using;

$$\eta = \frac{J_{mp} \times V_{mp} \times 100}{P_{in}} = \frac{J_{sc} \times V_{oc} \times FF \times 100}{P_{in}}$$

Where, FF = Fill Factor

$P_m = V_m \times J_m$ = Maximum Power Point (mW)

I_{sc} = Short circuit current (mA),

V_{oc} = Open circuit voltage (Volts)

J = Current density (mW/cm²)

η = photoelectric conversion efficiency

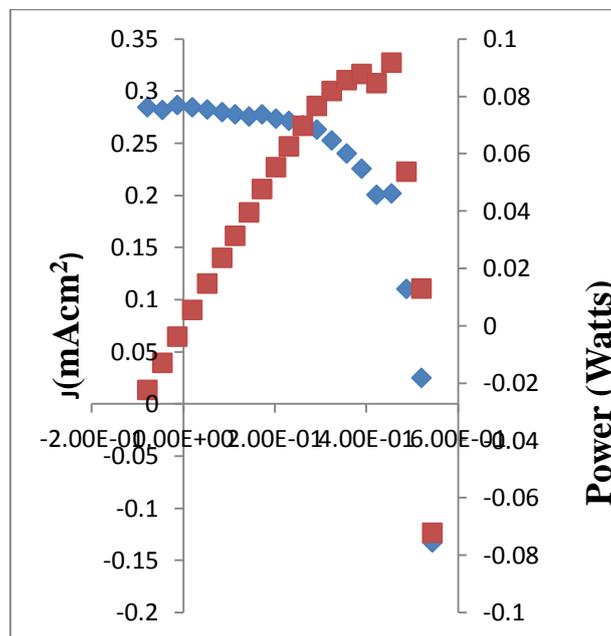


Fig 5 The I-V curve for cell sensitized with chlorophyll under light at 100m/w/cm².

The cell parameters obtained at 100mW/cm² are; open circuit voltage is 0.520 Volts, short circuit current is 0.286 mA, fill factor of 63 %, maximum power is 0.092 mW and photoelectric conversion efficiency of 0.092%.

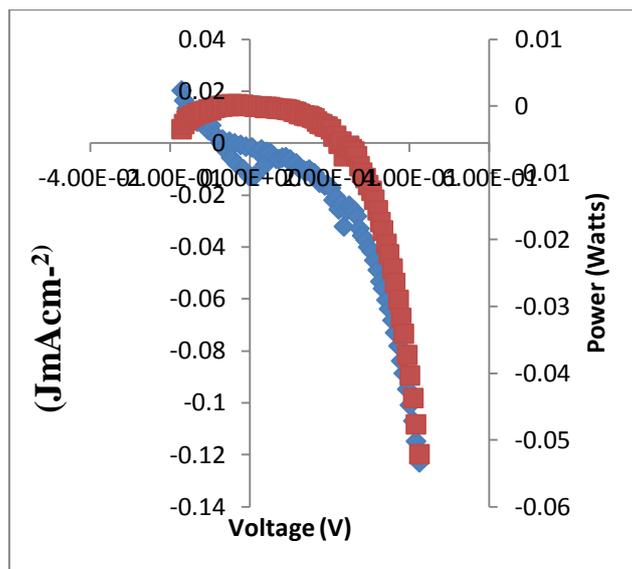


Fig. 6 The I-V Curve for cell sensitized with chlorophyll under dark

Photovoltaic parameters under dark intensity (no Halogen lamp) are; open circuit voltage is -4.24×10^{-1} Volts, short circuit photocurrent is -0.0016 mA, fill factor of -6.846% maximum power is 0.003 mW and photoelectric conversion efficiency of 0.003% .

IV. Conclusion

Dye sensitized solar cells have been successfully fabricated using natural dye that was extracted from Bush tea (*Hyptis Suaveolens*), using Dr. Blade and screen printing deposition methods. A comparative study was carried out for the DSSCs which extracted using ethanol and deionized water and their optical properties were also investigated using Avaspec 2.1 spectrophotometer. It was revealed that the ethanol based dye sensitized solar cell absorbs more photon energy than the water based dye sensitized solar cell in visible regions of the electromagnetic spectrum. Hence ethanol based cell is more efficient. Based on high efficiency of the ethanol based dye sensitized solar cell, I-V characterizations of the cell were measured in dark (no halogen lamp) and illumination intensity at $100\text{mW}/\text{cm}^2$ with an aid of Oriel Class A Solar Simulator.

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