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Efficiency enhancement of photovoltaic performance of quasi-solid state dye sensitized solar cell with TPAI and KI binary iodide salt mixture

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Abstract

Quasi-solid-state dye-sensitized solar cells have drawn the attention of scientists and technologists as a potential candidate to supplement future energy needs. The conduction of iodide ions in quasi-solid-state polymer electrolytes and the performance of dye sensitized solar cells (DSSCs) containing such electrolytes can be enhanced by incorporating iodides having appropriate cations. Gel-type electrolytes, were prepared by solution cast technique, based on PVP-co-VAc + PMMA host polymers and mixture of salts Potassium iodide (KI) and tetrapropyl ammonium iodide (TPAI) salts have been used to provide the conducting ions. The salt composition in the binary mixture was varied in order to optimize the performance of solar cells. The electrochemical impedance spectroscopy (EIS) measurements showed that the electrolyte (C6) which contain (KI%25: 5%TPAI) have highest conductivity 3×10^{-3} S/cm at 298 K. The DSSCs with TPAI or KI as the only iodide salt showed the efficiencies 4.136%and 2.532 %, respectively, under AM 1.5(1000 Wm^{-2}) illumination while the DSSC with mixed cations with (TPAI25%:KI5%) molar ratio shows the efficiency of 3.179%.

Keywords: Binary Iodide, Gel Polymer Electrolyte, Dye-Sensitized Solar Cells, Electrochemical Impedance Spectroscopy.

Introduction

The conversion of sunlight to electricity using dye-sensitized solar cells (DSSCs) has been researched as one of the most promising methods for future low cost power production from renewable energy sources. In DSSC the light absorption function is fulfilled by the dye and the electron and hole transporting are fulfilled by the nanocrystalline metal oxide and electrolyte. Therefore the absorption properties of the dye dictate the light-harvesting capacity of the cell [1,2] . Dye-sensitized nanostructured Titanium dioxide TiO_2 semiconductor materials are of considerable interest and intensively investigated nowadays due to their demonstrated high conversion efficiency , low cost and potential application in photovoltaic devices. It is well known that the basic mechanism in a dye-sensitized solar cell involves the transfer of photoexcited electrons from the excited states of dye molecules to the conduction band of TiO_2 [3,4] . Polymer electrolytes are of technological interest due to their possible application as solid electrolytes in various electrochemical devices such as energy conversion units (batteries/fuel cells), electrochromic display devices, photochemical solar cells, supercapacitors and sensors .Studies on polymer electrolytes have attracted great attention in the efforts to clarify the mechanism of conductivity enhancement in such systems Electrolytes in DSSC are mainly concerned with the iodide/triiodide (I^-/I_3^-) redox couple for the regeneration of dye and completion of the external electrical circuit [5]. The problems caused by liquid electrolytes have the effect of limiting the long-term performance and practical use of these traditional DSSCs, even with hermetic sealing. Comparing among various charge transport materials employed for DSSCs, gel polymer electrolytes (GPE) appear to have superior properties in terms of thermal stability, contacting and filling properties to the nanostructured TiO_2 electrode[6]. More importantly, the GPE have ionic conductivities as high as that of liquid electrolytes, and can be cast easily onto TiO_2films without the hassles of leaking and the volatilizing of solvent , therefore, many research studies have been focused on replacing the liquid electrolyte in these DSSCs by a gel polymer electrolyte (or quasi-solid electrolyte) to minimize the above drawbacks [7] .The complexation, nature and concentration of the various ionic species are important to understand the overall mechanism of conductivity. [8] . In the present work, a new gel polymer electrolyte composed of Poly(1-vinylpyrrolidone-co-vinyl acetate) (PVP-co-VAc) as the host polymer with poly(methyl meth acryl ate) PMMA blend containing TPAI and KI iodide salts in addition to iodine has been synthesized and characterized Tetrapropyl ammonium iodide (TPAI or$(C_3H_7)_4NI$) and potassium iodide (KI) salts have been used to supply the necessary ions. Some electrical properties of the GPE and ruthenium 535 (N3) dye sensitized solar cells have been studied. The effect of salts concentration on ionic conductivity have been studied, in addition to the variation of ionic conductivity of gel polymer electrolytes with temperature.

