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Fabrication of Dye-Sensitized Solar Cell Using Natural Dye Extracted from *Elaeocarpus Serratus* Red Leaf

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1. ABSTRACT

In this Research study, natural dye was extracted from *Elaeocarpus serratus* (Sri Lanka olive or werallu) plant red leaf as the sensitizer for a Dye-sensitized Solar Cell (DSSC). For the extraction of the dye, 1 g of chopped leaves were boiled with 2.5 ml of ethanol at 80°C for 30 minutes. The solar cell was fabricated by using a film of TiO_2 nanoparticles deposited on Fluorine doped Tin Oxide (FTO) glass plates, electrolyte containing iodine/tri iodide (I_2/I_3^-) and a platinum-coated FTO glass as the counter electrode. Solar cells were characterized by using a light source with an intensity of 100 mW/cm^2 and also in direct sunlight. The short circuit current (Isc) of this cell was 3.86 mA, and the open circuit voltage (Voc) was 380 mV. The fill factor of the cell was around 0.507 with an efficiency of 0.68 %. The absorption spectrum of the dye was measured by using a UV-Vis Spectrometer and a bathochromic shift could be observed after chelating the dye with TiO_2. The Incident Photon to Current Efficiency (IPCE) of the cell was calculated and peaked around 625 nm in the visible region. The cell was tested over a period of three hours and the efficiency of the cell seems to increase with prolonged illumination in the sunlight. The active pigment in the extract seems to be stable compared to other natural dyes extracted from plants.

2. INTRODUCTION

Energy is more important for our everyday life and various energy sources are utilized for different purposes in the world. One of the most abundant natural energy sources is the sun (solar energy), and also it is environmentally friendly when compared with other sources. We can convert solar energy to usable forms in different ways and conversion to electrical energy by using solar cells is a popular method. Solar cells are categorized into four generations depending on the time of development and type of materials used for their fabrication. The first generation is crystalline silicon solar cells, the second generation is thin-film solar cells, and the third generation is solar cells with emerging technologies (Dye-sensitized [1], organic [2], CZTS [3], Perovskite [4], Quantum dot [5]). A dye-sensitized solar cell comes under the third generation and DSSC was first developed by Gratzal and co-workers in 1991 [1] . DSSC Consists of the film made of TiO_2 Nanoparticles deposited on Fluorine doped Tin Oxide (FTO), or Indium Tin Oxide (ITO) Coated Transparent glasses where dye is coated for sensitization, electrolyte and a platinum counter electrode. Dye-sensitized solar cells are different from other solar cells because of their flexibility, lightweight, low cost, small size, and high performance under outdoor and indoor conditions.

DSSCs were fabricated by using different dyes extracted from flowers, fruits, leaves, seeds, etc. of plants which are referred as natural dyes. In this research study, red dye pigment was extracted from *Elaeocarpus serratus* (werallu or Sri Lanka olive) red leaf for the fabrication of a DSSC. This research study discusses the development of a DSSC using the Elaeocarpus serratus red leaf dye and its effect on the enhanced performance of dye-sensitized solar cells.

3. METHODOLOGY

3.1. Natural Dye Extraction

Elaeocarpus serratus (werallu or Sri Lanka olive) leaves (1 g) were chopped and boiled with 2.5 ml of ethanol at 80°C for 30 minutes in a beaker placed on a hot plate until de-colorization of the leaves. After that extracted red coloured dye was filtered and collected into a sample bottle, covered with aluminum foil, and stored in the refrigerator at 4°C until use.

3.2. Preparation of Dye Coated Film

The following steps were used to clean FTO glass sheets cut into the size of 2 cm×1cm. First, the FTO glass plates were placed in a beaker with water and few drops of washing liquid and cleaned five minutes in an ultrasonic bath. After that FTO glass plates were sonicated again with distilled water and few drops of con.H_2SO_4 for 5 minutes. When the sonicating process was over, FTO glass plates were boiled in isopropyl alcohol in a beaker at 80° C. After completing the above steps, FTO glasses were finally dried using a hair dryer with mild heat and determine its conducting surface with the aid of a conductivity meter.

