Dependence of the characteristics of dye-sensitized solar cells on amount tetrapropylammonium iodide

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В данной работе было подготовлено несколько жидких электролитов (LE). Электролиты содержат соль йодида тетрапропиламмония (TPAI) с различным содержанием соли, пропиленкарбонат (PC), этиленкарбонат (EC), полиэтиленоксид (PEO), диметилформамид (DMF) и (I/I^{3-}) окислительно-восстановительную пару. LE был использован в DSSC. Были изготовлены DSSC и измерены характеристики плотности тока (J-V). Самая высокая эффективность преобразования падающих фотонов (IPCE) при 520 нм составляет 45.5% для DSSC с 0.25 г TPAILE. В AM1,5 DSSC с LE демонстрирует эффективность 6,61% с J_{sc}=18,69мА $см^{-2}$, V_{oc}=0,68В и коэффициентом заполнения (FF)=0,52.

Ключевые слова: ионная проводимость; жидкий электролит; сенсибилизированный красителем солнечный элемент (DSSC); тетрапропиламмоний йодид (TPAI).

In this work, several liquid electrolytes (LE) have been prepared. The electrolytes contain tetrapropylammonium iodide (TPAI) salt with different salt content, propylene carbonate (PC), ethylene carbonate (EC), polyethylene oxide (PEO), dimethylformamide (DMF) and (I^-/I^{3-}) redox couple LE was used in the Dye-Sensitized Solar Cell (DSSC). DSSCs were fabricated and current density-voltage (*J-V*) characteristics measured. The highest incident photon conversion efficiency (IPCE) at 520 nm is 45.5% for DSSC with 0.25 g TPAI LE. At AM 1.5, DSSC with LE exhibits efficiency of 6.61% with J_{sc}= 18.69 mA cm^{-2}, V_{oc}= 0.68V and fill factor (FF) = 0.52.

Keywords: Ionic conductivity; liquid electrolyte; dye-sensitized solar cell (DSSC); tetrapropylammonium iodide (TPAI).

I. Introduction

Dye-sensitized solar cells (DSSC), being one of the topmost popular and fast growing solar renewable energy, are flexible, low in cost and simple to fabricate [1]. Moreover, they can be operated under diffused light condition and used for indoor applications [2]. A DSSC primarily consists of three elements i.e. redox mediator-containing electrolyte sandwiched between dyed photo anode and counter electrode. The electrolyte is one crucial constituent in restoring the dye rejuvenation by means of oxidation [3]. A typical electrolyte for DSSC is in liquid form. The redox couple is a key component of the DSC. The reduced part of the couple regenerates the photo-oxidized dye.The formed oxidized species diffuses to the counter electrode, where it is reduced. The photovoltage of the device depends on the redox couple because it sets the electrochemical potential at the counter electrode. The redox couple also affects the electrochemical potential of the TiO_2 electrode through

the recombination kinetics between electrons in TiO_2 and oxidized redox species [4]. Using liquid electrolyte (LE), the highest photo conversion efficiency of 14.3% has been attained owing to its excellent ionic conductivity [5].

In this work, we have prepared LE varying amount and the influence of this type of electrolyte on the performance of DSSCs will be presented. The polymer chosen here is polyethylene oxide (PEO) which is a synthetic polymer with monomer unit –CH_2CH_2O–PEO was first used as polymer host for electrolyte in solid form by Prof. P.V. Wright in 1975 [6]. Since then, it has become one of the most popular polymer matrices as it is capable of solvating many types of salts in high concentration. The LE contain the same ingredients, i.e. tetrapropylammonium iodide (TPAI) salt, ethylene carbonate (EC), propylene carbonate (PC) and iodine (I_2) crystals. Additionally for LE, dimethylformamide (DMF) is used to dissolve PEO. TPAI salt is preferred here as it is deemed as the best performing salt following the work of Bandara et al. [6].