2.Experimental Part

2.1 Materials

PVP-co-VAc with an average molecular weight of 5,0000 , PMMA with an average molecular weight of 996,000 , The solvent used was Dimethyl sulfoxide DMSO with molecular weight of 78.13, TPAI with molecular weight of 313.26, and KI with molecular weight of 166, all above purchased from Sigma Aldrich and used as received. Iodine with molecular weight of I:126.9 was purchased from Amco chemie – Hamburg – Germany.

2.2 Preparation of electrolytes

GPE assigned as Cs were prepared by solution cast technique with two types of salts with different weight ratio as follows. First we dissolve the salts (TPAI and KI) one by one in 2 ml of DMSO solvent in a glass bottle by using stirrer and heat to 70°C and then the two polymers PVP-co-VAc and PMMA were added one by one with weight ratio 2:1, the mixture was stirred for 1h until became gel. The mixture was then allowed to cool down to room temperature , then iodine I_2 chips were added. Finally , the mixture was again continuously magnetically stirred (24 h) to obtain a homogeneous gel electrolyte. The gel electrolytes were prepared and studied under controlled temperature and humidity conditions (25°C and RH~50%). The polymer electrolytes were then transferred into a desiccator for further drying. This procedure was repeated for all the compositions shown in Table 1. I_2

Table 1: Polymer electrolyte C with different salts & I_2 weight ratio.

Cs	**KI %**	**TPAI %**	**KI (g)**	**TPAI (g)**	**KI (mole)**	**TPAI (mole)**	**Total mole**	**I_2 mole**	**I_2 (g)**
C1	0	30	0	0.642	0.1807	0.0000	0.1807	0.01807	4.5869
C2	5	25	0.107	0.535	0.1506	0.0003	0.1509	0.01509	3.8311
C3	10	20	0.214	0.428	0.1205	0.0007	0.1212	0.01212	3.0753
C4	15	15	0.321	0.321	0.0904	0.0010	0.0914	0.00914	2.3195
C5	20	10	0.428	0.214	0.0602	0.0014	0.0616	0.00616	1.5637
C6	25	5	0.535	0.107	0.0301	0.0017	0.0318	0.00318	0.8078
C7	30	0	0.642	0.000	0.0000	0.0020	0.0020	0.00020	0.0520

2.3 Photoelectrochemical cell fabrication and Characterization

Fluorine-doped tin oxide FTO glass has been coated with two layers of nanoporous Titanium dioxide TiO_2 , the first layer, compact layer made by spin coating technique ,and second layer made by doctor blade. A TiO_2 nanoporous layer was coated on FTO glass using Degussa P90 for spin coating and P25 for doctor blade powder. For this layer preparation, 0.5 g of Degussa powder TiO_2 was grounded well for about 30 minutes with ~2 ml of HNO_3 (pH=1) in an agate mortar. The above obtained TiO_2 paste solution was spin-coated on an FTO glass substrate at 1000 rpm for 4 s and 2350 rpm for 50 s to form compact layer. The formed thin layer was annealed at 450 °C for 30 min. To made TiO_2 nanoporous layer by doctor blade about 0.1 g of carbowax and few drops of Triton X 100 (surfactant) were added and mixed well to the above obtained TiO_2 paste solution. This colloidal suspension was casted using a doctor blade method for obtaining porous c layers of about 5–10 mm thickness after sintering at ~450 °C for 30 min. TiO_2 coated electrodes were immersed in an ethanolic solution of dye sensitizer ruthenium 535 also known as N3 (Solaronix SA) while both were hot (~60 °C). After 24 h , the electrode was withdrawn from the dye solution and washed with acetone to remove unabsorbed dye and loosely bound TiO_2 particles in the dye-coated electrode. Counter electrode was prepared by thermal method, an alcoholic solution of platinum salt (e.g. $PtCl_4$ or H_2PtCl_6) is spread on the substrate and after the solvent evaporation, the substrate is fired in an oven in 385º C for ~15 minutes. When Pt is sputtered producing a mirrorlike effect, the photocurrent is slightly increased due to the light-reflection effect. The fabricated DSSC has configuration FTO/TiO_2-N3/GPE/Pt/FTO. TiO_2 serves as photoanode and Pt as counter electrode. The Gel Polymer Electrolyte is sandwiched between the two electrodes. The *J-V* characteristics of the DSSC were measured with a Keithley 2400 source meter under 1000 W m^{-2} illumination.

