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Efficiency enhancement of Dye-Sensitized Solar Cells using Gel Polymer Electrolytes

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Abstract

Sustainable development is the prime criterion for the conservation of natural resources and to keep an environmental balance between conserving natural resources such as coal, gas and oil, which are non-renewable sources of energy, it is necessary to introduce renewable sources of energy such as solar, tidal, wind and geothermal. Solar energy has shown great potential in the last two decades due to Sunlight readily available source. Different photovoltaics like organic and inorganic are developed in the previous several years for power generation in various applications. At present silicon-based solar cells are commercialized as they have shown good conversion efficiency compared to other solar cells and good stability in terms of life. However, the high price and complex fabrication process limit its application. For these reasons, researchers are looking forward to organic photovoltaic cells out of which dye-sensitized solar cell shows good efficiency, low cost of fabrication, and easy process of construction. In this paper, the cost-effective and easy fabrication process is used to fabricate four types of Dye-sensitized solar cell Dye-sensitized solar cell (DSSC) using onion peel dye sensitizer, polymethylmethacrylate (PMMA), and triiodide-based gel polymer electrolyte (GPE). All four Dye-sensitized solar cell (DSSC) have a different ratio of PMMA gel and Triiodide as liquid Electrolyte (LE). Out of these four fabricated DSSC's, the DSSC which has 80:20 liquid and gel solution provided the highest efficiency of range 11.32%. All the dye-sensitized solar cells are tested under the solar luminance of 37.288 mW/cm2. A maximum open-circuit photovoltage of 0.386 V with a fill factor of 0.439 made it the best proto-model to be used for practical applications.

Keywords: Dye-sensitized solar cell (DSSC), Onion peel dye sensitizer, PMMA, Triiodide, Liquid Electrolyte, Gel polymer electrolytes, efficiency.

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1. Introduction

Presently, fossil fuels (coal, oil, gas) act as a major source of energy, but are perishable [11], [6]. [3]. Burning of these fuel releases hazardous gases like carbon dioxide, sulfur dioxide, etc., which is the primary cause of global warming is that these fuels are non-renewable [17],[20]. So, renewable energy sources (Solar, wind, geothermal, Biomass, Biofuel) are emerging as the best substitute for declining fossil fuels [7], [3].

Solar energy is available free available of cost, is a clean source, and possesses low operating cost [2], [7] and can be easily converted into electricity using a solar cell with the help of photovoltaic effect [11], [6]. So, it has been coming into use as a sustainable source of energy [7]. Silicon solar cell has a high conversion efficiency of 15% to 18% for a commercially available cell and 25% overall conversion efficiency. Still, it has limited applications and usage due to its high production cost, environment hazards

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and difficult production techniques [6], [17]. To reduce the production cost of silicon solar cells, a second-generation thin-film solar cell was introduced having amorphous silicon. Still, it gives low efficiency correlates to silicon solar cells [7]. The third-generation solar cell is dye-sensitized solar cell introduced by Micheal Gratzel and Brian O Regan in 1991 using iodine as an electrolyte which gave an efficiency of 7.9% in Sunlight and 12% in low light [7], [10], [16],[20]. Currently, the maximum efficiency of DSSC is 14.3% [14], [4]. The basic structure for the fabrication of DSSC has Fluorine doped tin oxide (FTO)/Indium doped tin oxide (ITO) coated glass, Titanium dioxide (TiO_2), dye (ruthenium, organic), Electrolyte (Liquid and Polymer electrolyte), platinum or graphite glass substrate [6], [2]. FTO/ITO coated glass having a TiO2 layer act as an anode, and FTO/ITO coated glass having a Platinum/Graphite layer act a cathode or counter electrode [6].

