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Dye-Sensitized Solid State Solar Cells Sensitized with Natural Pigment Extracted from the Grapes

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Abstract- The solar energy is an abundant, continuous and clean source of energy that can be used to produce electricity using many different photovoltaic designs. Dye sensitized solar cells based on TiO2 have drawn attention worldwide due to their low cost and easy preparation techniques compared to conventional silicon based photovoltaic devices. The objective of this work was to develop dye-sensitized solid-state solar cell (DSSC), in which the liquid electrolyte, commonly applied in photoelectrochemical cells, is replaced by CuSCN and compared the performance of the solar cells with anthocyanin extracted from grapes.

Highly porous, TiO2 films have been prepared, on fluorine doped tin oxide (FTO) glass substrate, using P25 nm TiO2 particles in a TiO2 colloidal suspension. These films were used to construct FTO/TiO2/Natural Dye/CuSCN/Pt/FTO, DSSCs with natural anthocyanin sensitizer extracted from grapes and CuSCN as the hole conductor. The cells show open circuit voltage (Voc) of 0.449V, short-circuit current density (Jsc) of 1.91 mA cm-2 and 0.50 fill factor (FF) with an overall efficiency (η) of 0.43 % .

Index Terms- Dye Sensitized Solid State Solar Cells; Anthocyanin; Grapes; natural dyes; electrolyte.

I. INTRODUCTION

Silicon based solar cells were the most popular before the emerging of dye-sensitized solar cells. These solid-state junction devices have dominated photovoltaic industry. Since Grätzel et al. developed dye-sensitized solar cells (DSCs), a new type of solar cells, in 1991 [1], these have attracted considerable attention due to their environmental friendliness and low cost of production. A DSSC is composed of a nanocrystalline porous semiconductor (TiO2) electrode-absorbed dye, an electrolyte (p-type semiconductor) and a counter electrode. In DSSCs, the dye as a sensitizer plays a key role in absorbing sunlight and transforming solar energy into electric energy. Numerous metal complexes and organic dyes have been synthesized and utilized as sensitizers. By far, the highest efficiency of DSCs sensitized by Ru-containing compounds absorbed on nanocrystalline TiO2 reached 11–12% [2,3]. However, noble metals limited in amount, and costly in production. On the other hand, organic dyes are not only cheaper but have also been reported to reach an efficiency as high as 9.8% [4]. However, organic dyes have often presented problems as well, such as complicated synthetic routes and low yields. Nonetheless, the natural dyes found in flowers, leaves and fruits can be extracted by simple procedures. Due to their cost efficiency, non-toxicity, and complete biodegradation, natural dyes have been a popular subject of research. Thus-far, several natural dyes have been utilized as sensitizers in DSCs such as anthocyanin, carotene, tannin and chlorophyll [5-11].

For ideal performance and excellent efficiency, electrolyte should have high ionic conductivity so that it can transfer oxidized/reduced species to respective electrodes efficiently and should prevents back electrode reactions completely. Polymeric electrolyte is an ideal choice used in lithium ion batteries, supercapacitors, photoelectrochromic display devices and solar cells [12-14]. Organic liquid electrolytes DSC have attractive features of high energy conversion efficiency and low production cost [15]. However, presence of traditional organic liquid electrolytes in such cells has some problems such as a less long-term stability and a need for airtight sealing. One of the major problems of such DSC is the electrolyte loss caused by the leakage and volatility of the electrolyte solution that lowers the durability of the cell. Solid-state dye-sensitized solar cell (DSSC) did not need hermetic sealing, but energy conversion efficiency of them decreased in comparison to those of dye-sensitized solar cell with traditional organic liquid electrolytes. Various approaches to these problems have been tried so far.

In this research, dye-sensitized solid-state solar cell, in which the liquid electrolyte, commonly applied in photoelectrochemical cells, was replaced by CuSCN as the hole conductor and compared the performance of the solar cells with anthocyanin extracted from grapes. This extracted dye was characterized by UV–vis absorption spectra. The photoelectrochemical properties and photovoltaic properties of the DSSCs using these extracts as sensitizers were studied.

II. EXPERIMENT

Solid state dye-sensitized solar cell devices was prepared, using natural dyes as photosensitizers, sandwiched with nanocrystalline semiconductor oxide of TiO2 deposited and FTO coated glass as working electrode and Pt coated glass as counter electrodes respectively.

A. Preparation of Natural Dye Sensitizers

The anthocyanin based natural dye was extracted from black Grapes using 25% acetic acid. Skin of the Grapes were taken off and boiled with acetic acid and the filter solution was an anthocyanin solution.

B. Preparation of TiO_2 Electrode (Photoanode)

The photoanode is prepared by adsorbing a dye on a porous titanium dioxide, TiO2 layer deposited on FTO (Fluorine-doped SnO2) conducting glass. The semiconductor paste was prepared to fabricate TiO2 layer, by the following procedure. First Titanium tetraisopropoxide (5.00ml), Glacial Acetic Acid (5.50ml), and Iso-propyl Alchohol (20.00ml) were poured in to a ceramic motor and grind well to disperse all reagents in the medium. Then water (5.00ml) was added to the solution mixture. In this step a gelatinous form was occurred. P25 Degussa TiO_2 powder (0.650 g) was added to the mixture while grind the gelatinous solution to obtain a thicker solution of TiO_2.

The prepared paste was coated on an FTO glass by using cooking method with an approximate thickness of 10-12 micrometre and the area of the cell was 1cm2. Then the coated plate was annealed at 500^oC for 30 min.