2.4 Ionic conductivity measurements

Impedance spectroscopy measurements were carried out to determine the conductivity of the GPE samples. The electrochemical impedance spectroscopy (EIS) measurements were done by using a computer interfaced HIOKI 3532-50 LCR Hi TESTER BU CH1 Glass Oven B-585 , the frequency range between 50 Hz and 1MHz. The sample was placed in a poly(tetrafluoroethylene) spacer ring compressed between two stainless steel electrodes and sealed in a testing cell. The EIS measured at over temperatures range 273-373 K. Fig. 1 show the Nyquist plot for gel polymer electrolyte, From the Cole–Cole plot, the bulk resistance (R_b) for each sample was determined and thus the conductivity (σ) of the sample could be calculated by using the following equation (1)[6]:

$$\sigma = \frac{t}{AR_b} \quad (1)$$

Where t is thickness for the sample , A is the area of the electrode and R_b is the bulk resistance of the gel electrolyte measured by impedance analyzer at 0.1MHz..After calculate the conductivity(   ) of the two electrolytes, and plotting (Log σ) vs T/1000, σ vs TPAI, and σ vs KI , weight ratio. The dielectric constant (ε_r)values were calculated using the following equation (2) :

$$\varepsilon = \frac{Z_i}{\omega C_o\left[Z_r^2 + Z_i^2\right]} \quad (2)$$

where ω is the angular frequency($\omega=2\pi f$) being the frequency in Hertz (Hz), C_o is vacuum capacitance and Z_r and Z_i are real and imaginary parts of impedance .

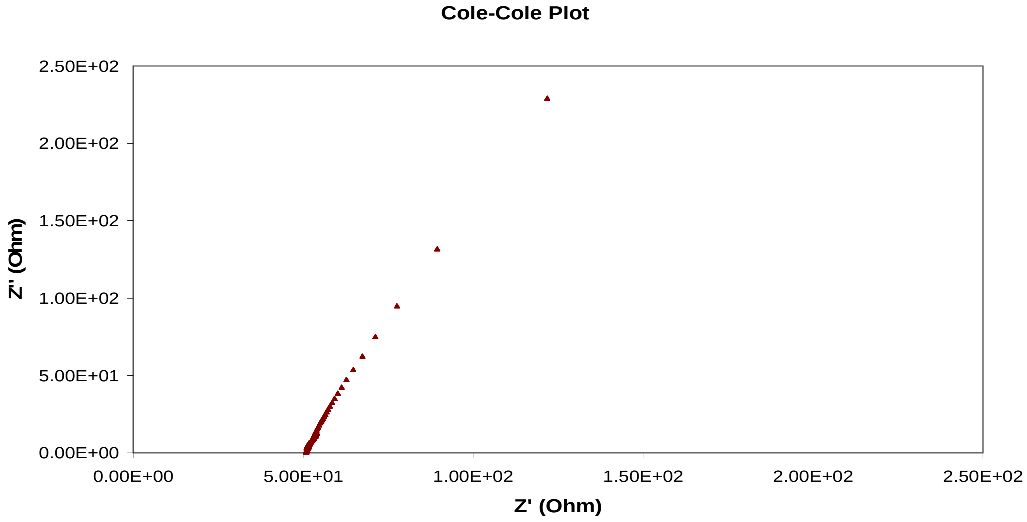


Figure 1: a Cole–cole impedance plot of gel polymer electrolyte PVP-co-VAc+PMMA with 30%KI/0%TPAI, at room temperature.