TiO_2 past was prepared by using 0.25 grams of TiO_2 nanoparticle (20 nm) powder, 01 mL of 0.1M HNO_3, one drop of Triton-X 100, and a spec of PEG 400. The prepared TiO_2 paste was applied on the conductive surface of the FTO glass plate by the doctor blade method. Then the cell was sintered in a furnace for 30 minutes at 450°C, and allowed the TiO_2 film to cool down. Afterward, TiO_2 film-coated glass was dipped in the Elaeocarpus serratus (werallu or Sri Lanka olive) red leaf dye solution in a test tube for 12 hours.

3.3. Fabrication of the Cell

The electrolyte for the dye-sensitized solar cells was prepared using 0.127 g of iodine (I_2), and 0.83 g of potassium iodide (KI) dissolved in 10 ml of acetonitrile and ethylene carbonate in 8:2 ratio in a volumetric flask. Then the mixture of the solution was stirred for 5 hours to ensure that all the solid particles have completely dissolved [6]

Finally, the DSSC was fabricated by using the dye-coated TiO_2 film as the anode and the Pt sputtered glass as the counter electrode positioned side by side clamped together using crocodile clips. The capillary space between the two plates was filled with the electrolyte.

3.4. Solar Cell Characterization

A UV-Vis spectrometer was used to obtain the wavelength of the absorption spectra of the natural dye. TiO_2 nanoparticles and extracted dye were mixed together to make a solution. The solution is then centrifuged to remove the excess dye unabsorbed to TiO_2 after 12 hours and collect the dye-absorbed TiO_2 suspension solution. Then, a UV-Vis spectrometer was used to get the absorption spectrum of the dye adsorbed TiO_2 nano-particles.

The photovoltaic measurements of the Dye-Sensitized Solar Cell were measured under an LED light source with an intensity of 100mW/cm² and in direct sunlight with the help of a computerized PK-I-V 100 I-V Analyzer. Incident Photon to Current conversion Efficiency (IPCE) was taken using a computerized VK-IPCE-10.

4. RESULTS AND DISCUSSION

Besides chlorophyll that absorb light in red and blue regions, other pigments in tree leaves enhance utilization of white light for photosynthesis and these molecules pass their electronic excitations to chlorophyll referred to as auxiliary or accessory pigments. Two groups of accessory pigments that are important for photosynthesis are carotenoids and phycobilins. Phycobilins are light-harvesting pigments found in cyanobacteria, but not present in higher plants. The carotenoids that serve as accessory pigments absorb blue and green light strongly having triple banded spectra from 400 to 540 nm. The absorption spectra of carotenoids shift to longer wavelengths when interacted with other compounds. Carotenoids are subdivided into two groups as carotenes, which are hydrocarbons and xanthophylls, which are oxygenated hydrocarbons. Major carotene in plants is *β*-carotene and lutein is the most common xanthophyll [7].

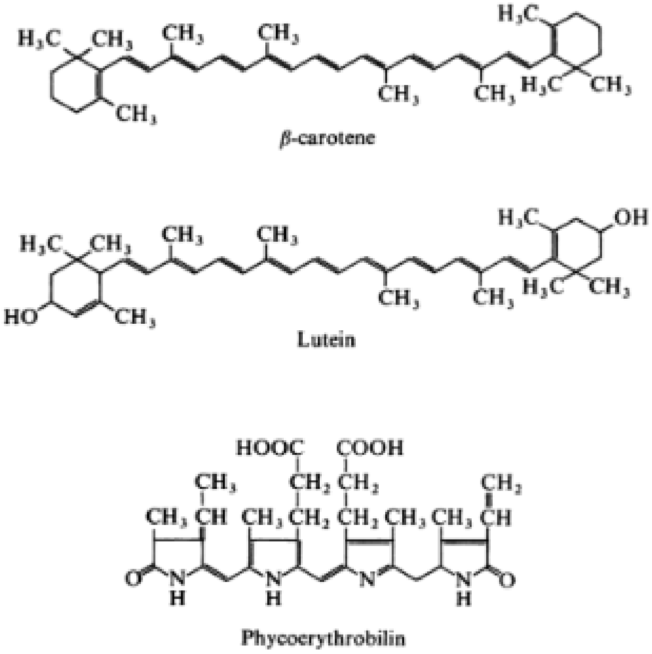

Figure 1: Structures of accessory pigments; Phycoerythrobilin is one of the chromophore of phycobilins which is covalently bond protein

Unlike carotenoids, anthocyanins are not present in the leaves throughout, but are produced in late summer in the sap of leaf cells, resulting from complex interactions. Orange leaves in autumn result from a combination of anthocyanins and carotenoids. Moreover, there can be large number of pollypenolic compounds present in leaves that can vary with the plant species. Therefore, the red colour pigment in *Elaeocarpus serratus* red leaf dye is most probably a xanthophyll that facilitates hydroxyl groups to chelate with TiO_2 film.

