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Dye sensitized solar cells based on solid state electrolyte with poly (styrene-co-acrylonitril)

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Abstract

Solid state electrolytes consisting of iodide salt potassium (KI) and iodine (I_2) dissolved in poly (styrene – co- acrylonitrile (P(S-A))) were prepared by mixtures method and applied to dye sensitized solar cells. The cells were coated a conducting glass sheet (TCO) by means of doctor blade technique. The solid state polymer electrolytes were prepared by adding iodide salt potassium (KI) and iodine (I_2) into solid state polymer electrolyte composed of 1, 2, 4, 5 – tetrakisbromomethyl benzene (TB), propylene carbonate (PC), 1-methyl-3-propylimidazodium iodide (MPI), poly (styrene – co – acrylonitrile) (P(S-A)) and ethylene carbonate (EC). The solid state electrolytes mixtures became homogenous and could not flow under sintering at temperature of 70-80 °C. The dye sensitized solar cells based on the solid state electrolytes with poly (styrene-co-acrylonitril) yielded an open- circuit voltage (V_{oc}), the short-circuit current density (J_{sc}), fill factor (FF) of 0.582 V, 6.31 mA/cm^2, and 0.542, respectively, and overall light to electrical energy conversion efficiency (η) of 2.49 %, under irradiation of 80 mW/cm^2.

Keywords: Dye sensitized solar cells, Solid state electrolytes, Energy conversion efficiency, Iodide salt potassium, Iodine

1. Introduction

During the last quarter of the 20th century to the 21st century, many researchers have shown an increased of interest in the development of renewable and non-conventional energy sources having appreciable energy conversion characteristics without pollution. The use of alternative energy sources that generate electricity in an intermittent basis, for example, solar energy and wind power, requires low cost and high efficiency electricity storage systems. [1] The development of a new low cost and durable, dye sensitized solar cell is based on the optimization of several factors including: a) the preparation of nanostructured, high surface area semiconductor titanium dioxide (TiO_2) thin film electrodes b) the synthesis of light capturing antennas, presenting broad and strong absorption bands and bearing functional anchoring, and c) the use of the I^-/I_3^- redox couple in an appropriate medium.

Dye-sensitized solar cells (DSSC) have generated considerable research interest for the past decade [2], because of their high energy conversion efficiency (~10 %) and low production cost [3, 4]. Recently, some researches have been reported on the high performance DSSC employing quasi solid polymer electrolytes. [5] prepared polymer electrolytes consisting of poly (epichlorohydrin-co-ethylene oxide) (Epychlomer), NaI and I_2 and applied to solid-state DSSC. Epychlomer electrolytes show relatively high ionic conductivity of 1.5×10^{-5} S/cm at 30 ℃ and solar cell efficiency of 2.6 % at 100 mW/cm^2 due to the reduced crystallinity of polymer chains. Stergiopoulos et al. also reported highly efficient nanocrystalline TiO_2 solar cells employing binary poly (ethylene oxide) (PEO)/titania/LiI/I_2 electrolyte. Their photoelectrochemical cells resulted in high overall energy conversion efficiency,i.e. 4.2 % at 65.6 mW/cm^2.

Very recently, Stergiopoulos reported that a supramolecular electrolyte was designed for use in DSSCs by modifying low molecular weight polyethylene glycol (Mw = 1000 g/mol) at both chain ends with functional groups having quadruple hydrogen bonding sites [6]. The overall conversion efficiency of these dye sensitized solar cells was 3.34 % at 100 mW/cm^2 (4.59 % at 42.9 mW/cm^2). We also have demonstrated that composite polymer electrolytes consisting of PEO, fumed nanosized silica, an iodide salt, and iodine to provide improved dye sensitized solar cells performance, 4.5 % at 100 mW/cm^2, which is one of the highest value sever reported for dye sensitized solar cells employing solid polymer electrolytes [2].