3. Result and Discussion

3.1 Ionic conductivity measurements for gel polymer electrolytes

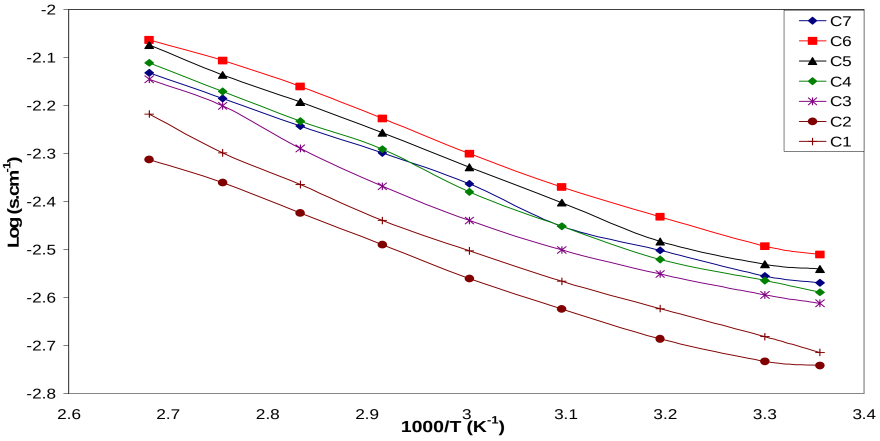
The conductivity value at room temperature for all gel polymer electrolytes with different weight ratio of the binary salts (TPAI& KI) is shown in Table 2, the conductivity of electrolytes(Cs) was investigated over temperatures range 298-373 K, from Figure(2-a), it can be seen that electrolyte (C6) which contain (KI%25: 5%TPAI) is highly conductive {$3\times10^{-3} - 8.6\times10^{-3}$ S.cm^{-1}} in the temperature range 298-373 K. The conductivity for each GPE has increased with increasing temperature range from 298 K to 373 K. This can be to attributed to the increase in ion mobility. The increase in conductivity with temperature is mainly due to increase in free volume for the motion of ions through the polymer backbone. This can be understood with the emphasis that as temperature increases, the vibrational energy of segmental motion operates against the hydrostatic pressure imposed by its neighboring atoms. Consequently, it creates a small amount of space surrounding its own volume in which vibrational motion can occur. Therefore, free volume around the polymer chain causes augmentation in mobility of ions and hence enhances the conductivity. This can also be linked to decrease in viscosity and, hence, increase in chain flexibility [9]. As temperature increases, the hydrogen ions jump into neighboring vacant sites and, hence, ionic conductivity increases . Similar results have also been reported for different types of polymer electrolytes. It is widely accepted that for most polymer/salt systems, both anions and cations are mobile and both have a large effect on the total conductivity. The concentration dependence of the conductivity is a very complex function. High conductivity is achieved in polymer electrolytes by ensuring that the salt concentration is optimized to give sufficient charge carriers, without unduly immobilizing the polymer [10].

Figure(2-b) shows the ionic conductivity behavior for the electrolytes Cs, PVP-co-VAc + PMMA with iodide salts (TPAI and KI) at different weight ratio in room temperature. From the observation, the ionic conductivity increase with increasing the KI weight and reach maximum value at 25% of KI and 5% of TPAI mixture exhibit the highest conductivity in all the system . The synergist effect of binary salts plays an important role to softening of polymer host. The proper formulation of TPAI/KI ratio may help to optimize the synergist effects to the host polymer. Thus, pre-determining the ratio of TPAI/KI mixture is important to enhance the flexibility and performance of polymer electrolyte. The mixed of the two salts is helpful in improving the electrical conductivity , Also from Figure(2-b), it can be seen that the ionic conductivity for the GPE with only KI as the iodide salt sample C7, originates from two types of ions, namely K^+ ions and iodide (I^-/I^-_3) ions and all these ions contribute to the conductivity of this sample which is higher compared to the GPE containing only TPAI salt. Wang, et al. [11] attributed this to the strong interaction between the larger $(C_3H_7)_4N^+$ cations with the coordinating atoms in the polymer. It may also be argued that due to the larger cation in TPAI, $(C_3H_7)_4N^+$ may be immobile or its movement is sluggish. As the cation $C_3H_7)_4N^+$ in this electrolyte sample is bulky, the iodide ions (I^-) are expected to make the dominant contribution to the ionic conductivity of this sample. Ionic dissociation also should be high for $(C_3H_7)_4NI$ rich samples. Hence, the number of mobile ions in the PVP-co-VAc+PMMA+TPAI (C1) complex is lesser than in the PVP-co-VAc +PMMA+KI (C7) complex. Since the total conductivity is the sum of the conductivity of anions and cations, the conductivity of C1 complex is lower than the conductivity of C7 complex. This explanation is also shared by Dissanayake et al. [12]. It is still unclear what actual species are involved in carrying the electric charge; it has even proved difficult to establish reliably the fractions of current carried by cationic and anionic constituents. The decrease of conductivity in some of the lower and higher concentrations of KI salts in PVP-co-VAc +PMMA may be due to the formation of different types of reaction mechanisms in addition to the presence of ion-pair.[10]