FTO/ITO coated glass (15 Ω/sq) or Transparent conducting glass is used because it offers good light transmittance and good conductivity inner charge carriers to outer terminals [9], [6]. The dye used for the fabrication of DSSC should be such that it releases electrons when light strikes it [18]. The dye extracted from plants, flowers, vegetables, and even plants' roots is called natural dyes. It has anthracene content in which acts as a catalyst for the liberation of photon [1]. The most common electrolytes used for fabrication of Dye Sensitised Solar Cell (DSSC) are liquid electrolyte (Triiodide, iodine), quasi solid-state electrolyte (polyethylene oxide redox electrolyte, polyvinylidene fluoride, polyethyleneimine, polymethylmethacrylate) or solid-state electrolyte (Spiro OMETAD, poly-3-hexilthiophene) [12], [22], [15], [19]. Liquid electrolytes face problems like leakage and evaporation, which decreases the life span of Dye Sensitised Solar Cell (DSSC). To solve such problems of leakage, quasi solid and solid-state electrolytes are used [8]. The main function of Electrolyte is to transfer an inner electron to outer terminals, and it also regenerates the dye. The counter electrode or cathode is made up of FTO/ITO coated with platinum or graphite layer. Platinum and graphite layer increases the electron conduction [6], [5].

2. Performance Parameters of DSSC

Different performance parameters of DSSC are fill factor, open-circuit photovoltage, short circuit current density, incident photon conversion efficiency, and energy conversion efficiency [11].

$$\text{Fill Factor (FF)} = \frac{Vm \times Jm}{Voc \times Jsc} \quad (1)$$

Where, Voc = Open circuit photovoltage of DSSC (V), Jsc = short circuit current density (mA/cm2), Vm = voltage of DSSC across load and Jm = Current density across load

$$\text{Energy conversion efficiency } (\eta\ \%) = \frac{Voc \times Jsc \times FF}{Pin} \quad (2)$$

Where, P_{in} = Incident optical power (mW/cm^2).

3. Materials and Methods

3.1 Experimental Technique & Mathematical Analysis

i) Fabrication of DSSC: The materials required for the preparation of organic dye is 6gm of Onion peel, 250 ml of distilled water, 2 ml of dilute acetic acid (M.W 60.05), To prepare Titanium Dioxide: 4 gm of Titanium dioxide 98% (TiO_2), 2 ml of Triton X-100, 10 ml of de-ionized water. To prepare liquid Electrolyte, 525 mg of Potassium iodide, 336 mg of iodine, 21 ml of distilled water, 73.5 ml of Acetic acid is needed. For the preparation of Polymer Electrolyte: 25 gm of polymethylmethacrylate (PMMA), 35gm of Propylene carbonate (PC) (M.W 102.09), 40 gm of Ethylene carbonate (EC) (M.W 88.06), 100 gm of Tetrahydrofuran (THF) (M.W 72.11), is required. FTO glass sheets (L25mm×W25mm×T2.2mm) (resistivity < 15 Ω/sq), Graphite pencil, Alligator clip, filter paper, scotch tape

ii) Equipment and apparatus required: Incubator, Oven, Magnetic stirrer, Hot plate, Beakers, Glass tubes, Glass rod, Flask, Digital balance are also part of the fabrication process.

3.2 Preparation of Natural Dye

The dye is prepared, as shown in figure 1. The process for preparing natural dye involves the following steps:

Figure 1. Steps for Dye preparation

a) Disperse onion peel distilled water in a flask and
b) place the flask in an incubator for 24 hours at 90°C. After 24 hours, the dye is ready for use.
c) Filter the Dye and Store the Dye in a dark place [1].

3.3 Preparation of Titanium Dioxide

TiO_2 is prepared, as shown in figure 2. The preparation steps involve the following steps:

Figure 2. Steps of making TiO_2 slurry solution.
a) Mix dilute acetic acid, Titanium dioxide, Triton X-100, and de-ionized water in a beaker.
b) Stir the solution for 2 hours. After 2 hours TiO_2 solution is ready for use.

3.4 Preparation of Liquid Electrolyte

Liquid Electrolyte is prepared, as shown in figure 3. dissolve potassium iodide (KI) and I2 into distilled water and acetic acid. Stir it with a magnetic stirrer for at least 15 minutes or until I2 has dissolved. The final solution will be a rich dark brown colour [13].

