Dye-sensitized solar cells fabricated using a novel, 2, 4 DFP dye and standard N-719 and Z-907 dyes: a comparative study

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We report on the sensitization of a novel dye and fabrication and characterization of dye sensitized solar cells (DSSCs) using the novel dye. The novel dye was tested for solar cell applications and the DSSCs fabricated with this dye were compared with DSSCs based on commercially available N719 and Ruthenium/5DN (Z-907) dyes. The devices fabricated with 2, 4 DFP dye shows efficiency of 0.90% while similar devices based on N-719 dye and Z-907 dye exhibit 3.005% and 6.59% respectively. The open circuit voltage of devices based on the novel dye is comparable to N719 dye and gives fill factor of about 73% (highest among the fabricated solar cells), which shows high quality of the devices based on novel dye

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Photovoltaic (PV) power is one of the well-known subjects among all the clean energy sources. A significant fraction of the cost of solar panels comes from the photoactive materials and sophisticated processing technologies. Recently, it has been shown that the inorganic materials can be replaced by inexpensive and easily synthesizable semiconducting polymers capable of achieving reasonably high power conversion efficiencies. In 1991 O' Regan and Gratzel [1, 2] developed a new type of PV cell, called Dye-sensitized solar cells (DSSCs) which have lower cost of production and environment friendly nature. The high efficiency, i.e. approaching to the direct conversion of light into electrical power has recently attracted large research interest into these devices.

In the DSSC's, photons from sun are absorbed by a monolayer of charge-generated molecular dye sensitizer that is covalently bonded to the surface of a nonporous semiconducting film surface (TiO_2, ZnO_2 etc) as shown in Fig. 1a. Photo-excitation results from light absorption by the dye and the injection of excited electrons into conduction band of the TiO_2 oxide layer occurs. Electrons and holes recombination does not quickly occur in the film, therefore electrons diffuses toward the transparent conductive oxide films (ITO, FTO etc) and reaches the electrical contact and hence to the external circuit. The original or normal state of the dye is achieved simultaneously by electron donation from the electrolyte (usually based on I-/I3- couple in organic solvents) reaction.

The state of the art efficiency of DSSCs is 11-12% [3-5]. A lot of research is currently in progress related to increasing stability and efficiency, avoiding electrolyte loss due to the leakage or volatility of the electrolyte solution. Many types of dyes have been developed for better performance of DSSCs. Different dye groups such as organic metal complexes, natural dyes organic dyes are used in DSSCs [4-7]. The Ruthium (Ru) based dyes such as N3 and N-719 are mainly used in the DSSCs [1- 7].

We report on the sensitizing a novel dye (2,9-bis(2,4-difluorophenyl)-5,6,12,13-tetrakis(p—tolyloxy) anthra [2,1,9 def:6,5,10-d'e'f']diisoquinoline-1,3,8,10(2H,9H)-tetraone (2,4 DFP).) for solar cells applications and fabrication of DSSCs using different dyes and their comparison. The efficiency of novel 2, 4 DFP based solar cell is less than that of N-719, Z-907 based similar devices while the open circuit voltages of novel 2, 4 DFP dye is comparable to that of N719 device. The fill factor (FF) of the devices based on the novel dye is 73% while the FF of devices fabricated using N-719 and Z-907 is 56.8% and 29.4% respectively.

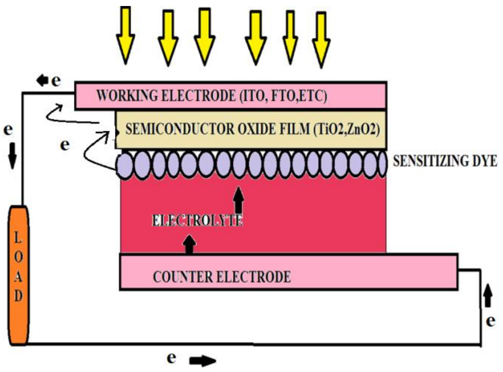

Fig. 1. Schematic of DSSC showing different layers of the device

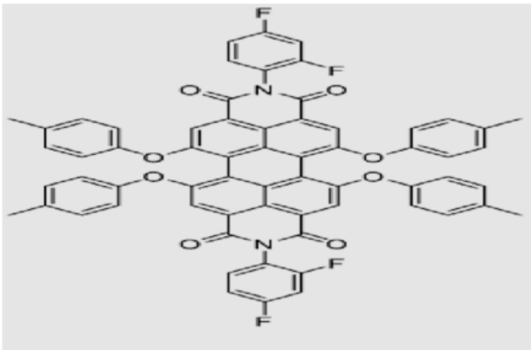

Fig. 2. Structure of the sensitized 2,9-bis(2,4-difluorophenyl)-5,6,12,13-tetrakis(p—tolyloxy)anthra[2,1,9 def:6,5,10-d'e'f']diisoquinoline-1,3,8,10(2H,9H)-tetraone dye