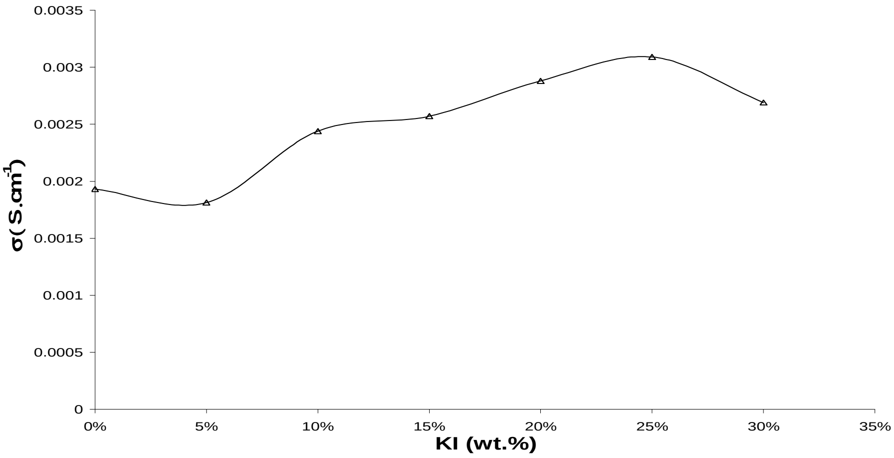
Activation energy, Ea is the required energy of an ion to detach from its initial site to become free ion. In order to determine E_a of each electrolyte the influence of temperature on conductivity was studied. From Fig.(2-a), the conductivity is observed to increase with increasing temperature. The electrolytes are easily expand as temperature increases hence creating more free volume [13]. This phenomenon enhances ionic mobility and polymer segmental motion thus increasing the conductivity . Since the regression values in Fig. (2-a) are close to unity, the conductivity– temperature plots can be best fitted by Arrhenius equation[14]:

$$\sigma = \sigma_\circ \exp \left\{ \frac{-E_a}{kT} \right\} \qquad (3)$$

Here, $\sigma_\circ$ is pre-exponential factor, k is the Boltzmann constant (8.6×10^{-5} eV K^{-1}) and T is absolute temperature. Whereas, { - E_a / kT}is represented by the graph slope, m. Value for $\sigma_\circ$ and E_a can be calculated from y-axis and plot intercept between log σ versus 1000/T. The calculated E_a values are listed in Table 2. E_a decrease with increasing conductivity indicates that the ions in higher conducting electrolyte require lesser energy to migrate, from observation activation energy decreases as the iodide salts concentrations increases . The variation in activation energy strongly supports the change in the electrical conductivity. It is observed that the minimum activation energy is the characteristics feature of the optimum conductivity value[15].



(a)



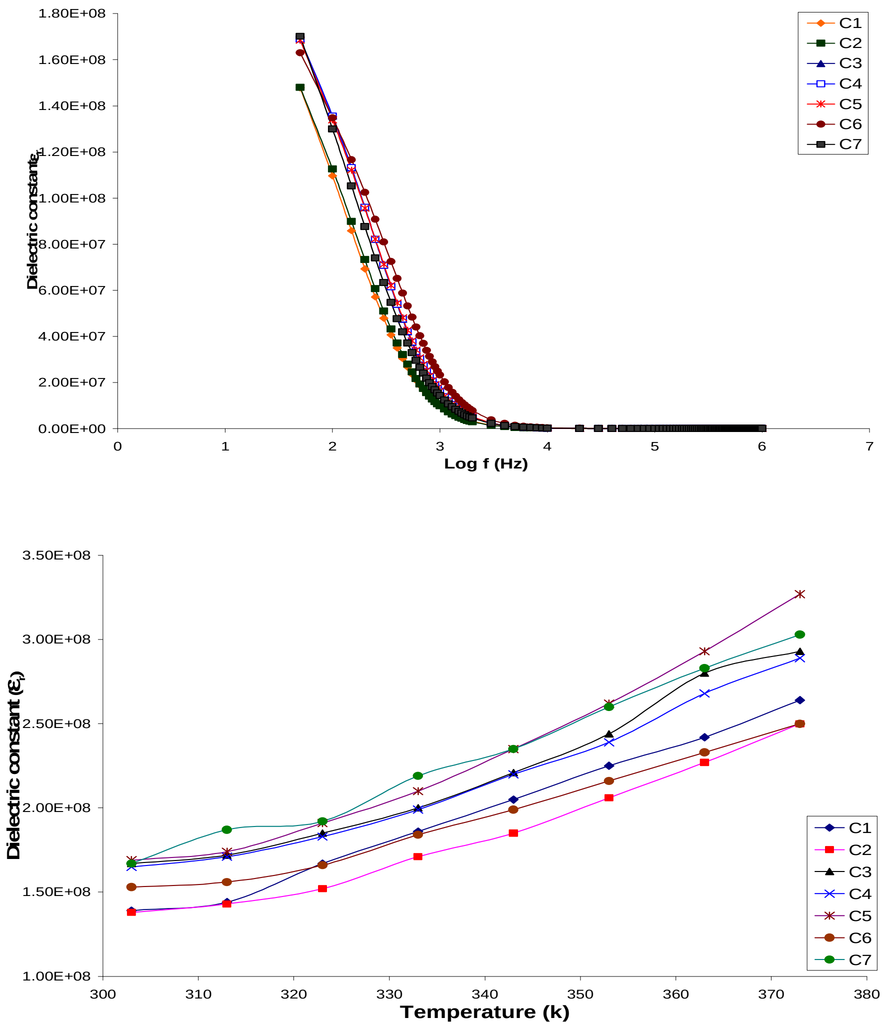
(b)

