Performance Analysis of Jatropha Oil-Based Polyurethane Acrylate Gel Polymer Electrolyte for Dye-Sensitized Solar Cells

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ABSTRACT: Biobased polymers are useful materials in substituting conventional petroleum-derived polymers because of their good properties, ready availability, and abundance in nature. This study reports a new jatropha oil-based gel polymer electrolyte (GPE) for use in dye-sensitized solar cells (DSSCs). The GPE was prepared by mixing jatropha oil-based polyurethane acrylate (PUA) with different concentrations of lithium iodide (LiI). The GPE was characterized by infrared spectroscopy, thermal analysis, lithium nuclear magnetic resonance analysis, electrochemical analysis, and photocurrent conversion efficiency. The highest room-temperature ionic conductivity of $1.88 \times 10^{-4}$ S cm$^{-1}$ was obtained at 20 wt % of LiI salt. Additionally, the temperature-dependent ionic conductivity of the GPE exhibited Arrhenius behavior with an activation energy of 0.42 eV and a pre-exponential factor of $1.56 \times 10^3$ S cm$^{-1}$. The electrochemical stability study showed that the PUA GPE was stable up to 2.35 V. The thermal stability of the gel electrolyte showed an improvement after the addition of the salt, suggesting a strong intramolecular interaction between PUA and Li, which leads to polymer–salt complexation, as proven by Fourier transform infrared spectroscopy analysis. A DSSC has been assembled using the optimum ionic conductivity gel electrolyte which indicated 1.2% efficiency under 1 sun condition. Thus, the jatropha oil-based GPE demonstrated favorable properties that make it a promising alternative to petroleum-derived polymer electrolytes in DSSCs.

1. INTRODUCTION

Polymer electrolytes (PEs) have been extensively explored for electrochemical device applications such as fuel cells, batteries, sensors, photochemical solar cells, and supercapacitors.1 PEs offer numerous advantages over conventional liquid electrolytes in terms of stability, ease of handling, and good safety performance. PEs should possess specific criteria including a high ionic conductivity, or at least comparable to that of liquid electrolytes, as well as thermal, chemical, and electrochemical stability2 if the materials are to be considered as a practical replacement for the liquid electrolytes.

Solar energy is one of the most promising renewable energy sources among other options available nowadays. One important application of polymer electrolytes is in solar cells. The solar cell or photovoltaic cell is a device that converts light into electrical energy. It is convenient as it does not require any mechanical movement or movable parts to generate electricity. Dye-sensitized solar cells (DSSCs) are the third generation of photovoltaic cells invented in 1991 by a team led by Gratzel.3 The main challenge in the existing DSSC is the evaporation and leakage of the liquid electrolyte that hinders the long-term performance and practical use of the DSSC. Thus, much attention has been given and thorough investigation has been conducted to tackle this problem, for example, by introducing solid-state or gel polymer electrolytes (GPEs).8 In contrast with liquid electrolytes, such gel polymers have no or very limited leakage problems.9,10 Gel electrolytes exhibit higher ionic conductivities compared to the solid polymer electrolyte systems. Various kinds of gel electrolytes have been reported, in which different types of polymer matrices have been used, electrolyte in between. The photoanode consists of a dye-coated nanocrystalline semiconductor oxide, typically TiO$_2$. It acts like a roadway for the electrons coursing through the cell. The counter electrode is usually a film of graphite or platinum. An electrolyte containing a redox couple fills the gap between the electrodes. The redox mediator is usually an organic solvent containing a redox system, such as an iodide/trimiodide couple.5,6

The solar cell or photovoltaic cell is a device that converts light into electrical energy. It is convenient as it does not require any mechanical movement or movable parts to generate electricity. Dye-sensitized solar cells (DSSCs) are the third generation of photovoltaic cells invented in 1991 by a team led by Gratzel.3 The main challenge in the existing DSSC is the evaporation and leakage of the liquid electrolyte that hinders the long-term performance and practical use of the DSSC. Thus, much attention has been given and thorough investigation has been conducted to tackle this problem, for example, by introducing solid-state or gel polymer electrolytes (GPEs).8 In contrast with liquid electrolytes, such gel polymers have no or very limited leakage problems.9,10 Gel electrolytes exhibit higher ionic conductivities compared to the solid polymer electrolyte systems. Various kinds of gel electrolytes have been reported, in which different types of polymer matrices have been used, 