1. Devices fabrication

The 2, 4 DFP dye is sensitized by modifying the PTCDI dye (also called as Energy relay dyes). The structure of the 2, 4 DFP dye is given in Fig. 2. It has highest occupied molecular orbital (HOMO) of -4.4653eV and lowest unoccupied molecular orbital (LUMO) is -2.9593ev. The band gap is 1.506eV. The DSSCs based on this novel dye were compared with the DSSCs based on N719 and Z907 standard dyes.

To fabricated the DSSCs, the Indium doped Tin Oxide (ITO) coated substrates with surface resistance of 150Ω/sq) were first cleaned in a detergent solution using an ultrasonic bath for 10 min then rinsed with de-ionized (DI) water. The ITOs were dipped in Ethanol and IPA and sonicate for 10 minutes and blow dried. The TiO_2 dense layer (made from solution of 20ml of tri-isopropoxide, 14ml of acetyl acetone and 52 ml of ethanol) was deposited on ITO by spin coating. To deposit TiO_2 nanoporous layer, Ti-nanoxide paste was prepared using 5.5g of TiO_2 powder P25 (Degussa), 120 ml of ethanol, 0.5ml of Ti-isopropoxide and few drops of Triton x-100. The Ti-nanoxide paste was deposited on the ITO conductive glass using doctor blade technique. TiO_2 nanoporous layer of 35 µm thickness with an area of 5cm^2 was obtained. The TiO_2 film was annealed at 450 ˚C for 60 min. The TiO_2 coated ITO electrodes were immersed in three different dyes solutions (i-e 2, 4 DFP, N719, Z907) which were prepared by using ethanol as solvent with 3×10 -4 M solution, for 12 hours.

Subsequently, counter electrode (CE) was prepared by coating carbon on conductive side of another ITO glass substrate. The dye-sensitized TiO_2 electrode and a carbon coated CE were assembled to form a solar cell by sandwiching a redox (I−/I3−) electrolyte solution. The electrolyte solution was prepared by mixing 0.10M KI and 0.015M I2 dissolved in ethylene glycol. Two binder clips were used to hold the working and counter electrodes together. The Schematic of fabricated dye-sensitized solar cell is shown in Fig. 3.

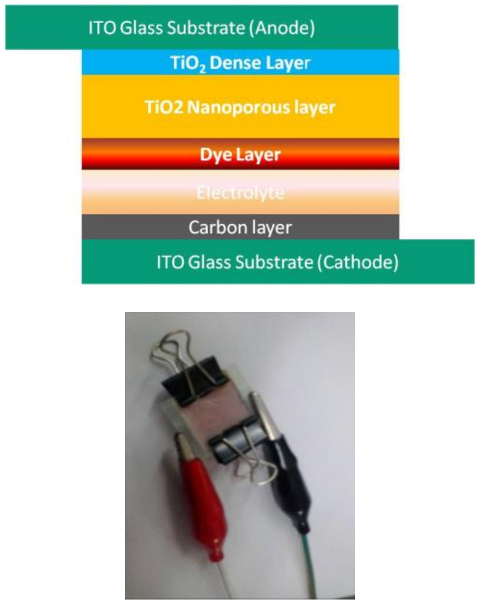

Fig. 3. (a) Shows the schematic of fabricated DSSC (b) Shows the picture of fabricated DSSC

2. Devices characterization

Three different types of devices were fabricated using three different dyes. The current voltage (IV) characteristics, UV transmission and absorbance spectra were measured. To measure the IV characteristics, the devices were connected to a Keithly source meter (Model 2420) using crocodile clips, as shown in Fig. 3b. The IV characteristics were measured under solar radiation intensity of about 100W/cm^2. The UV transmission and absorption spectra of the devices was measured by SPECORD 200 which was connected to a computer.

