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Cost-Effective Carbon Cathode for Dye-Sensitized Solar Cell Using Eco-Friendly Eosin Y Dye

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ABSTRACT

Due to high catalytic properties and stability against deterioration, Platinum coated films on fluorine-doped tin oxide (FTO) glass surfaces have been preferred commonly as the cathodes in the research of dye-sensitized solar cells (DSSCs). The platinum cathode films have been synthesized by drop casting the alcoholic solution of hexachloroplatinic acid (H_2PtCl_6) on the cleaned TiO_2-coated glass plates. Still, the cost of platinum is too high, being a heavy and rare element. Consequently, the intention of producing a low-cost and eco-friendly DSSC suffers. In the current study, efforts have been done to replace the heavy and expensive platinum cathode with a light and cost-effective carbon cathode. An attempt has been done to prepare the DSSC using Platinum and Carbon cathode under similar circumstances i.e. using Al-doped TiO_2 nanoparticles photoanode, eco-friendly Eosin Y dye has been used for sensitization of anode and iodine triiodide has been employed as the electrolyte. Study reveals carbon cathode can successfully replace the platinum cathode as the efficiency of DSSC using carbon cathode has been found to be greater as compared to the DSSC using the platinum cathode.

Keywords: Dye-sensitized solar cell, Al-doped TiO2 photo anode, carbon cathode, eosin Y dye,

I. INTRODUCTION

Dye-sensitized solar cells (DSSC), another class of third-generation hybrid solar cells, have been extensively studied since O'Regan and Gratzel reported 7.1% solar energy conversion efficiency in 1991 [1]. Actually, DSSC being an electrochemical sensing solar cell and does not rely on expensive or energy-intensive processing methods, offers a particular promise as an efficient, low-cost alternative to silicon semiconductor solar cells. Since the working principle of DSSC is the mimicry of the natural photosynthesis process, DSSCs are the most promisingly environmentally benign solar cells. Unlike silicon solar cells, DSSC uses sensing dye for light harvesting and electron transport which allows researchers to fine-tune each component separately and optimize the device's performance. Along with environmental friendliness, DSSCs pose attractive properties like flexibility, multicolored, and hence aesthetics [2].

In a typical DSSC, light photons are absorbed by a sensitizer, which is adsorbed to the surface of wide band gap semiconductor oxide. The sensitized nanoparticles of semiconductors in combination with the electrolyte and counter electrode produce the regenerative cycle of the photoelectrochemical cell [3]. In the literature, typical components of Dye-Sensitized Solar Cells (DSSCs),

Most often, doped or undoped titanium oxide (TiO_2) has been used as the wide band gap semiconductor oxide working as an anode, ruthenium complex dye employed as the most common and successful dye, and iodine tri-iodide is observed to be the traditionally used electrolyte whereas, Platinum coated FTO has been found to be frequently used as the cathode [3].

In our previous studies, Al-doped TiO_2 photo anode had been proven to be fruitful to increment the photovoltaic parameters i.e., photocurrent and efficiency of the DSSC [4-6].

Counter electrodes (Cathodes) have usually been prepared by depositing a thin layer of platinum (Pt) onto the FTO substrates. The FTO substrate without platinum coating can also work as the counter electrode however, its charge transfer resistance is very high of the order of mega ohm per square centimeter in iodine-triiodide electrolyte and hence, the platinum layer is deposited on the FTO to work as the catalyst. It reduces the oxidized form of the redox couple in the electrolyte so that the cathode material must be adapted to the redox system in the electrolyte. Although platinum is the most efficient catalyst for the counter electrode to date, the rarity and high cost of platinum make it unsuitable for low-cost DSSC. Hence, several other materials have also been adopted for the preparation of counter electrodes in DSSCs, such as conducting polymers such as poly (3,4-ethylene dioxythiophene) doped with toluene sulfonate anions, carbon materials, and cobalt sulfide, carbon black [7]. Moreover, platinum being heavy metal costs too high and elevates the overall cost of DSSC [8-9]. Whereas, DSSC comprised of carbon cathode has also been found to exhibit comparable results to that of the platinum cathode [10-15].

