2017 2nd International Electrical Engineering Conference (IEEC 2017)
May. 19-20, 2017 at IEP Centre, Karachi, Pakistan

Anthocyanin based Photosensitizer for Natural Dye-Sensitized Solar Cells

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Abstract: This work is focused in utilization of low cost and ecofriendly dyes for development of dye-sensitized solar cells. Pomegranate extract is used as anthocyanin based natural pigments. The efficiency, open circuit voltage, short circuit current and fill factor is determined and compared with standard cell using N719 dye. Pomegranate appeared as promising candidate for the dye giving an efficiency of 0.12%, V_{OC} of 0.5V, J_{SC} of 0.33mA/cm^2 and FF of 68.7%.

Keywords: Dye-Sensitized Solar Cells, Natural Dyes, Anthocyanin, eco-friendly, TiO_2

I. INTRODUCTION

Solar energy is the viable alternative among all renewable energy resources. Solar cells provide energy transformation from sunlight to electric current. Dye Sensitized solar cells belong to third generation photovoltaic technology, which is based on natural phenomenon of photosynthesis (1905 Albert Einstein).

Dye sensitized solar cells (DSSC) were first produced by Gratzel et al in 1991 [1], since then; because of their attractive features a plethora of publications have been appeared. Dye sensitized solar cells (DSSC) are low cost, easy to fabricate and ecofriendly. DSSCs are different from conventional solid state p-n junction solar cells. They are composed of a sandwich like structure of two electrodes and electrolyte in between them. The Photoanode is made of indium tin oxide (ITO) coated glass, layered with mesoporous titanium dioxide film of around 10um thick, covered with a light absorbing dye, a counter electrode is also made up of ITO coated glass usually coated with platinum and in between both electrodes an electrolyte containing iodide and triiodide ions. The nanostructured thin film of mesoporous titanium dioxide is breakthrough that drastically increased efficiency from 1% (cells with non-porous TiO2) to 7% [2]. The nanoparticles extended the area for photo generation, increased carrier life time and provided more dye absorption. The dye plays a major role in DSSC performance. Numerous synthetic dyes have been investigated and it is observed that Ru-containing compounds demonstrated highest efficiency of 11 -12 % [3][4] but noble metals are scarcely available and hence costly, while synthetic organic dyes exhibited 9.8% efficiency [5] but they have complex processing methods [6]. The use of natural pigments resolved both issues and created variety of choices from different parts of plants like roots, barks, leaves, flowers and fruits [7,8]. The use of coumarin by Wang et al presented an efficiency of 7.6%[9].

The counter electrodes must be highly conductive and they are usually made of noble metals like platinum (Pt), gold (Au) and silver (Ag) which are extremely expensive. A great effort has been made by researchers to look for alternative methods for development of counter electrode. Inorganic compounds, conductive polymers, carbon based material and composites are studied for counter-electrode.

In this work DSSCs are prepared by using natural extract from pomegranate (Punica granatum) as dye and compared with commercial ruthenium N719 dye. Natural dyes have been under study with various dye pigments like flavonoid, carotenoid, chlorophyll and anthocyanin. Among all of them anthocyanin dye is attractive because it has its peak absorbance within visible range of the spectrum [10] and it is excellent pigment in generation of charge carriers [11]. Anthocyanin has been investigated by many researchers for used as dye in DSSC [10- 18]. This pigment can be found in many red coloured flowers and fruits like pomegranate [10-12] plums, black currant [13] purple cabbage[14], cherries, raspberries [15], ixora [16] hibiscus [17], red tamarind [18] and many others among which pomegranate demonstrated highest output efficiency of 2% [11], hence it is major reason of interest and further exploration of this work.

The structure of the research paper is divided into five sections. This is the first part containing introduction. The remaining section II presents construction and working principle of DSSC, section III explains the experimental details of fabrication of DSSCs with subsections to elaborate them, while final results are explained and discussed in section IV. Lastly the research work is concluded in section V with future recommendations.