3. Experimental results

Photovoltaic tests of DSSCs using 2, 4 DFP, N-719 and Z-907 dyes as sensitizers were performed by measuring the current–voltage (I–V) curves as shown in Fig. 5. The Fig. 4 shows the transmittance and absorbance curves for dye dipped TiO2 substrate. The performance of these dyes as sensitizers in DSSCs was evaluated by the fundamental results such as conversion efficiency (η), an open circuit voltage (V_{oc}), a short circuit current density (J_{sc}) and a fill factor (F.F). The better solar conversion efficiency among the fabricated cells was obtained by Z-907 dye and least performance was obtained by the cell fabricated using novel 2, 4 DFP dye as displayed in Table 1 and Fig. 5, however V_{oc} of DSSC with novel dye is compatible to V_{oc} of device using N719. The V_{oc} varies from 0.429 to 0.76V, and the I_{sc} changes from 0.144 mA to 5.88 mA for devices fabricated using different dyes. High V_{oc} (0.76 V) and J_{sc} (2.94mA/cm^2) were obtained from the DSC sensitized by Z-907 with efficiency 6.59%.

The photo-electrochemical parameters of the DSSCs sensitized with above three dyes are summarized in Table 1.

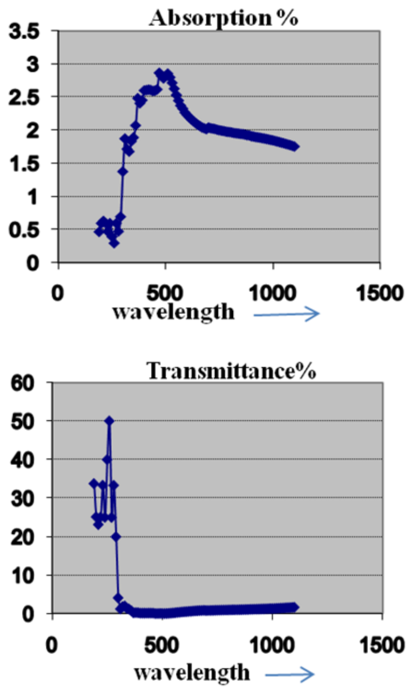

Fig. 4. Transmittance (a) and Absorption (b) graphs for dye dipped TiO_2 substrates

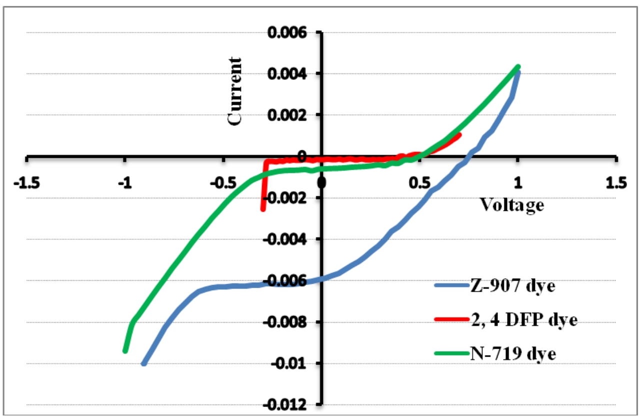

Fig. 5. I-V curves of devices based on 2, 4 DFP, N719 and Z907 dyes

Table 1. Measured parameters for DSSCs using 2, 4 DFP, N719 and Z907 dyes

Dye	I_{sc} (mA)	V_{oc} (V)	I_{max} (mA)	V_{max} (V)	Jsc (mA/cm^2)	FF (%)	η
2,4 DFP	0.144	0.42	0.146	0.31	0.028	73.2	0.90
N-719	0.54	0.49	0.43	0.32	0.108	56.8	3.005
Z-907	5.88	0.76	3.38	0.39	2.94	29.4	6.59

4. Conclusions

Three dyes namely 2, 4 DFP (novel dye), N-719 and Z-907, were used as sensitizers for the fabrication of DSSCs. The TiO_2 films were deposited on ITO layers by the doctor blade process and carbon -coated counter electrode and liquid Iodide/ tri-Iodine electrolyte solution were used to fabricate DSSC's. The photo electrochemical performance of the DSSCs based on these dyes showed that the V_{oc} ranged from 0.42–0.76 V, and J_{sc} is in the range from 0.02–2.94 mA/cm^2. The DSSC fabricated using Z-907 dye offered the highest conversion efficiency of 6.59% among the three different types of devices based on different dyes. The V_{oc} (i.e. 0.42 V) of the novel 2, 4 DFP dye is comparable to that of the DSSC sensitized by a Ru complex N-719. The fill factor (FF) of the devices based on the novel dye is 73% while the FF of devices fabricated using N-719 and Z-907 is 56.8% and 29.4% respectively.

The conversion efficiency is expected to be further improved by introducing functional groups, such as the carboxyl group or by increasing dye dipping time.

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