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such as polyvinyl alcohol,\textsuperscript{11} polyacrylonitrile,\textsuperscript{12–14} polyacrylamide,\textsuperscript{15} poly(methyl methacrylate),\textsuperscript{16} and polyethylene oxide.\textsuperscript{9,17,18} The interest in utilizing biobased polymers as the host polymer has accelerated in recent years because of the desire to find an alternative to the petroleum-based polymers. It is a well-known fact that fossil fuels will be to run out in the near future. In view of this, the use of easily accessible natural sources could provide a better strategy.

Polyurethane is a versatile material suitable to be used as the host polymer matrix. Typically, polyols used in polyurethane synthesis are made from a chemical intermediate derived from petroleum or natural gas. With the increasing emphasis on environmental issues and the importance of utilizing renewable resources in industrial processes, efforts have been made to produce biobased polyols to replace the conventional counterparts.\textsuperscript{19} A variety of renewable feedstock can be used for the production of biobased polyols such as vegetable oils,\textsuperscript{20–22} fatty acids,\textsuperscript{23} fatty acid methyl esters,\textsuperscript{24} crude glycerol,\textsuperscript{25} wood,\textsuperscript{26,27} crop residues,\textsuperscript{28,29} and protein feedstocks.\textsuperscript{30} Among all, vegetable oils have proven to be the most attractive source for the preparation of biobased polyols, owing to the fact that they are readily available and abundant in nature. In fact, the conversion of vegetable oils into polyols has been one of the most promising developments transforming the oil industries. Jatropha oil is a nonedible oil that is extracted by crushing the seeds of the Jatropha curcas plant. It is a small or large shrub plant and is a drought-resistant crop belonging to the Euphorbiaceae family. In Malaysia, jatropha is one of the important crops after oil palm and rubber. Commercial cultivation of jatropha in Malaysia is mainly for biodiesel production.\textsuperscript{31} The oil is nonedible because of the presence of the toxic phorbol ester group.\textsuperscript{32} Jatropha oil is odorless and colorless when fresh and becomes yellow on standing. As for the chemical composition, the oil contains unsaturated fatty acids which are oleic acid (18:1) and linoleic acid (18:2). Herein, jatropha oil was used to prepare polyols for the production of a polyurethane acrylate (PUA) GPE. The characteristics of the jatropha oil-based GPE were evaluated and its performance in a DSSC application was investigated.

2. RESULTS AND DISCUSSION

2.1. Infrared Spectroscopy Analysis. Fourier transform infrared spectroscopy (FTIR) was used to study the interaction and the effect of lithium iodide (LiI) salt concentration on the
properties of the gel electrolytes. Figure 1 shows the FTIR spectra for PUA and PUA−LiI gel electrolytes at various LiI salt concentrations. Generally, PUA was made up of a soft segment region of the oil-based polyol and a hard segment region of the urethane linkage and end-capped with the acrylate group. The spectra for the whole system did not show the stretching vibration band at 2270 cm$^{-1}$ of the isocyanate (−N=C=O) group, which confirmed that all of the isocyanate groups reacted during polymerization. Three important regions of the spectra were considered, including the NH stretching mode (3700−3100 cm$^{-1}$), carbonyl stretching mode (1750−1600 cm$^{-1}$), and ether stretching mode (1150−1000 cm$^{-1}$). These regions were the subject of focus as they correspond to the oxygen and nitrogen atoms in the PUA molecules that could coordinate with the lithium ions from the doping salt.

