Research Article

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Dye-Sensitized Solar Cell with Natural Dye Extract from Beetroot

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ABSTRACT

Solar cells have attracted increasing attention over the last two decades. One of the emerging technologies in the solar field is Dye-sensitized Solar Cell (DSSC). Dye-sensitized Solar Cells have been extensively used owing to their advantages of low cost, lower toxicity, environmental-friendliness and low weight. DSSC is the most promising new generation system for photovoltaic technology. In this work, TiO_2 photoelectrode was prepared by Doctor Blade technique and was sensitized using beetroot extract as a natural sensitizer. The sensitizer is an essential component to absorb sunlight to its extent and convert the incident photons into electric current. With the counter-electrode and electrolyte solution, DSSC was fabricated. UV and Current-Voltage characteristics have been studied and solar power conversion efficiency has been determined.

Keywords: DSSC; Beetroot dye; Doctor Blade Technique; UV and I-V characterizations.

1. INTRODUCTION

India has a vast potential for renewable energy. One of the non-conventional energy sources is solar energy. Sun is the best source of light and heat. The thermal energy radiated by the sun is inexhaustible. Hence the solar energy is called a renewable source of energy. It is believed that with 0.1 percent of the 75,000 trillion kWh of solar energy that reaches the earth, the planet's energy requirements can be fulfilled.

A solar cell is a device which converts sunlight directly into electricity by the photovoltaic effect. Dye-Sensitized Solar Cell (DSSC) is also known as Third Generation Solar Cell or Gratzel Solar Cell. Solar energy can be utilized to a maximum extent, only by using Solar cells.

Dye-sensitized solar cells (DSSCs) are receiving increasing attention from researchers because of their low-cost materials (Gokilamani *et al.* 2013). The operational principle of DSSC is very simple: the dye is the photoactive nano-level material of DSSC and can produce electricity once it is sensitized by light. The dye catches photons of incoming light and uses its energy to excite electrons. Then, it injects the excited electron into TiO_2, where the electron is conducted away by TiO_2. A chemical electrolyte in the cell then closes the circuit so that the electrons are returned back to the dye. It is the movement of these electrons that creates energy that can be harvested into a rechargeable battery, supercapacitor or another electrical device.

The DSSC developed in this work was composed of TiO_2 layer, acting as an electron carrier, a dye, acting as an electron generator which will recover to its original state by the electrolyte solution. Fig. 1 represents an ideal DSSC.

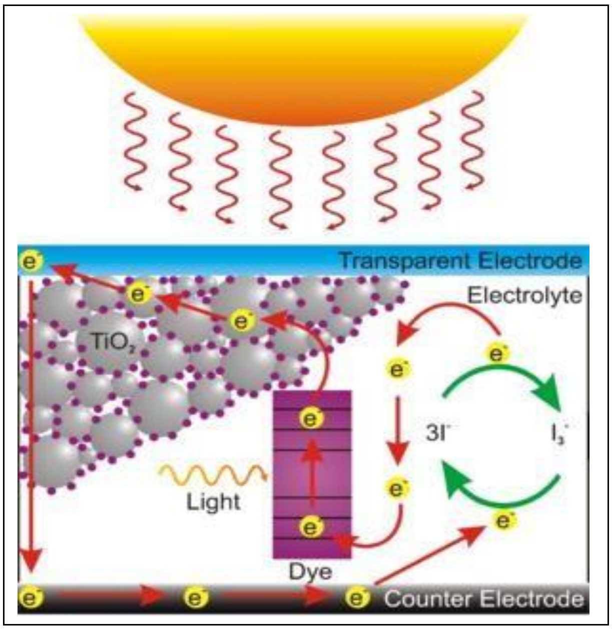

Fig. 1: Ideal DSSC

India is rich in natural plant resources. Many plants possess the dye products (Sathyajothi *et al.* 2017).

These dyes can be utilized for various applications. In this research work, beetroot *(Beta vulgaris)* dye was used as a sensitizer. It preferably grows in moist and fertile soil in a sunny spot but will also thrive in raised beds or pots. Some of the pigments present in the beetroot are betanins, betalains, betacyanins and betaxanthins. These pigments give the red or red-violet color.