II. Experimental

II.1. Electrochemical Impedance Spectroscopy of Liquid Electrolyte

The electrolyte was placed between two stainless steel electrodes of 2 cm diameter. Impedance measurement was carried out using the HIOKI 3531 Z Hi-Tester at room temperature (RT) from 50 Hz to 100 kHz [7, 8]. The bulk resistance (ρ) of the electrolyte was obtained at the point of intersection of the impedance data with the real impedance axis of the Nyquist plot. The ionic conductivity (σ) for every sample was calculated following the equation [9, 10, 11]:

$$\sigma = l/\rho s ,$$

where l and s are the thickness of the electrolyte sample and the electrolyte/electrode contact area, respectively.

II.2. TiO_2 Photoelectrode and Pt Counter Electrode Preparation

P90 TiO_2 powder of 0.5 g mass was mixed with 2mL nitric acid, HNO_3 (pH=1) and ground for 30 min in a mortar. The slurry obtained was spin-coated for 60s on a cleaned fluorine doped tin oxide (FTO) glass at 2350 rpm to form the compact layer. The electrode was annealed at 450°C for 30 min. A second TiO_2 layer was prepared by mixing and grinding 0.5 g P25 TiO_2 powder in 2 mL HNO_3. For homogeneity, 0.1 g carbowax and a few drops of Triton X-100 surfactant were added and by the doctor blade method was deposited on the compact layer [8]. The electrode was again annealed for 30min at 450°C. The Pt counter electrode (CE) was prepared using drop cast method on bare FTO glass and sintered as for the TiO_2 photoelectrode. The photoanode TiO_2 layer was soaked in 10mL solution of ethanol and N3 dye for 24 h in a dark environment at RT [12,13].

II.3. Fabrication of Dye-Sensitized Solar Cell

The LE were used as electrolyte in DSSC fabrication following the configuration of FTO/(TiO_2/dye/LE/Pt/FTO.

The photocurrent density (J) and voltage (V) were measured using the Keithley 2400 electrometer under irradiation intensity of 1000 Wm^{-2}. The active area of the DSSC was 0.20 cm^2. The fill factor (FF) was calculated following the equation [14, 15, 16]:

$$FF = \frac{J_{max} V_{max}}{J_{sc} V_{oc}},$$

where J_{max} and V_{max} are the maximum current density and maximum voltage, respectively. J_{sc} is the short-circuit current density and V_{oc} is open-circuit voltage. Power conversion efficiency (η) was calculated following:

$$\eta = \frac{V_{oc} J_{sc} FF}{P_{in}} 100\% ,$$

where P_{in} is incident light power density [9].

The incident photon to current conversion efficiency (IPCE) measurements were obtained using a Newport Model 70528 Oriel Monochromator Illuminator [8-9]. IPCE value demonstrates how much current was produced by the cell as it was illuminated by photons of a given frequency.

III. Result and discussion

III.1. Conductivity of Liquid Electrolyte

Table 1 lists the bulk resistance and conductivity values of LEs having different salt content. Bulk resistance decreased with salt content and the conductivity showed an opposite trend. Conductivity has been incremented with the addition of more salt that provided more conducting ions. The RT ionic conductivity increased with TPAI content for LEs.

It can be clearly seen that the conductivity shows increment with increasing TPAI salt concentration up to 0.25 g TPAI. TPAI consists of $(CH_3CH_2CH_2)_4N^+$

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cations and I^- anions, which formed a crystal salt by ionic bonding between the two.

When TPAI was dissolved in EC, PC and DMF, the cations and anion ions were separated and created free charges in the PEO- and PMMA-based LE where conduction can be occurred when a potential is applied[17, 18]. Hence, the number of free ions is dependent on the TPAI salt concentration.

Therefore, the increment in conductivity with increasing TPAI content shown in Table 1 was due to increasing number density of free ions in PEO and PMMA-based LE.

Table 1: The bulk resistance and conductivity values of LEs at different TPAI amounts,

TPAI (g)	P (Ω)	Σ (mS cm^{-1})
0.05	31.1	4.00
0.10	19.8	6.34
0.15	15.5	8.06
0.20	14.8	8.47
0.25	14.2	8.98

III.2. *J-V* Characteristics of Dye-sensitized solar cells

The *J-V* characteristics of the fabricated DSSCs are shown in Figure 1. All LEs have been used to fabricate DSSCs. The *J-V* characteristics of corresponding parameters are tabulated in Table 2.