The corresponding peaks in Figure 1 show the vibration region and the possible coordination sites of Li$^+$ ions at different positions: (A) to the nitrogen atoms of the NH groups, (B) to the carbonyl oxygen, and (C) to the ether oxygen. There were notable peak shifting to a higher wavenumber and changes in the peak intensity for the amine region after the addition of the LiI salt. As for the carbonyl and ether regions, the peak shifted to a lower wavenumber for the PUA−LiI electrolytes. From these observations, it can be deduced that the Li$^+$ ions coordinated with the oxygen atoms (C=O and C−O−C), which resulted in the stretching of the C=O bond toward Li$^+$. The stretching affected the neighboring N−H by restricting the N−H bending and stretching. A similar observation has been reported for PU−LiI and PU−NaI systems. The possible formation of complexes between Li$^+$ ions with the oxygen atoms from the PUA host is schematically shown in Figure 2a,b. All of these interactions led to a change in the microstructure of the polymer, which was also evident from the thermal characterization.

2.2. $^7$Li Nuclear Magnetic Resonance Analysis. The overall lithium nuclear magnetic resonance (NMR) properties of the system were studied by using four selected representative compositions. Figure 3 displays the $^7$Li NMR spectra for the PUA−LiI GPE at different salt concentrations, and the inset shows the magnified version. Chemical shifts were externally referenced to solid LiCl. The NMR spectra displayed a single resonance peak for all of the samples. As illustrated by the spectra, the addition of LiI significantly shifted the $^7$Li signal downfield, implying that there was an interaction between LiI and PUA. It was suggested that the interaction occurred between the Li$^+$ ions and the oxygen atoms in the soft segments and the urethane group in the hard segments.

2.3. Thermal Analysis. Thermal stability is one of the key factors determining the suitability of the GPE application in DSSCs. The thermogravimetric (TG) and its corresponding differential thermogravimetric (DTG) thermograms of pure PUA and PUA−LiI gel electrolytes are depicted in Figure 4A,B. Related thermal stability data are shown in Table 1, where $T_{\text{dmax}}$ refers to the temperature at which maximum degradation occurred. Three main processes of degradation can be observed in the thermograms as the gel electrolytes are subjected to continuous heating. The thermal decomposition ($T_d$) stages of pure PUA were observed at the temperature regions of 50−230, 230−350, and 350−530 °C for $T_d1$, $T_d2$, and $T_d3$. Meanwhile, for PUA−LiI gel electrolytes, the decomposition stages were at 50−270, 270−415, and 415−
which explained the increase in thermal stability. Figure 4 and the PUA chain required more heat to break the bond, the strong intermolecular interaction between the lithium ions disrupt the PUA chain, creating a randomized arrangement. The presence of lithium salts. These changes could be explained by thermograms of pure PUA and PUA stable matrix suitable for normal conditions and outdoor with the LiI content. The inference indicated an appreciable decrease in thereafter. The decrease in observed as the LiI loading increased up to 20 wt % and the ionic conductivity of the gel electrolytes, which was enhanced mobility of the ions, and subsequently an increase in T

\[ T^{\text{dmax1}} \] 

\[ T^{\text{dmax2}} \] 

\[ T^{\text{dmax3}} \]

\[ \text{dmax1}, \text{dmax2}, \text{dmax3} \]

Overall, pure PUA showed an early degradation temperature compared to the rest of the systems. Upon the addition of Li salts, the degradation temperature increased, suggesting there were changes in the dimensional arrangement of the matrix. The DTG peak of \[ T^{\text{dmax1}} \] and \[ T^{\text{dmax2}} \] increased in the presence of lithium salts. These changes could be explained by the fact that the lithium salts in ionic form would be capable to disrupt the PUA chain, creating a randomized arrangement. The strong intermolecular interaction between the lithium ions and the PUA chain required more heat to break the bond, which explained the increase in thermal stability. Figure 4 also shows that the residue of the sample slightly increased with the LiI content. The inference indicated an appreciable stable matrix suitable for normal conditions and outdoor applications. The differential scanning calorimetry (DSC) thermograms of pure PUA and PUA–LiI gel electrolytes at different salt loadings are depicted in Figure 4C, and the \[ T^{\text{g}} \] values are listed in Table 1. A decreasing trend of \[ T^{\text{g}} \] could be observed as the LiI loading increased up to 20 wt % and decreased thereafter. The decrease in \[ T^{\text{g}} \] resulted in an enhanced mobility of the ions, and subsequently an increase in the ionic conductivity of the gel electrolytes, which was revealed in the impedance study.