Figure 2: The ionic conductivities of PVP-co-VAc + PMMA prepared using various weight ratio of TPAI& KI. (a) Temperature dependence of the ionic conductivity of the gel polymer electrolytes.(b) Dependence of ionic conductivity on TPAI & KI weight ratio in the gel polymer electrolytes.

Table 2: Conductivity value at room temperature for electrolyte C.

Electrolytes Cs	σ_{RT} (S/cm)	Activation energy E_a (eV)
C1	0.001932	0.0711
C2	0.001813	0.0728
C3	0.00244	0.0688
C4	0.00257	0.0676
C5	0.00288	0.0665
C6	0.003089	0.0655
C7	0.00269	0.0676

Figure 3, shows the variation of the real part of dielectric constant(ε_r) with log frequency at room temperature for PVP-co-VAc+PMMA polymer electrolyte Cs system. It is evident from the figure (3-a) that ε_r decreases with frequency, which shows the tendency of dipoles in macromolecules to orient themselves in the direction of applied field [16]. In all the cases, a strong frequency dispersion of permittivity is observed in the low frequency region followed by a nearly frequency independent behavior above 4. The decrease of ε_r with increasing frequency this could attributed to the electrical relaxation processes, but at the same time the material electrode polarization cannot be ignored, as the samples of our investigation are ionic conductors. The material electrode interface polarization superimposed with other relaxation processes at low frequencies[17]. As frequency increases ,the dipoles which were oscillating with the applied field frequency are now lagging to the field and hence decrease in value of ε_r with increase in frequency is observed [18]. High value of ε_r at low frequency side is mainly due to polarization at electrode– electrolyte interface [19]. It is evident from the Fig. (3-b) that dielectric constant values increases with increasing temperature. Enhancement in dielectric constant with temperature is mainly due to the decrease in viscosity of the polymeric material. This leads to an increment in the degree of dipole orientation of polar dielectric material and hence dielectric constant increases [20]. The maximum dielectric constant value is obtained for polymer electrolyte C5 having one order increment in their magnitudes at room temperature. In fact, the addition of iodide salts to the polymer matrix creates amorphicity in the polymeric material and as a result increase in ε_r is observed [21]. Figure 3 also reveals that on further addition of salts weight ratio, there is decrement of ε_r due to reduction in chain segmental mobility.



(a)

(b)

Figure 3: (a) Dielectric constant vs. Log frequency at room temperature for electrolyte Cs with different salts concentration.(b) Dielectric constant vs. Temperature for electrolyte Cs with different salts weight ratio.

3.2 Performance of dye-sensitized solar cell

The photocurrent density-photovoltage characteristic curves (*J*-*V*) for cells fabricated using PVP-co-VAc+PMMA based quasi-solid electrolytes containing different TPAI and KI weight ratio are shown in Figure 3 at room temperature. Seven different cells were fabricated employing seven different electrolyte compositions. Dye Sensitized Solar Cell parameters such as short-circuit current density, J_{sc}, open-circuit voltage, V_{oc} were measured under the irradiation of 1000 W m^{-2} of each of the cells are shown in Table 3. The fill factor FF, was calculated using

$$FF = \frac{J_{opt} \times V_{opt}}{J_{sc} \times V_{oc}}$$

$$FF = \frac{P_{\max}}{J_{sc} \times V_{oc}} \qquad (4)$$

where J_{opt} and V_{opt} are the current density and voltage at maximum power output. The fill factor and the energy conversion efficiency η, are shown in Table 3 for all cells. The η is calculated using [5]:

$$\eta = \frac{J_{sc} \times V_{oc} \times FF}{P_{in} \times 100} \qquad (5)$$

All cells exhibited energy conversion efficiencies of more than 1.3%.