C. Preparation of Solid State Electrolyte

Structure modified CuSCN was prepared by using THT and dissolving in prophylsulphide to use as a better hole conductor. This solution was allowed to crystallize. Then the crystals were filtered out and mother liquor was used to fabricate in photo electrode.

D. Assembly of DSSC or Grätzel Solar Cell

The TiO_2 coated glass plate was soaked in natural dye for 24 hrs in a dark and sealed place. Then glass plate was washed using acetonitrile and dried in air for few minutes. CuSCN was deposited on the pigment-coated electrodes as described below.

First the dye coated plate was placed on a hotplate under 110^0C temperature. Then the solution (mother liquor) was lightly spread over the dyed surface using a glass dropper. This procedure was repeated until CuSCN surface gets filled just above the level of TiO_2. After depositing the CuSCN, the electrical contact was made by applying graphite powder onto the CuSCN surface. Then I-V measurements were carried out by applying a platinum coated glass plate on top of the CuSCN film.

III. RESULTS AND DISCUSSION

A. Absorption of natural dyes

To understand the potency of selected natural dye as a sensitizer, UV-vis absorption spectra was observed. Fig. 1 shows UV–vis absorption spectra of the dye (diluted solution) extracted with acetic acid from Grapes, exhibit an absorption peak at around 520 nm. This absorption ascribes to their identical components, namely, anthocyanin, a group of natural phenolic compounds. The chemical adsorption of these dyes is generally accepted to occur because of the condensation of alcoholic-bound protons with the hydroxyl groups on the surface of nanostructured TiO_2.

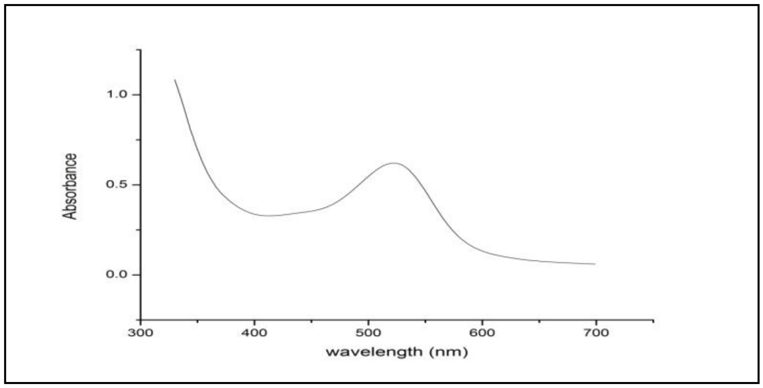

Figure 1 . UV-vis absorption spectra of anthocyanin extraceted from grapes.

B. Photoelectrochemical properties of DSCs sensitized with natural dyes

Photovoltaic tests of DSSCs using this natural dye as a sensitizer was performed by measuring the current–voltage (I–V) curves under irradiation with white light (100 mW cm−2) from AM 1.5 solar simulator with solid electrolyte. The performance of natural dye as sensitizer in DSSCs was evaluated by short circuit current (Jsc), open circuit voltage (Voc), fill factor (FF), and energy conversion efficiency (η). The photoelectrochemical parameters of the DSSCs sensitized with natural dye are listed in Table 1.

Table 1. Photovoltaic performances of the cell

Dye source	Electrolyte	J_{sc} / mA cm^{-2}	V_{oc} / V	Fill Factor	Efficiency %
Black Grapes	CuSCN	1.91	0.449	0.50	0.43

Figure 2 shows the Variation of current-voltage curve of anthocyanin extracted from grapes based DSSCs. Experiment was carried out less than 1 sun illumination, (100 mW/cm2, and air mass 1.5) with solid state electrolyte.

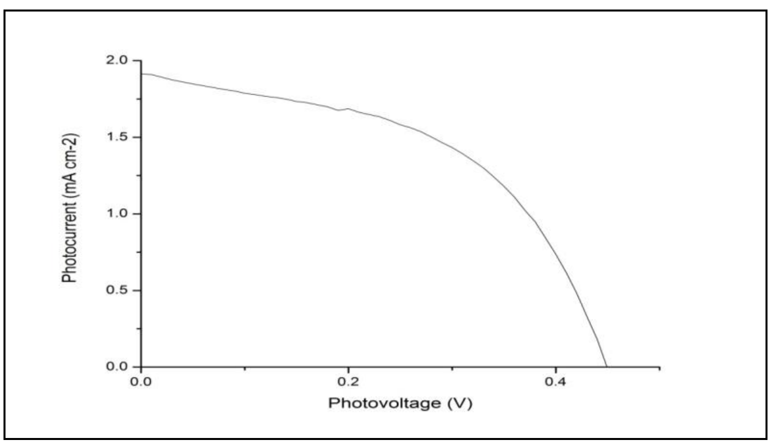

Figure 2. I-V characteristic curve of the cell

IV. CONCLUSION

In this work we have reported an investigation on anthocyanin extracted from grapes as natural photosensitizer and CuSCN as the solid electrolyte, studying its sensitization and Photoelectrochemical activities. The raw pigments simply extracted in acidic conditions from grapes achieved solar energy conversion efficiency of 0.43 %, which is the highest obtained among all sensitized cells. Natural dye based cells appear to be limited by low Voc and a large decrease in photocurrent, probably due to dye degradation. Finding different additives for improving Voc might result in larger conversion efficiencies. Although the efficiencies obtained with these natural dyes are still below the current requirements for large scale practical application, the results are encouraging and may boost additional studies oriented to the search of new natural sensitizers and to the optimization of solar cell components compatible with such dye.

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