II. STRUCTURE AND WORKING

The basic components of DSSC are photoanode, dye, electrolyte and counter-electrode as shown in fig. 1.

The two electrodes are based on glass with one side coated with transparent conductive oxide (TCO) which is usually indium tin oxide (ITO) or fluorine tin oxide (FTO) to make conductive glass. The photoanode is made of titanium dioxide (TiO_2) layer onto which the photosensitizer dye is adsorbed, the counter-electrode is usually made of platinum coated or with graphene. The electrolyte is filled in between the two electrodes to provide redox reaction within the cell assembly.

When the cell is exposed to sunlight the dye gets sensitized and produces electrons which are collected by mesh of TiO_2. The TiO_2 mesoporous layer serves as the path way for the flow of electrons within the cell. The lost electrons from the dyes get replenished from the iodide/ tri-iodide electrolyte solution filled in spaces of TiO_2 [8].

III. EXPERIMENTAL SECTION

A. Preparation of dye sensitizer extracts

Anthocyanin is present in pomegranate and it is water soluble. A solvent is prepared by mixing water and ethnol in the ratio of 1:2. The weight of 100g of fruit is immersed in 150 ml of solvent in a beaker for 12 hours under darkness.

B. Fabrication of dye sensitized Solar Cells

All material used in this experiment was purchased from Solaronix, Switzerland. The photoanodes were heated at 450^oC for 20 minutes in carbolite furnace and then immersed in the two dyes separately overnight for 12 hours in darkness. These photoanodes were then assembled with platinum counterelectrodes keeping the gasket in between them making a sandwich like structure as shown in fig.1 . It was then placed over hot plate for a few seconds for sealing. Few drops of electrolyte were introduced into the space between two electrodes, via the hole provided in counterelectrode. Lastly the hole was closed, the cell was sealed and finally characterized.

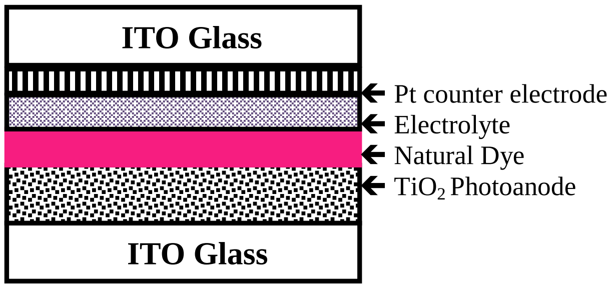

Fig. 1 Simplified Structure of DSSC

C. Measurements

The absorption spectra of solution was recorded by Perkin Elemer Lambda 19 spectrophotometer and photoelectrochemical characteristics were measured from digital meter provided in Keithley SCS-4200 alongwith OAI TriSOL solar simulator.

IV. RESULTS AND DISCUSSION

A. UV-Visible Absorption Spectra

The UV-Vis absorption spectra of as prepared natural dye and commercial N719 dye can be seen in fig. 2. Pomegranate dye gives its peak absorbance at 380nm and another rise at 480nm in its absorption spectrum that corresponds to anthocyanin dye. The commercial metallic dye, ruthenium N719, produced its highest peak at 315nm, whereas two more peaks can be observed at 380nm and 520nm as well. For dye sensitized solar cells the dye must have absorbance capability within visible region and this can be observed from fig.2 that pomegranate dye demonstrated its peaks within the range of visible region.

B. Photoeletrochemical characterisitics of DSSCs

The photoelectrical properties of the prepared cells are summarized in table 1. The natural dye pomegranate based DSSC produced lesser efficiency than commercial dye, however it gives pretty good value of open circuit voltage of 0.5V and fill factor of 0.68 that can be enhanced further for achieving better efficiency.