4.1. UV-Visible Absorption Spectrum of the Dye

A UV-Vis absorption spectra of the *Elaeocarpus serratus* red leaf dye and Elaeocarpus serratus red leaf dye coated TiO_2 nanoparticle suspension is shown in figure 2. The wavelength range used for the absorption measurement was 200 nm to 800 nm. Two peaks could be observed for the dye in the absorption spectrum at 272 and 355 nm. Also a bathochromic shift could be observed in the absorption spectra after chelating the dye with TiO_2 nanoparticles where the red colour dye change to dark blue which can even be visually monitored.

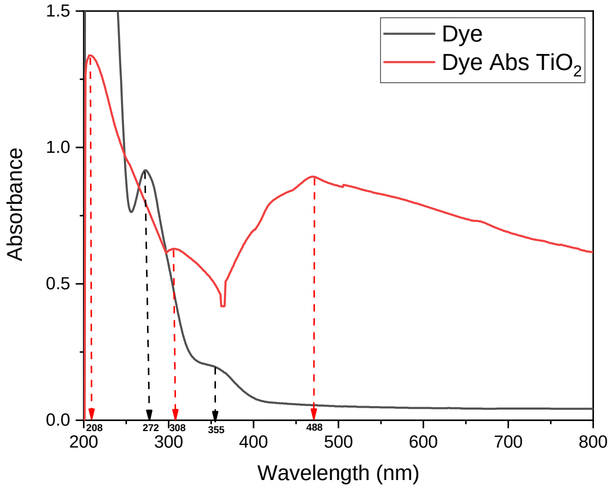

Figure 2: UV-Vis absorption spectra (a) Elaeocarpus serratus red leaf dye in Ethanol and (b) Elaeocarpus serratus red leaf dye-absorbed TiO_2 suspension in Ethanol

Tauc plot was drawn using the data obtained for absorption spectrum of the dye (figure 2).

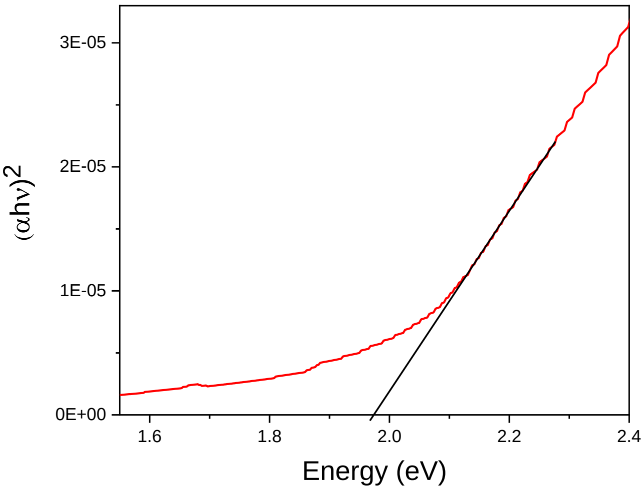

Figure 3: Tauc plots for Band gap energy

The energy band gap between Highest Occupied Molecular Orbital (HOMO) and Lowest Unoccupied Molecular Orbital (LUMO) for the minimum energy band was calculated by using the Tauc relation given by the following equation [[8], [9], [10]].

$$(\alpha h\vartheta)^n = A(h\vartheta - E_g)$$

$$\alpha = \frac{4\pi k}{\lambda}, \qquad E = Ah\vartheta$$

Here, A = 1, $h\vartheta$ is the photon energy, α is the absorption coefficient, k is absorbance, E_g is the band gap between LUMO and HOMO levels. For direct band gap n = 2 and for indirect bandgap n =1/2. Since dyes have a direct bandgap n is taken as 2. Using the graph plotted $(\alpha h\vartheta)^2$ vs $Ah\vartheta$, the band gap energy was calculated and found to be 1.97 eV.

