Preparation of Dye Sensitized Solar Cells containing Pomegranate and Black Plum Dyes

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Abstract—**Dye sensitized solar cells (DSSC) have received considerable attention as a cost-effective alternative to conventional solar cells. Natural pigments extracted from fruits and vegetables, such as chlorophyll and anthocyanins, have been extensively investigated as sensitizers for DSSCs. The use of natural pigments as sensitizing dyes for the conversion of solar energy into electricity is highly attractive because it not only improves the economic feasibility of the process but also offers significant environmental advantages. This paper reports the preparation and preliminary results of our attempt to fabricate dye sensitized solar cells using natural dyes, extracted from black plum (Eugenia Jambolana) and pomegranate seeds (Punica Granatum).**

Index Terms—**Blackberry dyes, Dye sensitized solar cells (DSSC), NanoTiO_2, Natural dyes, Pomegranate dyes.**

I. INTRODUCTION

Dye Sensitized Solar Cell (DSSC) is a low- cost solar cell belonging to the group of thin film solar cells. It is a photo electrochemical system, based on a semiconductor formed between a photo-sensitized anode and an electrolyte. Dye sensitized solar cell based on nanocrystalline TiO_2 on fluorine doped tin oxide (FTO) coated glasses was invented by Chen et al. [1]. DSSCs provide an economically credible alternative to conventional inorganic photovoltaic devices. Owing to their high energy conversion efficiency and low production cost, they have received considerable attention [2]- [4].

Mainly dye sensitizers can be classified into organic dyes and inorganic dyes. Organic dyes mainly consist of fruit dyes and natural extract dyes. A variety of transition metal complexes and organic dyes has been successfully employed as sensitizers in DSSCs. Inorganic dyes used for this purpose are mainly metal complex dyes such as complexes of Ruthenium, Osmium, Iridium etc. The most efficient inorganic photo sensitizers are ruthenium (ll) polypyridyl complexes that yielded more than 11% sunlight to electric power conversion efficiencies [5].

Although high efficiency cells have been achieved with nanoporous TiO_2 electrodes which sensitized with ruthenium complexes, there still remains the need for alternative photo sensitizers. This is because ruthenium complexes are high-cost materials and have long-term unavailability issues. Moreover, they also require time consuming chromatographic purification procedures.

In this context, the application of natural dyes offers several advantages over rare metal complexes and synthetic organic dyes. Natural dyes are widely available, easily extracted, can often be used without further purification, environmentally friendly, and significantly reduce the overall cost of the devices.

Wongchareea, Meeyooa, and Sumaeth fabricated DSSCs using natural dye extract from rosella, blue pea and a mixture of the extracts in the year 2007. The efficiency obtained was 0.37%, 0.05% and 0.15% respectively [5].

Lai, Su, Teoh, and Hon have fabricated water-based DSSC which used gold nanoparticles as a Schottky barrier on a TiO_2 electrode. Both commercial dyes and free natural dyes were used as sensitizers. Their study revealed that natural dyes have higher efficiency than commercial dye due to the presence of carbonyl and hydroxyl groups in anthocyanin molecules, which enhance the binding of the TiO_2 film and hence improve the efficiency. On the other hand, commercial dyes lead to significant thermal energy loss and reduced cell efficiency [6].

Fernando and Senadeera fabricated DSSCs sensitized using the extract of few flowers and the efficiency obtained was less than 2% [7].

Huizhi Zhou, Liqiong Wui, Yurong Gao and Tingli Ma have fabricated dye sensitized solar cell using 20 natural dyes as sensitizers in the year 2011. The photoelectrochemical properties of these cells showed open circuit voltages (V_{oc}) in the range 0.337 to 0.689V, and short circuit photocurrent densities in the range 0.14 to 2.69mAcm^{-2} [8].

II. WORKING PRINCIPLE

The schematic diagram of a DSSC is shown in Fig. 1. Light absorption is performed by a single layer of dye that is chemically attached to the rough surface of a layer of interconnected nanocrystalline titanium dioxide particles on conductive transparent glass. When the solar cell is excited by light (photons), the colored dye transfers an electron to the semiconducting TiO_2 layer. This process is called electron injection or sensitization. The interconnected network of the porous TiO_2 layer allows the transport of this electron to the conductive layer on the glass where it is collected.