2. EXPERIMENTAL PROCEDURE

2.1 Preparation of TiO_2 Electrode (Photo Anode)

The Fluorine-doped Tin Oxide (FTO) conducting glass substrate was cleaned in an ultrasonic digital cleaner with acetone for 15 minutes, then rinsed with distilled water and dried to prepare the photoanode (n-type) of dye-sensitized solar cells. To monitor the thickness of the film and mask electric contact strips, two sides of the FTO glass plate were sealed with a sheet of adhesive tape (Gokilamani *et al.* 2013). A small quantity of TiO_2 paste was placed in the sealed area and was coated well on the FTO substrate by Doctor Blade technique. The TiO_2 substrate was annealed at 450 °C for one hour in a muffle furnace. This was the first coating; the same process was repeated for the second coating.

2.2 Preparation of Natural Dye Sensitizer

Beetroots were well-cleaned and then they were finely chopped. The finely chopped beetroot was mixed with 50 ml of ethanol in a conical flask and then warmed at 45 °C for one hour. Then the residual parts were removed by filtration. This was directly used as a natural dye solution for sensitizing TiO_2 electrode. To sensitize the TiO_2 electrode, the dye solution was placed in a Petri dish, and the TiO_2-coated FTO was immersed in the extracted dye solution at room temperature for 24 hours so that the dye was absorbed inside TiO_2's active areas (Sathyajothi *et al.* 2017). The electrode was then rinsed with ethanol to remove the excess dye present in the electrode and dried in the open air. Thus, the dye-sensitized TiO_2 electrode was prepared.

2.3 Platinum-coated Counter Electrode

The counter electrode (p-type) material is a platinum-coated fluorine-doped tin oxide (FTO) conducting glass substrate, in which a hole is drilled for the passage of electrolyte solution.

2.4 Assembly of DSSC

The dye-sensitized solar cells were assembled by placing the counter electrode on the top of TiO_2 electrode with a spacer between the two electrodes, so that the counter electrode's conductive side was facing TiO_2 film (Gokilamani *et al.* 2013). A binder clip was used to secure the two electrodes together. High stability electrolyte (EL-HSE) was used as a liquid electrolyte solution. Now the liquid electrolyte solution was injected into the space between the clamped electrodes. The electrolyte entered the cell by capillary action, resulting in the formation of a sandwich-type cell.

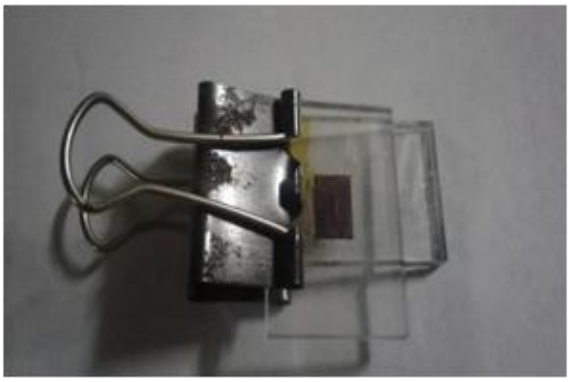

Fig. 2: Fabricated natural dye-sensitized TiO_2 Solar cell

Fig. 2 represents the fabricated natural dye-sensitized TiO_2 solar cell with an area of 0.4 cm^2. It was found that the cell efficiency was independent of cell area. By illuminating the cells with a light source or sunlight, the voltage across each individual cell can be measured (Sathyajothi *et al.* 2017).

3. RESULTS & DISCUSSIONS

3.1 UV-Visible Spectroscopy

The UV-Visible spectroscopy was carried out to study the absorption spectroscopy. Fig. 3 a and Fig. 3 b represent the absorption spectra of pure TiO_2 substrate, beetroot dye,and dye-sensitized TiO_2. The maximum absorption for pure TiO_2 was at 348.49 nm and that for beetroot extract and dye-sensitized TiO_2 electrode were at 631.81 nm and 343.61 nm respectively.

The bandgap is calculated using the formula,

$$E_g = hc / \lambda$$

where,

E_g - Bandgap energy in eV,
h - Plank's constant (6.623*10^34 J/s),
c - velocity of light (3*10^8 m/s) and
λ - wavelength of the sample in nm.

The calculated band gap of pure TiO_2 was 3.5 eV and that of beetroot extract and TiO_2 electrode were 1.96 eV and 3.6 eV respectively.