The highest energy conversion efficiency 4.136% is shown by the cell that contains electrolyte sample C1, this result is approached to data reported by Lu et al.[22]. We ascribe the increase in efficiency of the DSSC in presence of TPA^+ to the strong interaction between polymer blend groups and the positive charges on the nitrogen of TPA^+. This indicates that the larger TPA^+ cations are more likely to be bound to the polymerized blend, providing a better conduction of the iodide ions. While the cell with electrolyte sample C2 which have conversion efficiency 3.179% is the highest among the cells with electrolyte consists of binary salts , it can be observe that the conversion efficiency values decrease for other electrolytes with binary salts. That because the use of electrolytes with various cations have shown that short circuit current density increases with the increasing charge density of the cation in the electrolyte while the fill factor, open circuit voltage, and efficiency decreases [9,23]. While bulky cations such as $(C_3H_7)_4N^+$ and Hex_4N^+ are expected to minimize the cationic conductivity and enhance the iodide ion conductivity in the electrolyte, cations with high charge density, such as K^+, Li^+, or Na^+ and also Mg^{++} get adsorbed into the TiO_2 electrode and contribute toward better photogeneration of electrons at the dye and faster diffusion dynamics at the dye-semiconductor interface. Therefore, it would be natural to explore the combined effect of using a binary mixture of two iodide salts consisting of a bulky cation and a small cation with high charge density in the electrolyte to benefit from both above mentioned mechanisms. The use of quarternary ammonium iodide salt in the gel polymer electrolyte is to minimize the mobility of cations and maximize the conductivity of iodide ions which agree well with the data reported by Bandara et al.[5]. This can be understood from the higher efficiency exhibited by the DSSC using [(PVP-co-VAc +PMMA)+$(C_3H_7)_4NI$], GPE compared to the DSSC with [(PVP-co-VAc+ PMMA)+KI] electrolyte. The higher iodide ion transference number in the C1, GPE results in the increase in the difference between the Fermi level of TiO_2 and the redox potential. This leads to a higher V_{oc} for DSSC employing the C1, GPE. The increase in iodide ion transference number also resulted in the increase in J_{sc}. Since P_{in} *i*s the same for both DSSC, according to equation (3) the efficiency of the DSSC using C1, GPE should be higher. The redox reaction in the gel polymer electrolyte based DSSC is described as follows:

$$I_2 + I^- \text{—} I_3^- \qquad (6)$$

$$2D^+ \text{ (oxidized dye) } + 3I^- \text{—} 2D \text{ (dye) } + I^-_3 \text{ photoelectrode } (7)$$

$$I_3^- + 2e^- \text{ (Pt) } \text{—} 3I^- \text{ counter electrode} \qquad (8)$$

tri-iodide I_3^- is produced in the electrolyte and diffuses to the counter electrode. Similarly, iodide I^- produced by reduction of I_3^- at the counter electrode diffuses in the opposite direction towards the photoanode. Due to the smaller size of K^+ compared to TPA^+, the K^+ ion has a higher charge density. It is also easily adsorbed to the dye surface and is able to enhance the electron photogeneration from the dye to the TiO_2 semiconductor [12]. For a ruthenium dye adsorbed on the TiO_2 nanoparticles, the electron injection is very fast, in the femtosecond time scale [23-24]. The efficiency for DSSC using GPE with only KI salt in this work is higher compared to efficiency of 0.6% from DSSC containing PEO and KI as reported by Ileperuma, et al. [21] at 600 Wm^{-2} light intensity. The use of double salt in the electrolyte has also increased P_{max} (the maximum power output delivered by the DSSC). The increase in these parameters can be attributed to the better iodide transfer number compared to the DSSC utilizing the GPE with only the KI salt and to the higher conductivity of the electrolyte compared to that of the GPE containing only the TPAI salt. The interfacial contact between the dye adsorbed semiconductor nanoparticles and the electrolyte is dependent on the penetration of the electrolyte into the nanopores of the semiconductor layer. The lower energy conversion efficiency was due to the limited penetration of more viscous and high molecular weight (PVP-co-VAc + PMMA) electrolyte into the nanopores of the semiconductor layer.