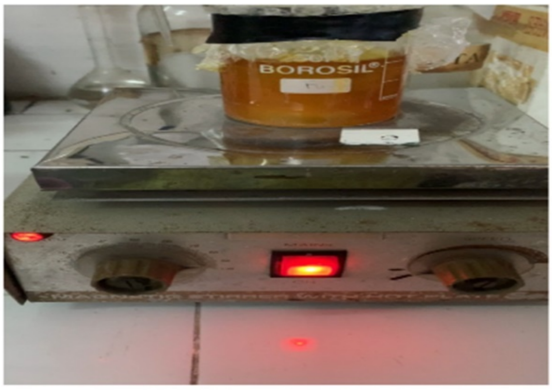

Figure 3. Preparation of liquid Electrolyte

3.5 Preparation of Quasi Solid-State Electrolyte

Quasi solid-state Electrolyte is prepared by mixing Triiodide (liquid Electrolyte) in PMMA based gel solution. The gel solution is prepared by dissolving the PMMA crystals, THF, PC and EC in a beaker. This mixture is stirred by using a magnetic stirrer at 70°C for 20 minutes. The gel solution is ready. THF dissolves PMMA crystals. PC and EC enhance the ionic conductivity of the gel solution. EC also plasticized Electrolyte [21].

Four electrolytes are prepared by varying the liquid Electrolyte and gel solution ratio, as shown in table 1. After mixing in a definite ratio, all four electrolytes are stirred using a glass rod and then place in an oven at 70°C for 25 minutes. Electrolytes are placed in an oven for evaporation. After 25 minutes, all four electrolytes are ready for use. Store it in a dark place.

Table 1. Final quasi solid-state electrolyte solutions

Electrolytes	Percentage Ratio of Liquid Electrolyte	Percentage Ratio of Gel-Solution
I. Electrolyte (A)	80%	20%
II. Electrolyte (B)	70%	30%
III. Electrolyte (C)	60%	40%
IV. Electrolyte (D)	50%	50%

The percentage combination of liquid and gel electrolyte is shown in table 1. The quasi solid-state electrolyte solutions are shown in figure 4.

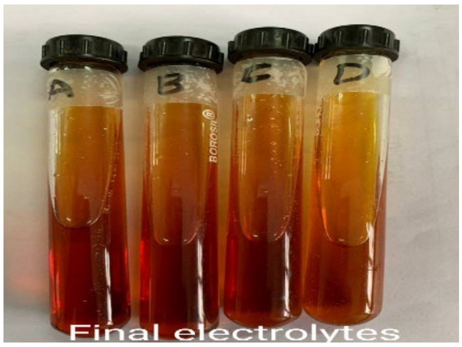

Figure 4. Quasi solid-state electrolyte solutions

3.6 Fabrication of Dye-Sensitized Solar Cell

For preparing four prototype sample models, the steps enlisted in the flowchart in figure 5 were followed.

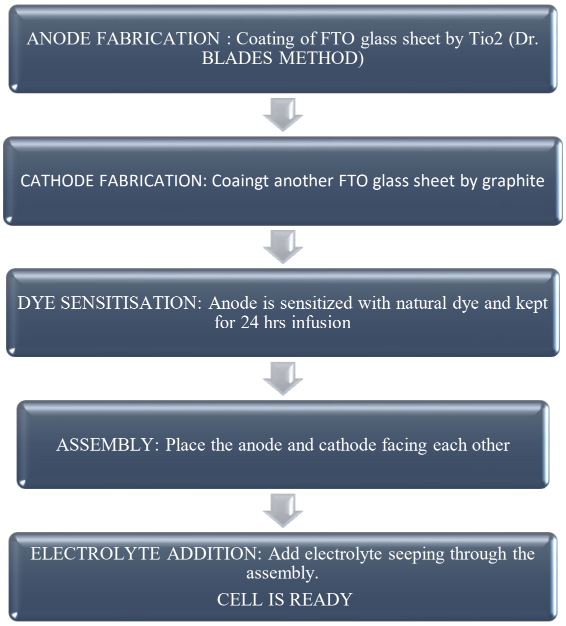

Figure 5. Steps of fabrication

3.7 Mathematical Modelling

Calculations of Fill Factor and Incident Photoenergy Conversion Efficiency were done for all four samples of DSSCs, as shown in figure 6 prepared by different ratios of electrolytes. The output depicted that sample A had the best FF & efficiency.