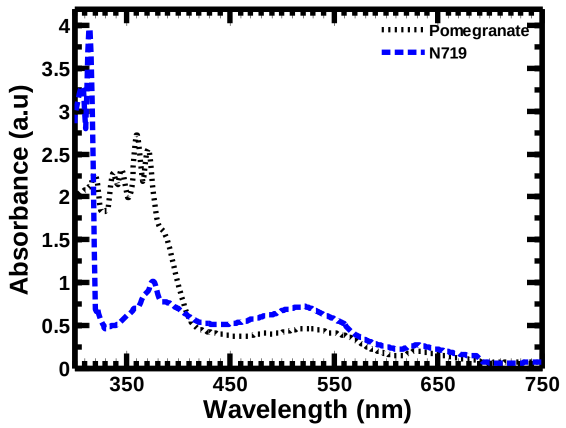

Fig.2 Absorption spectrum of natural and synthetic dyes

Table 1 Comparison of photoelectrochemical parameters of Dye-sensitized Solar Cells

Dye used	J_{SC} ($mA.cm^{-2}$)	V_{OC} (mV)	FF	Efficiency η (%)
Pomegranate	0.334028	500	0.687	0.12025
N719	13.57778	710	0.504	4.888

Figure 3 shows I-V characterization curve for N719 based DSSC, similar curve was obtained for pomegranate based DSSC which is presented in inset. Since anthocyanin pomegranate dye is not commercial dye hence it is giving very low value of current density which ultimately reflects in overall efficiency of the cell. However different extraction techniques may be deployed to enhance charge generation capability in the dye for example use of different solvents other than ethanol, the squeezing of fruit, dried fruit extraction and the use of peel rather than the edible part of the fruit. Whereas DSSC made of N719 dye which is a commercial dye, produced η=4.8% with V_{OC}=0.7V, J_{SC}=13.5ma/cm^2 and FF=50%. A comparative graph is presented in fig.4 for both natural and commercial dyes.

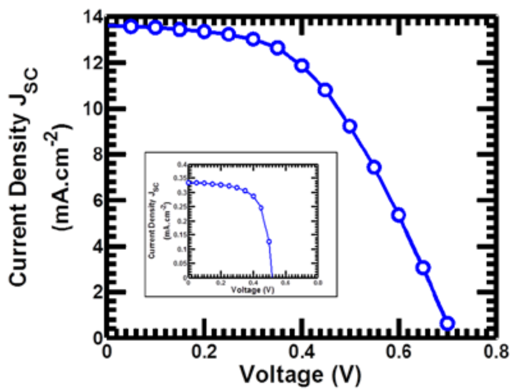

Fig. 3 Photoelectrical I-V characterization curve for N719 based DSSC. Inset is the I-V curve of pomegranate dye based DSSC.

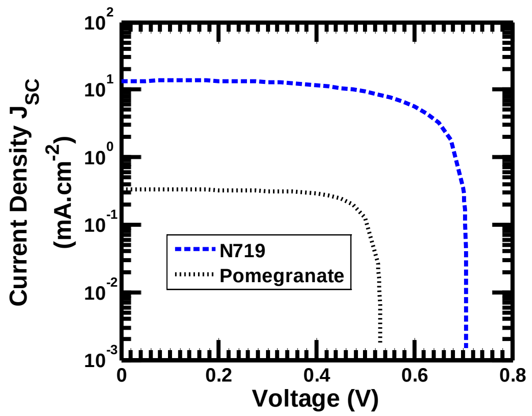

Fig. 4 Photocurrent-voltage curves for N719 and pomegranate based DSSC

V. CONCLUSION

Photoelectrical characteristics and UV-visible spectroscopy of anthocyanin based natural dye and N719 dye are compared. The conversion of sunlight into electrical energy is successfully achieved by using pomegranate extract containing anthocyanin. The results show that pomegranate can be used as natural dye for manufacturing of DSSCs because of its peak absorbance at 380nm and 480nm within visible region of the spectrum. The solar cell parameters like 68% fill factor and open circuit voltage of 500mV are promising results. However the efficiency of 0.12% is much low as compared to N719 dye 4.8%. Further optimization in dye preparation and cell fabrication can be made to enhance the current and performance of DSSCs.

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