4.2. IV Characteristics Measurement of the DSSC

The photovoltaic measurements of the Dye-Sensitized Solar Cell were measured under an LED light source with an intensity of 100 mW/cm^2 as depicted in figure 4. The photocurrent, photovoltage and efficiency of the Elaeocarpus serratus red leaf Dye-sensitized solar cell (DSSC) were respectively 3.86 mA, 380 mV and 0.68 % and the fill factor of the cell was 0.507. The cell was illuminated with sunlight at outdoor for 3 hours and gradual increment in photocurrent could be observed.

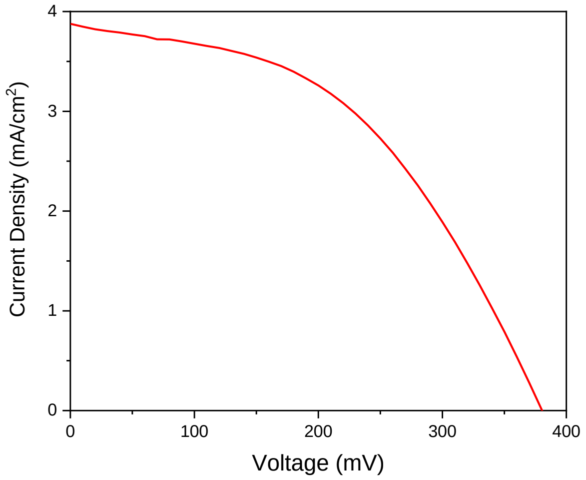

Figure 4: JV Characteristic curve of *Elaeocarpus serratus* red leaf Dye-sensitized solar cell (DSSC) under an LED Light source of 100 mW/cm^2.

4.3. IPCE Characteristic of the DSSC

Incident photon to current efficiency was measured and figure 5 shows the IPCE spectrum. The action spectrum of the cell is in the range of 500 nm to 700 nm which is in agreement with the absorption spectrum of the dye attached TiO_2.

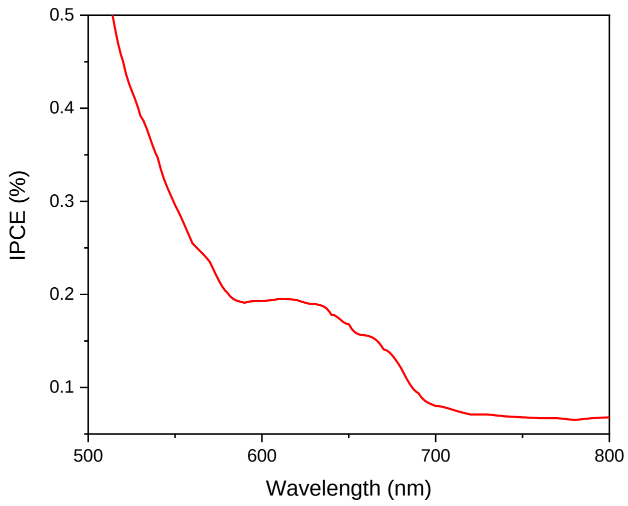

Figure 5: Incident photon-to-current efficiency (IPCE) Characteristic curve of Elaeocarpus serratus red leaf Dye-sensitized solar cell (DSSC)

5. CONCLUSION

Natural dye extracted from Elaeocarpus serratus (werallu or Sri Lanka olive) red leaf for the sensitization of DSSCs. The solar cell produced a short circuit photocurrent of 3.86 mA and an open circuit voltage of 380 mV with an efficiency of 0.68%. The fill factor of the cell was around 0.507. Two bands could be observed in UV-Vis spectra for this dye and the band gap was calculated using the wavelength of the lowest band which was found to be 1.97 eV calculated using Tauc plot. Redshift was observed for the dye when it is chelated with TiO_2 nano particles and also in the action spectrum of the cell. Literature was not available on the active pigments in Elaeocarpus serratus red leaf. But most probably the red colour pigment in Elaeocarpus serratus could be a xanthophyll present in the dye extraction. Therefore, further research studies are needed to identify the active pigments in the *Elaeocarpus serratus* red leaf for application in DSSCs. Compared to other natural dyes the active pigment in *Elaeocarpus serratus* red leaf seems to be more stable in prolonged illumination of sunlight.

6. REFERENCES

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