2.4. Impedance Analysis. Impedance spectroscopy analysis was performed to study the conductivity properties of the PUA electrolyte. Figure 5 shows the variation of log ionic conductivity of the GPE as a function of the LiI content at room temperature. Based on the data, it is observed that the conductivity increased by increasing the salt content from 0 to 20 wt %. The conductivity increased four orders of magnitude, from \[ 10^{-8} \] for pure PUA to \[ 10^{-4} \] for PUA–LiI 20 wt %. The increase in conductivity could be related to the increased in the amount of effective mobile charge carriers. The highest conductivity of \[ 1.88 \times 10^{-4} \text{ S cm}^{-1} \] for PUA–LiI 20 wt % was consistent with the DSC results for which this system had the lowest glass-transition temperature. Theoretically, as \[ T^{\text{g}} \] decreased, the polymer tended to become more flexible, therefore enhancing the ionic conductivity. Beyond the salt dopant of 20 wt %, the conductivity decreased. At this level, the interionic distance decreased and the ion–ion interactions became progressively significant. It has been deduced that at high salt concentrations, there would be a possibility of occurrence of ion aggregation, resulting in the formation of ion clusters, thereby decreasing the number of effective mobile charge carriers and, simultaneously, the ionic conductivity.

The temperature-dependent ionic conductivity of the highest conducting gel electrolyte (PUA–LiI20) is depicted in Figure 6 by using the Arrhenius model at a temperature range of 303–373 K. The conductivity of the gel electrolyte showed a linear relationship against temperature with a regression line of 0.9936, indicating that the system followed the Arrhenius behavior, which suggests that the conductivity was thermally assisted. An increasing trend of conductivity could be observed from the graph with temperature. As the temperature increased, the free volume increased because of lattice vibration. This promoted ion mobility to favor interchain and intrachain ion hopping, thus increasing the conductivity of the gel electrolyte. The pre-exponential factor \[ (\sigma) \] could be obtained from the y-axis and the plot intercept, whereas the activation energy \[ (E_a) \] could be calculated from the slope, \[ m, \] of the plot of log conductivity against 1000/\( T \). The activation energy and pre-exponential factor values were calculated from the graph as \[ 0.42 \text{ eV} \] and \[ 1.56 \times 10^3 \text{ S cm}^{-1} \], respectively.

2.5. Chronoamperometry. The total ionic transference number of the highest conducting gel electrolyte containing 20

| composition  | \( T^{\text{dmax1}} \) (°C) | \( T^{\text{dmax2}} \) (°C) | \( T^{\text{dmax3}} \) (°C) | residue (%) | \( T^{\text{g}} \) (°C) |
|--------------|----------------------------|----------------------------|----------------------------|-------------|----------------|
| PUA–LiI 0%   | 110                        | 282                        | 450                        | 5           | -19           |
| PUA–LiI 5%   | 218                        | 364                        | 467                        | 7           | -22           |
| PUA–LiI 10%  | 222                        | 352                        | 466                        | 11          | -23           |
| PUA–LiI 15%  | 217                        | 344                        | 472                        | 11          | -23           |
| PUA–LiI 20%  | 229                        | 339                        | 474                        | 17          | -24           |
| PUA–LiI 25%  | 222                        | 336                        | 472                        | 24          | -21           |
| PUA–LiI 30%  | 224                        | 333                        | 473                        | 22          | -21           |

Figure 5. Variation of log conductivity of the PUA–LiI electrolyte at room temperature.