Considering the support of these studies, the current study of DSSC comprised of Al-doped TiO_2 nanoparticles photo anode sensitized by eosin Y dye has been further explored towards the cost-effective and environmentally benign DSSC by employing the carbon cathode.

In all summaries, the DSSC comprising of Al-doped TiO2 nanoparticles photo anode sensitized by Eosin Y dye was found to be leading towards attractive results to acquire the environmentally benign DSSC. Hence, the combination deserves further studies towards minimizing the cost by replacing rare and hence costly Platinum counter electrodes with abundantly available, low-cost carbon cathode. Hence, the present investigation deals with the comparative study of DSSCs comprised of Eosin Y dye-sensitized Al-doped TiO2 nanoparticles photo anodes along with carbon cathode and platinum cathode for the development of the cost-effective and environment-friendly device.

II. METHODS AND MATERIAL

A. Materials

Titanium Tetra iso-propoxide (TTIP) (Otto Chemicals, Germany), Eosin Y dye andChloroplatinic acid (H2PtCl6) (Ward Hill, U.S.A.), Aluminium Nitrate (Al(NO3)3) and Poly-ethylene Glycol (Otto Chemicals, India), Lithium iodide and iodine all reagents were used without further purification.

B. Experimental

1) Synthesis and characterization of doped TiO_2 nanoparticles

Al-doped TiO2 nanoparticles have been synthesized as described in previous studies[6-8] and characterized using Raman spectra and FTIR spectra.

2) DSSC Fabrication and Testing

The DSSCs were assembled as follows: cleaned fluorine-doped tin oxide (FTO, Sigma- Aldrich) conductive glasses of size 2*2 cm^2 have been used as the substrate. The semiconductor paste has been prepared using mortar and pestle as explained in previous studies (4-6).

The semiconductor layer of the Al-doped TiO_2 nanoparticles paste prepared has been coated on an area of 1×1 cm^2 by the doctor blade method and maintained at 10-12 μm by using a double layer of scotch tape. Thereafter, the TiO_2 layer coated on the FTO substrate has been sintered at 450ºC for 1 h to enhance the bonding between the semiconductor and the FTO glass. After cooling to 80ºC, the prepared photoanodes have been immersed into 0.3mM Eosin Y dye solution in ethanol for 24 hours at room temperature (30ºC). The Carbon counter electrode has been produced just by spattering the HB pencil on a 1cm area of FTO glass whereas, the Platinum counter electrode was deposited on cleaned FTO glass by drop-casting the Cloroplutanic solution. The dye-adsorbed photo anodes and counter electrodes have been assembled using a Surlyn polymer spacer, crocodile clips, and alligator pins. An electrolyte prepared using 0.05mM Iodine and 0.5mM lithium tri-iodide in Acetonitrile has been inserted in the space between two electrodes just before connecting forthe photovoltaic characterization. The performance of DSSCs was determined by an indigenous solar simulator under irradiation of 100mW/cm^2 (Iin). The current density-voltage (J-V) curves have been obtained on a source measurement unit (Keithley 4200) to obtain Jsc, Voc, and FF of DSSCs. The efficiency of DSSCs has been calculated using the formula,

$$\%\eta = \frac{\mathrm{Jsc} * \mathrm{Voc} * \mathrm{ff}}{\mathrm{Iin}} * 100\%$$

Where Voc open circuit voltage and Iscrepresent the short circuit current density and FF is the fill factor of DSSC and Iin is the intensity of incident light.

III. RESULTS AND DISCUSSION

In the previous research [4-6], the synthesis, characterization, and optimization of Al-doped TiO2 nanoparticles have been illustrated in detail. The summary of the experimental results can be shortly explained as; the cost-effective, easy, and robust sol-gel technique has been used for the synthesis of TiO2 nanoparticles, which reduces the carbon footprint of the final device.