Meanwhile, positive charge is transferred from the dye to a mediator (like iodide) that is an electron donor present in the liquid with which the solar cell is filled. The oxidized mediator brings the positive charge from the dye to the opposite side of the cell which is called the counter electrode. After traveling through the electrical load, the electron collected at the TiO_2 side of the cell reacts at the counter electrode and the mediator is returned to its original reduced form. The circuit is thus closed and electricity is produced.

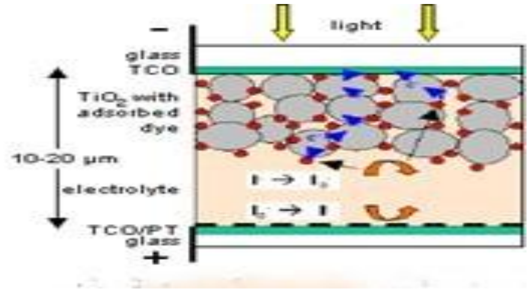


Fig. 1. Schematic diagram of DSSC

III. EXPERIMENTAL PROCEDURE

The main objective of this work is to extract the natural dyes from Pomegranate and Black Plum, use them to sensitize nanocrystalline TiO_2 deposited on Fluorine doped SnO_2 conductive glass and to fabricate DSSCs and to evaluate the current-voltage and power output characteristics of the assembled cell. The different steps involved in the fabrication process are described below.

A. Deposition of Titanium Dioxide (TiO_2) film

The first step in the fabrication process is the preparation of the TiO_2 suspension. For this, 6 g of Degussa P25 TiO_2 powder was ground in a mortar and pestle while 9 ml of acetic acid solution (pH 3–4 in deionized water) was added gradually in 1 ml increments. The grinding process helped to separate the aggregated TiO_2 particles and produced a uniform colloidal suspension.

For the deposition of the TiO_2 film, the conductive side of a fluorine-doped SnO_2 glass slide was placed facing upward. Scotch adhesive tape was applied along the edges and top portion of the slide to form a thin channel for coating and to leave a small uncovered area for electrical contact. The TiO_2 suspension was then applied near the edge of the slide using a dropper. A clean glass rod was moved smoothly over the surface several times to spread the suspension uniformly, forming a thin white TiO_2 film.

After coating, the adhesive tape was carefully removed and the slide was allowed to dry for one minute in a covered Petri dish. The coated film was then annealed in a hot air furnace at 450°C for 10 minutes and finally cooled to room temperature.

B. Sensitizing the TiO_2

Fig. 2(a) and Fig. 2(b) represent the natural dye solutions prepared by crushing the fresh black plums and pomegranate seeds. The filtered extracts were used for sensitizing the TiO_2 films. The TiO_2-coated glass slide was immersed in the black plum dye solution for about 10 minutes to ensure complete staining of the white TiO_2 film. The slide was then washed with deionized water, rinsed with isopropanol, and allowed to dry at room temperature.

Fig. 2(a) Black plum dye solution

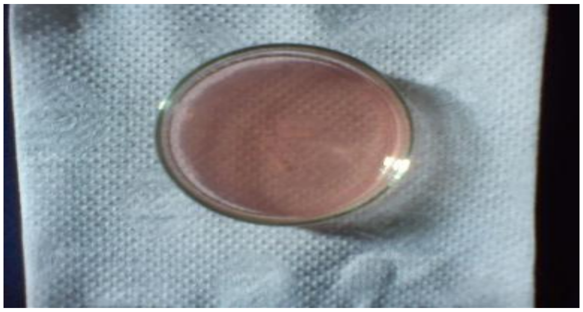


Fig. 2(b) Pomegranate dye solution

C. Preparation of counter electrode

Another conductive glass slide (fluorine-doped SnO_2) was held using tweezers, and a thin carbon layer was uniformly applied over the entire conductive surface using a soft pencil lead. This carbon coating acts as a catalyst for the regeneration reaction of triiodide to iodide. Since no adhesive tape was used for this electrode, the entire surface was coated with carbon. The counter electrode was then carefully handled at the edges and positioned appropriately.