Figure 6. Arrhenius plot for the conductivity of PUA–LiI20 GPE.
wt % LiI salt was determined by the dc polarization method. This technique was used to analyze the mobile species in the electrolyte, which were either ions or electrons. Figure 7 shows the plot of the normalized current against time for the gel electrolyte. It was observed that the current decreased with an increase in time because of the depletion of ionic species and becomes constant in the fully depleted condition. The residual current was due to the electron migration across the electrolyte interfaces. The graph shows the initial total current ($I_0$) falling rapidly in the first 50 s. The ionic ($t_{\text{ion}}$) and electronic ($t_{\text{electron}}$) transference numbers of the gel electrolyte were further determined by using 3 and 4. The obtained values of $I_0$ and $I_s$ were $6.94 \times 10^{-7}$ and $1.83 \times 10^{-8}$ A. The $t_{\text{ion}}$ and $t_{\text{electron}}$ values of the PUA gel electrolyte were 0.97 and 0.03, respectively. The ionic transference number was significantly higher than the electronic transference number. Thus, it could be concluded that the charge transport in the gel electrolyte was primarily because of ionic migration, and the electron contribution was negligible in the system. The result was found to be in agreement with the findings reported in previous studies.

**2.6. Electrochemical Stability.** The electrochemical stability of electrolytes is a crucial characteristic to be evaluated based on the application point of view in electrochemical devices such as photoelectrochemical cells, energy devices, and batteries. The electrochemical stability window of the PUA–LiI20 gel electrolyte was evaluated by linear sweep voltammetry (LSV), and its corresponding voltammogram is shown in Figure 8. Initially, a small current was observed through the working electrode from the open-circuit potential until it reached a potential of 2.35 V. After this, the current increased gradually, which could be related to the decomposition of the polymer electrolyte. The PUA–LiI20 gel electrolyte with an electrochemical window of 2.35 V was stable enough for use as the electrolyte material of a DSSC. This finding is consistent with the ionic conductivity trend of the gel electrolytes. It can be deduced that the ionic conductivity of the gel electrolyte has a significant influence on the efficiency performance of DSSCs. Table 2 shows the comparison of biobased PU from castor oil, palm oil, and jatropha oil having different iodide salt systems. Each one of the oils has its own unique characteristics and suitable to be used as in the production of PU-based polymer electrolytes. It is worth to mention that their performance is highly dependent on the preparation method of PU, choice of salts, as well as the fabrication method of the DSSC itself. The efficiency obtained in this study is comparatively higher than that of the previous systems. The physical properties of the gel electrolyte give an advantage that improves the overall DSSC performance. This could be explained by the enhancement of the contact among the working electrode, the electrolyte, and the counter electrode. The efficiency is still considered low for commercial applications; nevertheless, the properties could be enhanced with some improvement in the preparation techniques, especially during the formulation of the electrolyte. This includes the addition of (i) secondary polymer matrix, (ii)

![Figure 7. Polarization current vs time plot for the PUA–LiI20 gel electrolyte.](image)

![Figure 8. LSV of the PUA–LiI20 electrolyte.](image)

![Figure 9. Current–voltage characteristics of the PUA–LiI gel electrolyte systems under 1 sun condition.](image)
secondary/ternary salt, (iii) plasticizers, and (iv) fillers into the polymer electrolyte.3

3. MATERIALS AND METHODOLOGY

3.1. Materials. Jatropha oil was commercially obtained from Biofuel Bionas Sdn. Bhd., Kuala Lumpur, and was used as received. Dimethylformamide (DMF), absolute ethanol (99%), and iodine were supplied by R&M Chemicals. LiI was purchased from Sigma-Aldrich. FTO-coated glasses (3 mm, sheet resistance: 8 Ω/sq), TiO2 nanoparticles (particle size: 20 nm), ruthenium dyes, cis-diisothiocyanato-bis(2,2'-bipyridyl-4,4'-dicarboxylato) ruthenium(II) bis-(tetrabutylammonium) (N719), and platinum paste (Platisol T) were purchased from Solaronix, Switzerland. The FTO glass was ultrasonically cleaned with acetone, ethanol, and deionized water to remove any impurities before use.