Figure 6. DSSC's Models ready for testing

The experimental set up for calculations for all four samples and the equivalent circuit for the setup is shown in figure 7.

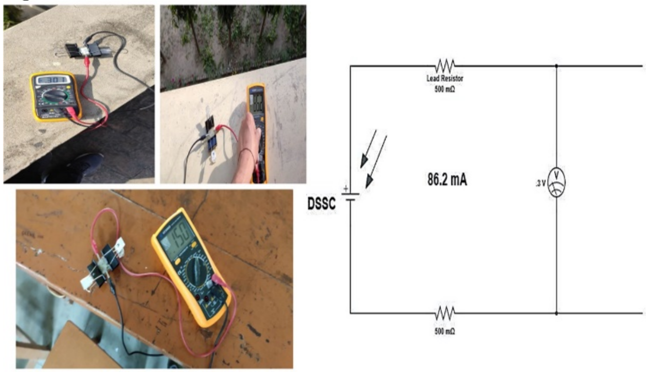

Figure 7. Experimental set up of the cell for efficiency calculations & equivalent circuit model for the same

3.7.1 Electrolyte Sample A based DCCSs Mathematical Modeling

Obtaining the equivalent circuit, as shown in figure 7, from the experimental setup made based upon the DSSC fabricated using electrolyte sample A, the following observation, as shown in Table 2, were made.

Table 2. Observations made for electrolyte sample A for load and no-load conditions.

Voltage at no light (V)	Voltage at no load (at light), Voc (V)	Voltage on load (under solar light), Vm (V)	Current at no load (under solar light), Isc (mA)	Current at load (under solar light), Im (mA)
0.15	0.0382	0.3	155.72	86.2

According to these observations obtained, the following set of calculations for finding the performance parameters, i.e. fill factor and efficiency of the cell were done

Maximum current density is given as J_m

$$Jm = \frac{Im}{A}, \tag{3}$$

Similarly, short circuit current density is calculated as

$$Jsc = 24.96 \text{ mA/cm}^2 \tag{4}$$

$Isc = V_{oc} / R_{dssc}$ from circuit (5)

Fill factor can be explored using

$$FF = \frac{Jm \times Vm}{Jsc \times Voc}; \tag{6}$$

Calculation of Incident Photoenergy Conversion Efficiency

$$\eta = \frac{Voc \times Jsc \times FF}{Pin(mWATT/cm2)} \times 100 \tag{7}$$

Table 3. Performance parameters of sample A

Maximum current density (mA/cm^2)	short circuit current density (mA/cm^2)	Open circuit voltage (V)	Short circuit current (mA)	Fill factor	Efficiency (%)
13.792	24.961	0.386	155.72	0.439	11.32

The various performance parameters of sample A are shown in table 3, which shows that this sample has 11.32% efficiency.

3.7.2 Electrolyte Sample B based DCCSs Mathematical Modeling

Obtaining the equivalent circuit, as shown in figure 7, from the experimental setup made based upon the DSSC fabricated using electrolyte sample B, the following observation, as shown in Table 4, were made.

Table 4. Observations made for electrolyte sample B for load and no-load conditions.

Voltage at no light (V)	Voltage at no load (at light), Voc (V)	Voltage on load (under solar light), Vm (V)	Current at no load (under solar light), Isc (mA)	Current at load (under solar light), Im (mA)
0.1764	0.3763	0.303	120.1	73.32

According to these observations obtained, the following set of calculations for finding the performance parameters, i.e. fill factor and efficiency of the cell were done, as shown in table 5.