Lower efficiencies of polymer electrolyte based DSSCs could be attributed to incomplete wetting of the TiO_2 particles by the electrolytic medium and the lower ionic mobility of the redox species[10].

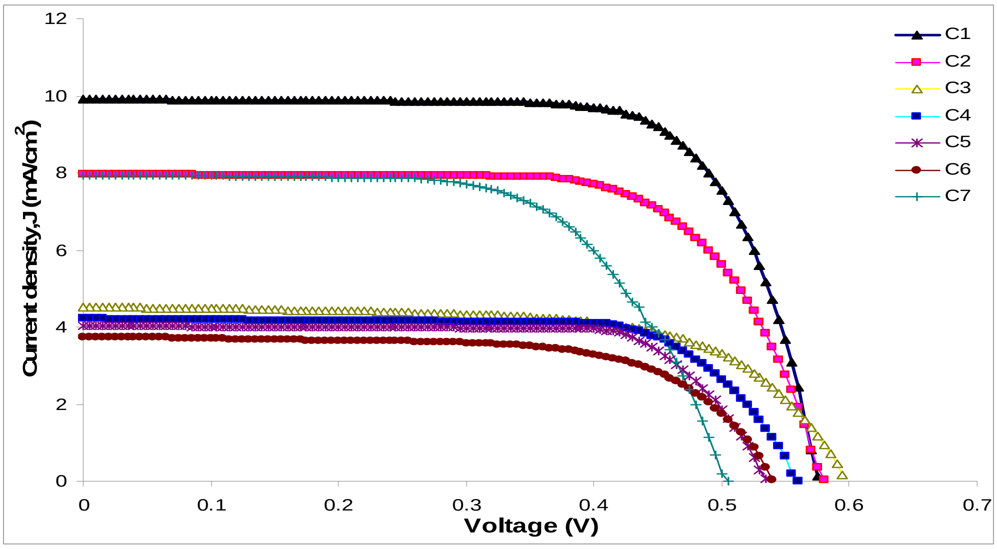


Figure 4:Photocurrent versus cell potential for seven different DSSCs fabricated using (PVP-co-VAc+PMMA) electrolyte containing total of 30 wt% salts with respect to weight of polymers under irradiation of a 1000 W m^{-2} xenon lamp. The DSSCs are named using the electrolyte name given in Table 1.

Table 3: The performance of DSSCs prepared using electrolytes containing different TPAI and KI compositions.

Electrolyte	J_{sc} (mA/cm^2)	V_{oc} (Volt)	Filling Factor, *ff*	η %
C1	9.923	0.575	0.725	4.136
C2	7.98	0.58	0.687	3.179
C3	4.52	0.595	0.646	1.737
C4	4.54	0.56	0.718	1.694
C5	4.028	0.535	0.755	1.627
C6	3.75	0.54	0.654	1.325
C7	7.947	0.505	0.632	2.532

4. Conclusions

This paper reports the enhancement of efficiency of a N3 dye sensitized solar cell, due to the mixed cation effect in a (PVP-co-VAc + PMMA) based gel polymer electrolyte with a binary iodide system consisting of a small alkali cation (KI) and a bulky cation (Pr_4NI). The electrolyte containing a (25% KI:5%TPAI) salt mixture with respect to (PVP-co-VAc + PMMA) weight showed the maximum conductivity out of the samples measured. This electrolyte membrane showed a conductivity {0.003089-0.0086 (S.cm^{-1})} in the measured region of the temperature (298-373 K). The temperature dependence of ionic conductivity obeys the Arrhenius-type thermally activated behavior. The electrolyte with the highest conductivity did not show the best energy conversion efficiency revealing that the effect of the cation on the efficiency of the DSSCs is equally important. The presence of a cation with high charge density in the electrolyte contributes to the performance enhancement of the DSSCs. The best cell result was an energy conversion efficiency of 3.911% and a short circuit current density of 7.98 mA cm^{-2}. It was shown that use of a mixed salt complex having cations with low and high charge densities can improve the efficiency of the DSSCs compared to having an electrolyte containing a single cation.

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