3.2. Preparation of the PUA-Based GPE. Jatropha-oil based PUA was prepared according to the procedure described in a previous report by the same authors.46 The prepared PUA was mixed with LiI at different percentage ratios (LiI: 0, 5, 10, 15, 20, 25, and 30%). Initially, a calculated amount of LiI and I2 was dissolved with DMF in a sealed vial at room temperature. Then, PUA was added, and the mixtures were stirred for 3 h at 50 °C. The resulting PUA–LiI GPEs were analyzed in terms of ionic conductivity, electrochemical properties, and thermal stability.

3.3. Characterization. 3.3.1. Fourier Transform Infrared Spectroscopy. Vibrational spectroscopic studies were conducted using a FTIR spectrometer (PerkinElmer: model 1000 series) instrument equipped with a universal attenuated total reflectance accessory. The analyses were conducted at room temperature. The samples were scanned at 4 cm−1 resolution, and the spectra were recorded in the wavenumber range 4000–280 cm−1.

3.3.2. Lithium Nuclear Magnetic Resonance. 7Li NMR measurement was performed by using a JEOL NMR spectrometer (JEOL JNM-ECS400, Japan). The gel electrolytes were dissolved with DMSO-d6 prior to testing. The chemical shifts were reported in ppm, and LiCl was used as the internal reference.

3.3.3. Thermogravimetric Analysis. Thermal stability of the GPEs was examined by thermogravimetric analysis (TGA) using a TG analyzer (TGA-7), PerkinElmer (USA). The experiment was carried out under a nitrogen atmosphere (flow rate: 50 mL/min) from 50 to 600 °C at a constant heating rate of 10 °C/min.

3.3.4. Differential Scanning Calorimetry. DSC measurements were carried out using a DSC Q20, TA Instrument (USA) in the temperature range of −60 to 100 °C at a constant heating rate of 10 °C/min under a nitrogen atmosphere (50 mL/min).

3.3.5. Electrochemical Impedance Spectroscopy. Impedance measurements were carried out by electrochemical impedance spectroscopy using VersaSTAT-4 (Princeton Applied Research, USA). The experiments were conducted in the frequency range of 1 Hz to 1 MHz with an applied ac amplitude signal of 10 mV at room temperature. The value of bulk resistance, $R_b$, of the gel electrolytes was determined from the Nyquist plots obtained. The conductivity, $\sigma$, can be calculated as follows

$$\sigma = \frac{t}{R_bA}$$  \hspace{1cm} (1)

where $t$ is the thickness of the sample, $R_b$ is the bulk resistance, and $A$ is the electrode–electrolyte contact area. A conductivity–temperature dependence study was conducted in the temperature range 30–100 °C at 5 °C intervals with a constant humidity. The gel electrolytes were heated in a thermostatic oven model Venticell. The temperature-dependent conductivity, $\sigma$, is expressed by the following Arrhenius equation

$$\sigma = \sigma_0 \exp \left( -\frac{E_a}{KT} \right)$$  \hspace{1cm} (2)

where $\sigma_0$, $E_a$, $K$, and $T$ are the pre-exponential factor, activation energy, Boltzmann constant, and absolute temperature, respectively.

3.3.6. Chronoamperometry Analysis. The chronoamperometry measurement was performed for the highest conducting GPE by the direct current (dc) polarization technique using VERSASTAT-4 (Princeton Applied Research, USA), under a fixed dc voltage of 10 mV. The transference number ($t_{\text{ion}}$) was determined from the current versus time plot. Wagner’s polarization technique was used to evaluate the transference number by using the following equations

$$t_{\text{ion}} = 1 - I_s/I_T$$  \hspace{1cm} (3)

$$t_{\text{electron}} = I_s/I_T$$  \hspace{1cm} (4)

where $I_T$ is the total current (ionic and electronic) at the starting time ($t = 0$) and $I_s$ is the current on saturation (electronic current only).