A. FTIR Study of Aluminium doped TiO_2 nanoparticles

FTIR study confirms the Al-doped TiO_2 nanoparticles bond formation. Ti-O stretching vibrations are observed at 552 for Al-doped TiO_2 nanoparticles whereas bending vibrations of Ti-O-Ti have been observed at 611.86 per cm for Al-doped TiO_2 nanoparticles, indicating the formation of TiO_2 nanoparticles (figure 1).

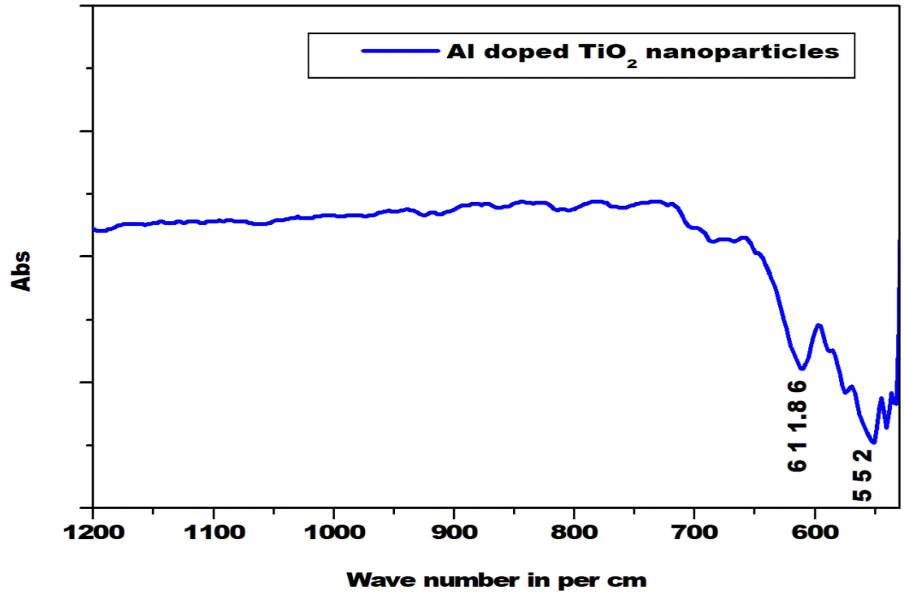

Figure 1:FTIR spectra of undoped TiO_2 nanoparticles,

B. Raman characteristics of Aluminium doped and undoped TiO2 nanoparticles

Raman spectroscopy has been found a very sensitive tool to confirm the phase of TiO_2 nanoparticles. Figure 2 shows the Raman spectra of undoped and Al-doped TiO_2 nanoparticles.