Table 5. Performance parameters of sample B

Maximum current density (mA/cm^2)	short circuit current density (mA/cm^2)	Open circuit voltage (V)	Short circuit current (mA)	Fill factor	Efficiency (%)
11.72	19.216	0.377	120.4	0.492	9.58

3.7.3 Electrolyte Sample C based DCCSs Mathematical Modeling

Obtaining the equivalent circuit, as shown in figure 7, from the experimental setup made based upon the DSSC fabricated using electrolyte sample C, the following observation, as shown in Table 6, were made.

Table 6. Observations made for electrolyte sample C for load and no-load conditions

Voltage at no light (V)	Voltage at no load (at light), Voc (V)	Voltage on load (under solar light), Vm (V)	Current at no load (under solar light), Isc (mA)	Current at load (under solar light), Im (mA)
0.14	0.379	0.318	89.22	60.6

According to these observations obtained, the following set of calculations for finding the performance parameters, i.e. fill factor and efficiency of the cell were done

Table 7. Performance parameters of sample C

Maximum current density (mA/cm^2)	short circuit current density (mA/cm^2)	Open circuit voltage (V)	Short circuit current (mA)	Fill factor	Efficiency (%)
14.27	14.275	0.379	89.22	0.57	8.27

The performance parameters of sample c are shown as in table 7.

3.7.4 Electrolyte Sample D based DCCSs Mathematical Modeling

Obtaining the equivalent circuit, as shown in figure 7, from the experimental setup made based upon the DSSC fabricated using electrolyte sample D, the following observation, as shown in Table 8, were made.

Table 8. Observations made for electrolyte sample D for load and no-load conditions

Voltage at no light (V)	Voltage at no load (at light), Voc (V)	Voltage on load (under solar light), Vm (V)	Current at no load (under solar light), Isc (mA)	Current at load (under solar light), Im (mA)
0.0734	0.3304	0.277	78.91	53.4

According to these observations obtained, the following set of calculations for finding the performance parameters, i.e. fill factor and efficiency of the cell were done. Table 9 shows the various performance parameters of sample D.

Table 9. Performance parameters of sample D

Maximum current density (mA/cm^2)	short circuit current density (mA/cm^2)	Open circuit voltage (V)	Short circuit current (mA)	Fill factor	Efficiency (%)

8.54	12.626	0.33	78.91	0.56	6.34

Calculations of P(in) from Lux meter

Figure 8. Observation for lumens using a lux meter

For the sun, there is an approximate conversion of 0.0079W/m2 per Lux.

So, as read on Lux meter, 472 Klux can be converted to 47200 Lux and further to 47200 X 0.0079 = 372.88 W/m2, which is also read as 37.288 mW/cm^2 for calculation of efficiency as P(in)

$$\eta = \frac{Voc \times Jsc \times FF}{Pin(mWATT/cm2)} \quad (8)$$

where P(in) = 37.288 mW/cm2

4. Results and Discussions

The performance parameters, i. e. the voltage at diffused light, open-circuit voltage, short circuit current density, and fill factor, were calculated. Further efficiency was determined for the cells fabricated based on the four samples of electrolytes hence prepared. Table 10 shows the comparative efficiencies of the DSSCs based on different samples.

Table 10. Performance comparison of various DSSC's

DSSC' s	Voltage at diffused light (V°) (V)	Open circuit photovoltage (Voc) (V)	Short circuit current density (Jsc) (mA/cm2)	Fill Factor	Efficiency (%)
A	0.15 V	0.386 V	24.91	0.439	11.32
B	0.176 V	0.376V	19.21	0.492	9.58
C	0.14 V	0.379V	14.27	0.57	8.27
D	0.073 V	0.33 V	12.62	0.567	6.34

DSSC based on electrolyte sample A produced the highest efficiency of 11.32 % among all DSSC's. A maximum open-circuit photovoltage of 0.386 V with a fill factor of 0.439 made it the best proto-model to be used for practical applications. Efficiencies of DSSC based on sample B, C & D were also studied along with the calculations of fill factors they produced. The comprehensive graphs depicting the same are shown in figure 9.