3.3.7. Electrochemical Stability. The electrochemical stability window was measured by linear sweep voltammetry using VersaSTAT-4 (Princeton Applied Research, USA). The measurement was carried out between 0 and 4 V at a scan rate of 10 mV/s.

3.4. Preparation of DSSC. A DSSC consisting of a photoanode and a counter electrode, with a gel electrolyte in between, was prepared as shown in Figure 10. The photoanode was prepared by coating a TiO2 paste on the FTO glass

Table 2. Properties of DSSCs with Biobased PU GPE Having Various Types of Iodide-Based Salts

| GPE systems         | $J_{sc}$ (mA cm$^{-2}$) | $V_{oc}$ (V) | FF | $\eta$ (%) | ref   |
|---------------------|--------------------------|--------------|----|------------|-------|
| castor oil-based PU–NaI–I2 | 3.60                     | 0.49         | 0.46| 0.80       | Ibrahim et al.45 |
| palm oil-based PU–MPII–EC–I2 | 3.30                     | 0.70         | 0.36| 1.00       | Su'ait et al.45  |
| jatropha oil-based PU–LiI–I2 | 5.54                     | 0.45         | 0.47| 1.20       | current study   |

Figure 10. Assembly procedure of the DSSC.
substrate using the doctor-blade technique and sintered at 450°C. The photoanode was immersed in ruthenium dye, Ruthenizer N719, solution in absolute ethanol (0.3 mM) for 24 h to allow the dye molecules to be absorbed by the surface of the TiO2 layer. After sensitization, the photoanode was washed with absolute ethanol and left to dry at room temperature. The PUA GPE was directly cast onto the dye-absorbed TiO2 electrode. Platinum-coated FTO was used as the counter electrode. It was prepared by the brush painting method of Platisol on the FTO glass and annealing at 450°C for 10 min. The photoanode and the counter electrode were assembled together in a sandwich-like configuration, with the gel electrolyte placed between the electrodes. The photovoltaic performance of the DSSC was measured under illumination using a Keithley high-voltage source model 237 under air mass (AM) 1.5G radiation at 100 mW/cm² controlled by a radiometer. All of the experiments were conducted at room temperature.

From the current−voltage characteristic curves, FF and light-to-energy conversion efficiency (η) were calculated using the following equations

$$\text{FF} = \frac{P_{\text{max}}}{J_{\text{sc}} \times V_{\text{oc}}} = \frac{V_{\text{max}} \times J_{\text{max}}}{J_{\text{sc}} \times V_{\text{oc}}}$$

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

where $P_{\text{max}}$ is the maximum power output, $J_{\text{max}}$ and $V_{\text{max}}$ represent the current density and voltage at maximum power output, respectively, $J_{\text{sc}}$ and $V_{\text{oc}}$ correspond to the short-circuit current and open-circuit voltage, and $P_{\text{in}}$ is the power of the incident light.

4. CONCLUSIONS

A biobased GPE created from jatropha oil-based PUA has been successfully prepared. The characteristics of the gel electrolyte were examined by vibrational, thermal, and electrochemical analyses. The FTIR study showed that a complexation took place between the Li⁺ ions and the nitrogen and oxygen groups from the PUA matrix. This resulted in an increase of thermal stability after the addition of the salt dopant. The effect of the salt concentration on the ionic conductivity of the gel electrolyte was analyzed by electrochemical impedance spectroscopy (EIS). The EIS study showed that the higher ionic conductivity obtained was 20 wt % LiI at room temperature. The temperature-dependent ionic conductivity followed Arrhenius behavior with an activation energy of 0.42 eV. Further, from the chronoamperometry study, the PUA gel electrolyte showed an ionic conductor behavior, and the system was stable up to 2.35 V. A preliminary study of application of a gel electrolyte in a DSCC obtained a photocurrent conversion efficiency of 1.2%. Further study of the DSSC preparation is needed in order to achieve a high conversion efficiency.

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Notes

The authors declare no competing financial interest.

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