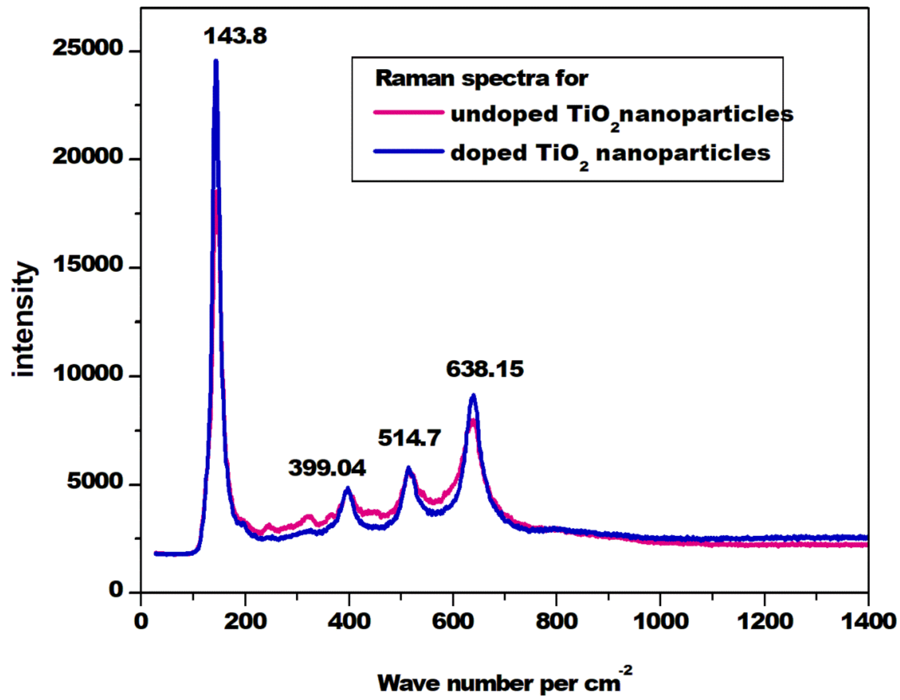

Figure 2:Raman spectra of TiO2 nanoparticles

Strong bands near 143.8, 399.4, 514.7, and 638.15 per cm have been observed for both undoped and Al-doped TiO_2 nanoparticles. According to factor group analysis, all of these have been assigned to the anatase phase and could be attributed to Eg, B1g, A1g, and Eg respectively [16]. SEM studies supported the spherical shape of nanoparticles (figure 3) and doping of Al in TiO_2 nanoparticles has been confirmed using EDX investigation

[5].Further, AFM investigation of the TiO_2 photo anode, focused on the surface roughness factor causing anchoring of more and more dye on the TiO_2 nanoparticles photo anode [6].

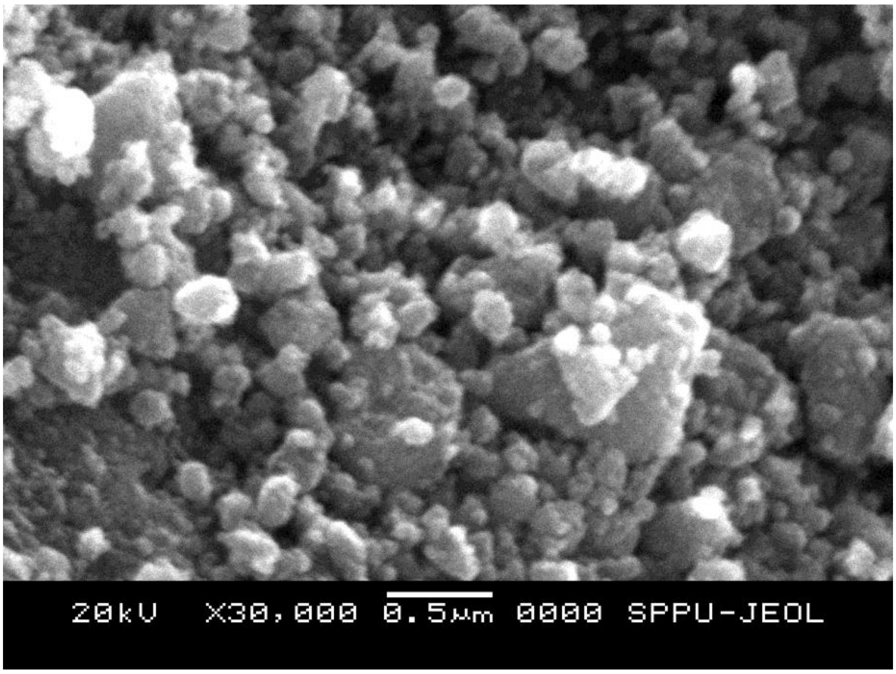

Figure3: SEM image of Al-doped TiO2 nanoparticles

C. Photovoltaic study of DSSCs

Figure 4 exhibits the comparative study of photovoltaic characteristics of the DSSCs using TiO2 nanoparticles photo anode and Platinum and Carbon cathode. The study reveals that in the case of the Al-doped TiO_2 photo anode DSSC also, the short circuit current has been found to be decreased when the platinum cathode of the DSSC was replaced by the carbon cathode. However, open circuit voltage has been increased by more than fivefold, and the efficiencyby 30 fold.

In Al-doped TiO_2 photo anode DSSC, the fill factor has been found to be increased comparatively when the platinum cathode has been replaced by a carbon cathode. Figure 4 exhibits the photovoltaic characteristics of the DSSCs using Al-doped TiO_2 nanoparticles photo anode and Platinum and Carbon cathode.