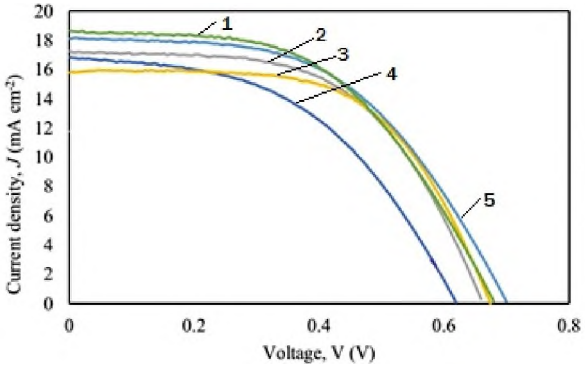


Figure 1. *J-V* characteristics of DSSC for LEs: *1* – 0.25 g TPAI, *2* – 0.1 g TPAI, *3* – 0.15 g TPAI, *4* – 0.05 g TPAI, *5* – 0.20 g TPAI.

Table 2. Dye-sensitized solar cells parameters of cells using Les.

Designation	0.05 g TPAI	0.1 g TPAI	0.15 g TPAI	0.20 g TPAI	0.25 g TPAI
J_{sc}(mA cm^{-2})	16.85	17.28	15.76	18.12	18.69
V_{oc}(V)	0.62	0.66	0.67	0.7	0.68
FF	0.48	0.53	0.6	0.52	0.52
Efficiency (%)	5.01	6.04	6.33	6.59	6.61

Since all the other components of DSSC except the electrolyte is same for all fabricated cells, the electrolytes' conductivity is very crucial to DSSC performance.

III.3. Incident Photon Conversion Efficiency (IPCE)

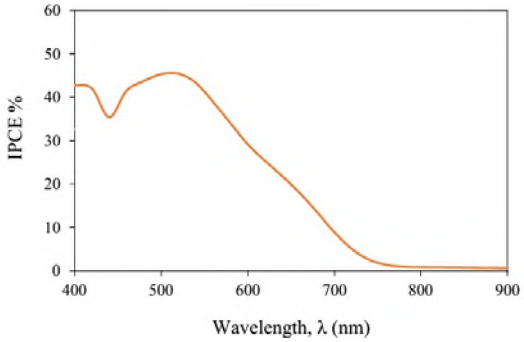


Figure 2. IPCE plots of DSSCs using the highest conducting liquid electrolytes with 0.25 g TPAI.

The IPCE graphs of DSSCs using the highest conducting LE under illumination at different wavelengths of light are shown in Fig. 2. As can be observed, the highest value of IPCE for DSSC is shown at the wavelength around 520 nm which is in agreement with the optical properties of the N3 dye. The most efficient DSSC in the LE system exhibits the highest IPCE value of 45.5 %.

IV. Conclusion

LE containing TPAI, EC, PC, DMF and I_2 have been prepared and tested in DSSCs.The higher conductivity of LE efficiency of 6.61 %. The most efficient DSSC in the LE system exhibits the highest IPCE value of 45.5 %.

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Юқори сезгир бўёқли қуёш элементлари характеристикаларининг тетропропил-аммоний йодид миқдорига боғлиқлиги

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Ушбу ишда бир нечта суюқ электролитлар тайёрланди. Электролитлар таркибида турли миқдордаги тетрапропиламмоний йодид (TPAI) тузи, пропиленкарбонат (PC), этиленкарбонат (EC), полиэтиленоксид (PEO), диметилформамид (DMF) ва (I/I^{3-}) мавжуд. Электролит DSSC тайёрлашда ишлатилди ва унинг волт-ампер характеристикаси олинди. Фотонларнинг фототокка айланиш самарадорлигининг энг юқори қиймати 0.25 г TPAI электролит учун 520 нм тўлқин узунликда 45.5% ни ташкил этди. DSSC нинг самарадорлиги 6.61%, J_{sc}=18.69 мА·см$^{-2}$, V_{oc}=0.68 В ва тўлдириш коэффициенти (FF)=0.52.

Калит сўзлар: ион ўтказувчанлик, суюқ электролит, юқори сезгир бўёғли қуёш элементи (DSSC), тетрапропиламмоний йодид (TPAI).

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