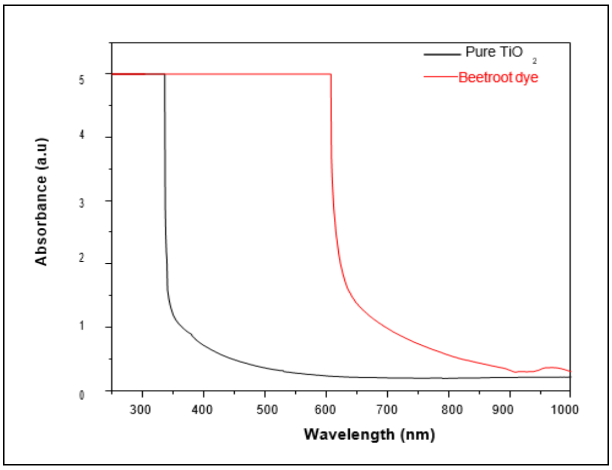

Fig. 3 a: Absorption spectra of Pure TiO_2 substrate and Beetroot dye

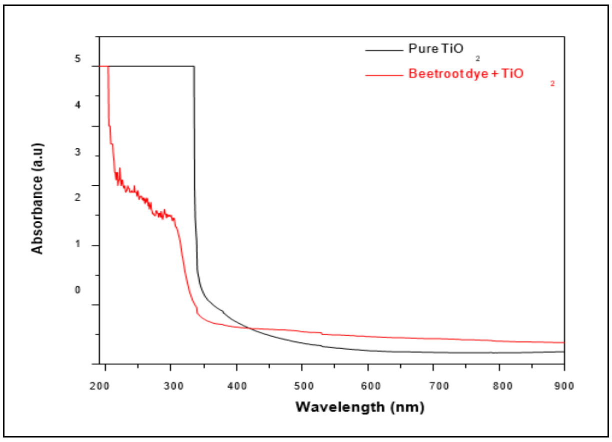

Fig. 3 b: Absorption spectra of Dye-sensitized TiO_2

3.2 I-V Characterization

The current-voltage (I-V) characteristics of DSSC define the operation within the electrical circuit. The I-V characteristic curve shows the relationship between the current flowing through DSSC and the voltage applied across its terminals. Fig. 4 represents the I-V curve of the DSSC, from which the basic parameters such as short circuit current (I_{sc}), open-circuit voltage (V_{oc}), fill factor (FF) and solar power conversion efficiency (η) were determined. The voltage applied to DSSC was up to 10 V and the current was measured and the graphs were drawn.

The efficiency parameters are given in Table 1 and the efficiency was calculated using the formula,

$$\eta = P_{max} / P_{in}$$

where, $P_{max} = V_{oc} I_{sc} FF$

$$\text{Hence, } \eta = V_{oc} I_{sc} FF / P_{in}$$

The input power for efficiency was 100 mW/cm^2.

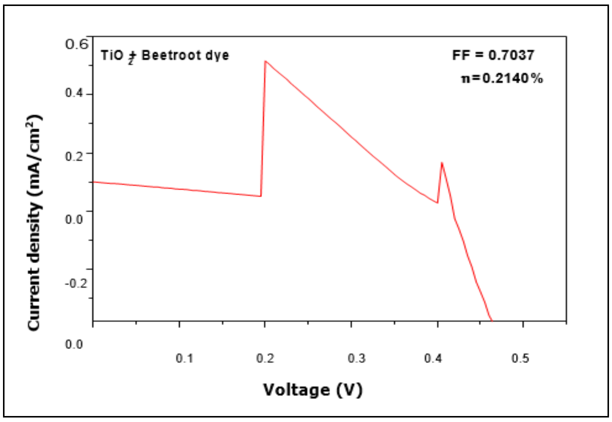

Fig. 4: I-V characteristics of DSSC

Table 1. The efficiency parameters

Name of the dye	Open Circuit Voltage (V_{oc})	Open Circuit Current (I_{sc})	Fill Factor (FF)	Solar Efficiency (η)
Beetroot dye	0.465	0.1	0.7037	0.2140%

Thus, the I-V characteristics show that the natural dye-sensitized solar cell has a solar efficiency of 0.21%.

4. CONCLUSION

Dye-Sensitized Solar Cells have been successfully prepared. In this work, the fabrication of DSSC by Doctor Blade technique and the use of natural dyes and their photovoltaic performance have been reported. The dye-sensitized solar cells fabricated were cost-effective, environment-friendly, renewable, clean and non-pollutant. The DSSC prepared with beetroot dye in this work has shown an efficiency of 0.21%; it can be increased further by using various other natural dyes.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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