In all the devices the photo anode has been sensitized by eco-friendly Eosin Y dye. Table 1 shows the photovoltaic parameters of the DSSC comprised of Al-doped TiO_2 nanoparticles photo anode sensitized by Eosin Y dye and Platinum and Carbon coated photocathodes

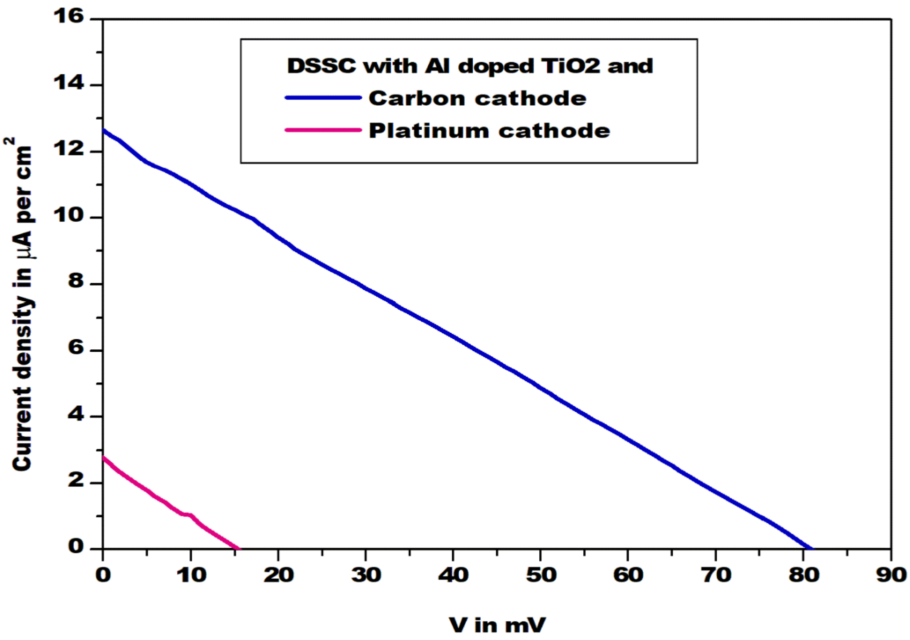

Figure 4: Comparative study of Photovoltaic characteristics of DSSCs using Al-doped TiO2 photo anode with platinum and carbon cathode

IV. CONCLUSION

It has been observed that the DSSCs using carbon cathode exhibits excellent result like an increase in open circuit voltage and efficiency, as compared to the DSSCs using Platinum cathode and the DSSCs using Al-doped TiO2 nanoparticles photo anodes sensitized by Eosin Y dye. Thus, the investigation leads to the conclusion that the carbon counter electrode could replace the platinum counter electrode to construct an eco-friendly DSSC using Al-doped TiO_2 nanoparticles photo anode sensitized by Eosin Y dye which will be a step towards eco-friendly DSSC.

Table 1: Photovoltaic parameters - maximum current density (Im), maximum voltage (Vm), Short circuit current density (Jsc), open circuit voltage (Voc), fill factor (FF), efficiency (η) using Eosin Y and Hibiscus dye

DSSC Fabricated using	Jsc (μAcm^{-2})	Voc (mV)	Im (μAcm^{-2})	Vm (mV)	FF	(%) η
0.05M Al-doped TiO_2nps& Pt cathode	12.6	15	1.4	10	0.07	0.00014
0.05M Al-doped TiO_2nps& C cathode	2.9	80	6.28	41	1.11	0.00300

V. REFERENCES

[1]. Brian O'Regan and Michael Gratzel, (1991), low cost, high efficiency Solar Cells based on Dye Sensitized Colloidal TiO2 film, Nature, 353, 737-739.

[2]. Jessika Crugger, Thesis number 2793(2003), Interface Engineering In Solid-State Dye-Sensitized Solar Cells, Federal institute of technology in Lausanne, Heidelberg, Germany.