D. Assembling the solar cell

Before applying the electrolyte, the sensitized TiO_2 film was rinsed with isopropanol and dried to remove moisture from the porous film. The dyed TiO_2 electrode was then placed on a flat surface with the film side facing upward. The carbon-coated counter electrode was carefully placed over the TiO_2 film such that the conductive side faced the TiO_2 layer, while leaving a 4–5 mm uncovered strip on each slide for electrical contacts.

The two electrodes were secured using binder clips along the edges. An iodide electrolyte solution containing 0.5 M potassium iodide in an organic solvent was introduced between the electrodes by placing a few drops at the edge of the cell. The electrolyte spread through the space between the electrodes by capillary action and wetted the TiO_2 film completely.

Excess electrolyte was removed from the exposed glass surfaces using tissue paper and isopropanol. Electrical contacts were made using copper foil pieces and alligator clips attached to the exposed conductive regions. Thus, the dye-sensitized solar cell (DSSC) was fabricated and is shown in Fig. 3. Then its performance was measured under diffused sunlight illumination.

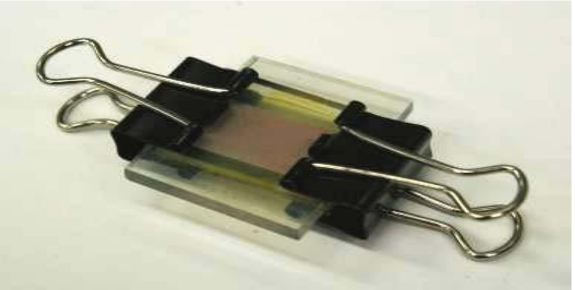


Fig. 3 Dye sensitized solar cell

From the output current (I) and the active area of the solar cell (A), current density, J = I/A is calculated. Then current density (j) versus voltage graph is plotted. From the graph, open circuit voltage (V_{oc}), short circuit current (I_{sc})

From the graph and data points, power density (the rate of supply of energy per sensitized area of solar cell), fill factor, maximum power point (maximum product of current density and voltage) and efficiency of the cells are determined.

Power density = voltage × current density (1)

Maximum power point, $P_{max} = J_{sc,max} \times V_{max}$ (2)

Fill factor , $FF = P_{max} / (V_{oc} \times I_{sc})$ (3)

Efficiency, $\eta = P_{max}/$ incoming solar power (4)

IV. RESULTS AND DISCUSSION

In the present work, two DSSCs were successfully prepared, using dyes obtained from black plum and pomegranate seeds.

A. Measuring the electrical output characteristics

Open circuit voltage (V_{oc}), short circuit current (I_{sc}) are measured under diffused sunlight using the connection diagram shown in Fig.4.

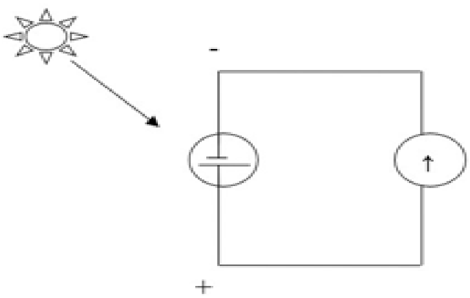


Fig. 4 Circuit diagram for measuring V_{oc} and Isc

The V_{oc} and Isc values obtained for the prepared cells are given in Table. I

Table I. The output parameters of the cell

DSSC using	V_{oc} (mV)	I_{sc} (mA)
Black Plum	39	0.037
Pomegranate seeds	20.3	0.074

Current-voltage (I-V) characteristic curve is measured under diffused light, using multimeters by connecting a 500 Ohm potentiometer as a variable load as shown in the circuit diagram, Fig. 5.