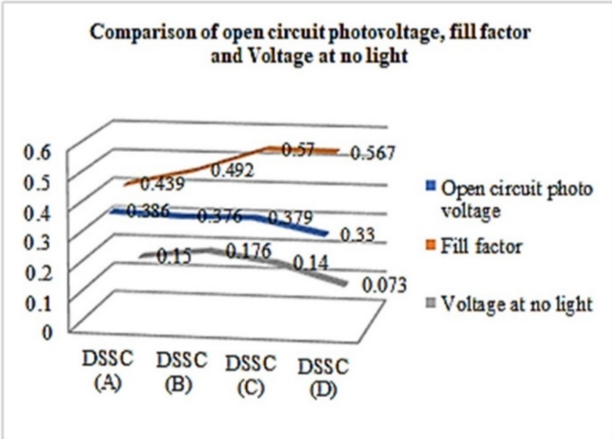

Figure 9. Performance comparison of DSSC's based on open circuit photovoltage, fill factor and voltage at no light

Figure 9 shows DSSC (C) gives the best fill factor of 0.57 and DSSC(A) gives the lowest fill factor of 0.439. DSSC (B) gives the best voltage at no light of 0.176V, and DSSC (D) gives the lowest voltage at no light of 0.073 V. DSSC (A) gives the best open-circuit photovoltage of 0.386V, and DSSC (D) gives lowest open-circuit photovoltage of 0.33V.

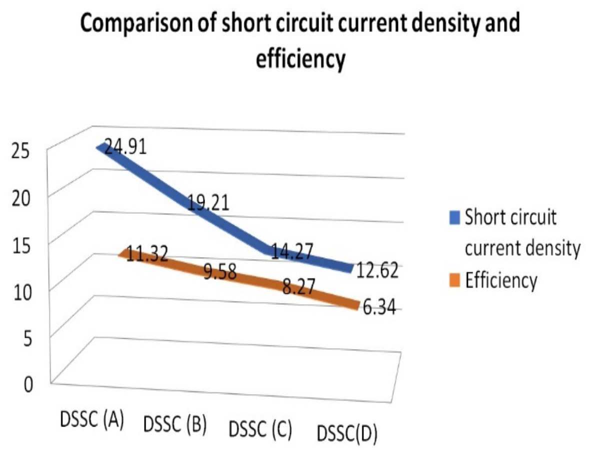

Figure 10. Performance comparison of DSSC's based on short circuit density and efficiency

Figure 10 shows DSSC (A) gives the best short circuit current density of 24.91 mA/cm2 and DSSC (D) gives the lowest short circuit current density of 12.62 mA/cm2. It also shows that DSSC (A) has the best efficiency of 11.32% and DSSC (D) has the lowest efficiency.

5. Conclusion and scope of further study

In this research article, four prototype models of Dye Sensitized Solar Cells (DSSC) are fabricated using onion peel based (organic) dye and polymethylmethacrylate based quasi solid-state Electrolyte and analyzed by using mathematical equations. Out of the four combinations, the first combination of gel polymer and liquid Electrolyte in a ratio of 20:80 shows the best efficiency (11.32%) in comparison to other three samples B, C and D which are capable of producing efficiency of 9.58%, 8.27% and 6.34% respectively. The fabricated solar cell's efficiency is still lesser than silicon-based solar cells but has a simpler and cost-effective method for fabrication gains popularity. If these cells' life time is increased alongside efficiency, the overall production cost will be reduced relatively. As a futuristic scope to this work, the cell's reliability can be studied to predict the cell's lifetime. When such Dye Sensitized Solar Cells (DSSC) are exposed to a real-time environment, its performance and efficiency may degrade. The sudden failure of one component can further shut down the complete system. So, by analyzing the fabricated cell's remaining useful lifetime, the better performance, long life, and successful operation can be assured.

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