[3]. Carmen Cavallo, Francesco Di Pascasio, Alessandro Latini, Matteo Bonomo, and Danilo Dini, (2017), Review Article: Nanostructured Semiconductor Materials for Dye-Sensitized Solar Cells, Journal of Nanomaterials, 2017, Article ID 5323164, https://doi.org/10.1155/2017/5323164

[4]. Swati S. Kulkarni, Gajanan A. Bodkhe, Sumedh M. Shirsat, S. S. Hussaini, N Nshejwal and Mahendra D. Shirsat, (2018), Dye Sensitized Solar Cell based on Environmental Friendly Eosin Y Dye and Al doped Titanium Dioxide Nano Particles, Mater. Res. Express, 5(3), 036205-036221, doi.org/10.1088/2053-1591/aab2d1

[5]. Swati S. Kulkarni, Gajanan A. Bodkhe, Pasha W. Sayyad, S. S. Hussaini and Mahendra D. Shirsat, Optimization OfAluminium Doping Concentration In Titanium Dioxide Nano Particles Photo Anode For Enhancing Efficiency Of Dye sensitized Solar Cell, under press

[6]. Swati S. Kulkarni, Gajanan A. Bodkhe, Pasha W. Sayyad, S. S. Hussaini and Mahendra D. Shirsat, Electrochemical Impedance Spectroscopic Study OfDye-Sensitized Solar Cell With Al Doped TiO2 Nanoparticles Photo Anode Sensitized By Eosin Y Dye, International Journal of Advance and Innovative Research, 6(1), 111-116

[7]. Shruti Agarkar, Thesis, Registration No.: 10CC12A26019, (2014), Dye sensitized solar cell: Optimizing materials, methods and optoelectronic effects, Thesis Submitted to AcSIR, Pune, India

[8]. Giuseppe Calogero, Antonino Bartolotta, Gaetano Di Marco, Aldo Di Carlo and Francesco Bonaccorso, Vegetable-based dye-sensitized solar cells, Chem. Soc. Rev., 2015, 44, 3244-3494.Doi. Org/10.1039/c4cs00309h

[9]. Fan Zhang, Feng Shi, Wei Ma, Fei Gao, Yang Jiao, Hui Li, Jingchuan Wang, Xinyan Shan, Xinghua Lu, and Sheng Meng, (2013), Controlling Adsorption Structure of Eosin Y Dye on Nanocrystalline TiO2 Films for Improved Photovoltaic Performances, J. Phys. Chem. C, 117, 14659-14666, dx.doi.org/10.1021/jp404439p

[10]. S.W. Rhee and W. Kwon,(2011), Key Technological Elements in Dye sensitized Solar Cells, Korean J. Chem. Eng., 28, 1481

[11]. Sang Hern Kim and Chang Woo Park,(2013), Novel Application of Platinum Ink for Counter Electrode Preparation in Dye Sensitized Solar Cells, Bull. Korean Chem. Soc. 34(3), 831-836

[12]. M. Gratzel ,(2003), Dye Sensitized Solar Cells, Journal of Photochemistry and Photobiology C: Photochemistry Reviews 4(2), 145–153

[13]. Souad A. M. Al-Bat'hi, Iraj Alaei, IisSopyan, (2013), Natural Photosensitizers for Dye Sensitized Solar Cells, International Journal Of Renewable Energy Research, 3(1), 138-143

[14]. Halil İbrahim Yavuz, Thesis, (2014), Design Of High-Efficiency Dye-Sensitized Nanocrystalline Solar Cells, Middle East Technical University, turkey

[15]. M. Kouhnavard, N. Ahmad Ludin, B. VazifehkhahGhaffari, K. Sopian, N. Abdul Karim, and M. Miyake, (2016), An efficient metal-free hydrophilic carbon as a counter electrode for dye sensitized solar cells, International Journal of Photoenergy, 2016, Article ID5186762, 7 pages,.

[16]. Y. Zhang, W. Wu, K. Zhang, C. Liu, A. Yu, M. Peng and J. Zhai, (2016), Raman Study of 2D Anatase TiO2 Nanosheets, Phys. Chem. Chem. Phys., 18(47), 32178-32184, DOI: 10.1039/C6CP05496J