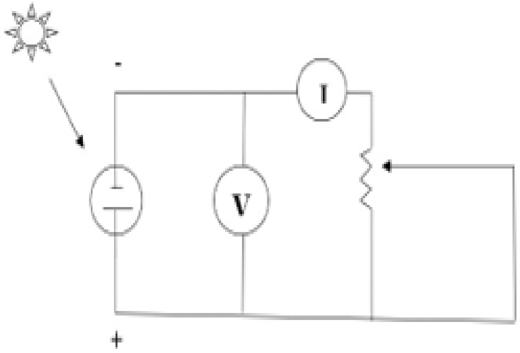


Fig.5 Circuit diagram for measuring I-V characteristics

Fig.6 and Fig.7 show the J-V characteristics of the DSSCs prepared using the dyes obtained from black plum and pomegranate seeds respectively. The active area (A) of both the cells prepared were 2.25 cm^2. From the output current (I), current density, J = I/A was calculated. P_{max}, FF and η of the cells were calculated using equations (2), (3) and (4) respectively. The values obtained for both the cells are tabulated in Table II.

From the Table II, it is clear that the efficiency of DSSC using black plum dye is more than the DSSC using pomegranate dye, even though J_{sc} value is slightly less.

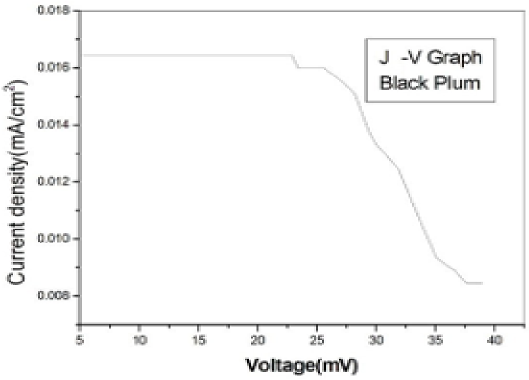


Fig 6. J-V Characteristics of the solar cell with black plum as the dye.

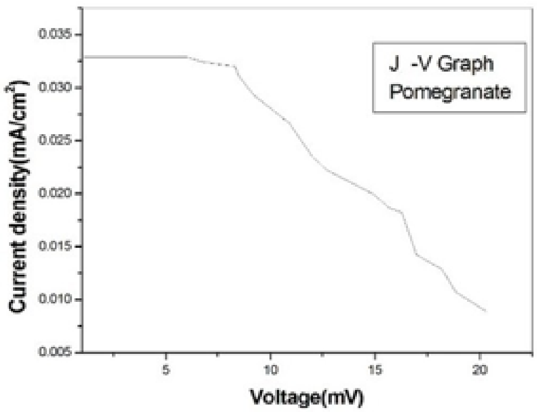
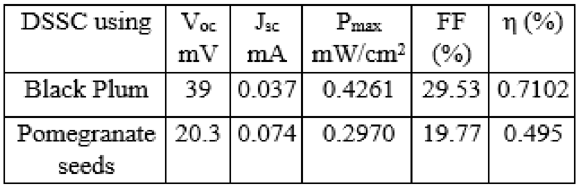


Fig. 7 J-V Characteristics of the solar cell with pomegranate dye.



DSSC using	V_{oc} mV	J_{sc} mA	P_{max} mW/cm^2	FF (%)	η (%)
Black Plum	39	0.037	0.4261	29.53	0.7102
Pomegranate seeds	20.3	0.074	0.2970	19.77	0.495

Table. II. Comparison between DSSCs constructed using black plum and pomegranate.

V. CONCLUSION

The main objective of this project was to fabricate dye-sensitized solar cells (DSSCs) using natural dyes extracted from black plum and pomegranate seeds. The fabricated cells exhibited good and fast photo response characteristics, and typical J–V characteristics were successfully obtained. Important photovoltaic parameters such as open-circuit voltage, short-circuit current, maximum power point, fill factor, and efficiency were evaluated for each cell.

The results showed that the DSSC sensitized with black plum dye achieved a higher efficiency (0.71%) compared to the cell fabricated using pomegranate seed dye (0.495%). The fill factor, which represents the ratio of maximum obtainable power to the theoretical power, was also determined and used to assess the performance of the fabricated solar cells.

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