In this paper, we report the method of preparation of polymer electrolytes and use them for dye sensitized solar cells. We have fabricated solar cell using nanocrystalline titanium dioxide (TiO_2) thin films with sol-gel method. TiO_2 was prepared by sol-gel method and the cells were made by doctor blade technique. The sol-gel was made by titanium dioxide powder 79.90 %, mixed into 0.1 M, nitric acid (HNO_3) in an iso-propanol solution, added DI water (distilled water) until pH 3 – 4 completely and then added triton X – 100 for surfactant. TiO_2 was coated on transparent conducting oxide glass (TCO glass) with doctor blade technique. The polymer solid state electrolytes were prepared by adding iodide salt potassium in iodine (KI/I_2) into polymer electrolyte consisting 1,2,4,5–tetrakisbromomethyl benzene (TB), I_2, KI, propylene carbonate (PC), 1-methyl-3-propylimidazodium iodide (MPI), poly (styrene – co – acrylonitrile) (P(S-A)) and ethylene carbonate (EC). The dye sensitized solar cells were tested for energy conversion efficiency from light to electricity, under irradiation of 80 mW/cm^2.

2. Materials and Methods

Materials

Iodide salt potassium and Iodine (KI and I_2 (A.R. grade), 1,2,4,5–tetrakisbromomethyl benzene (TB), I_2, KI, propylene carbonate (PC), 1-methyl-3-propylimidazodium iodide (MPI), poly (styrene – co – acrylonitrile) (P(S-A)) and ethylene carbonate (EC), were used as received. Conducting glass plates TCO glass (Transparent conducting oxide glass; fluorine doped tin oxide over layer, sheet resistance 8 Ω/sq) was purchased from Solaronix SA, Switzerland. Sensitizing dye bis (tetrabutylammonium)-*cis*-di thiocyanato)-*N*,*N*- bis (4-carboxylato-4-carboxylic acid-

2,2-bipyridine) ruthenium (II) (or commercial name is N719 dye) was purchased from Solaronix SA, Switzerland. Other solvents and reagent were used as received.

Preparation nanocrystalline Titanium Dioxide

Nanocrystalline titanium dioxide films were made by following procedure. Sol gel processing of titanium dioxide was prepared using by mixing powder 79.90 %, mixed into 0.1 M nitric acid aqueous solution in an iso-propanol solution, added distilled water (DI) until pH 3 – 4 completely, and then added a few drops emulsification reagent of surfactant Triton X – 100 to control the stability as well as phase formation of the colloidal or the slurry became a translucent blue-white liquid.

A conducting glass sheet transparent conducting oxide glass was coated with TiO_2 film with doctor blade technique. Finally, the titanium dioxide porous film was sintered by firing the conducting glass sheet at 450 °C for 30 minutes. After that, a titanium dioxide porous film electrode was immersed to absorb the dye for 24 h adequately and then the other impurities were washed up with anhydrous ethanol and dried in moisture-free air.

Gel polymer electrolyte

A series of mixtures were prepared by adding 0.5 g iodide salts potassium, 0.05 g iodine, 1.0 ml propylene carbonate (PC), 1.0 ml 1–methyl–3–propylimidazolium iodide (MPI), and 0.1 g 1,2,4,5–tetrakisbromomethyl benzene (TB), 1.5 g ethylene carbonate (EC) into 1.5 g poly(styrene – co – acrylonitrile) (P(S-A)). The solid state electrolytes were obtained when the mixtures became homogenous and could not flow under stirring at temperature of 70-80 °C.

Assembling of dye sensitized solar cell

Dye sensitized solar cells were assembled by placing a drop of solid state polymer electrolyte into the aperture between the TiO_2 porous film electrode (anode electrode) and Pt coated conducting oxide glass (cathode electrode, prepared by electrodepositing) was placed on the top of the anode electrode. The two electrodes were clipped together and a cyanoacrylate adhesive was used as a sealant to prevent the electrolyte solution from leaking.

Measurements

The detailed surface images were obtained by means of scanning electron microscopy (SEM). Surface morphology, roughness and fractality of the modified TiO_2 films were examined with digital instrument nanoscope, transmission electron microscopy (TEM), X-ray diffraction (XRD) spectra of porous nanocrystalline TiO_2 film by X-ray diffraction XRD with Cu-tube (Philips X'Pert). The photovoltaic test of the dye sensitized solar cells was carried out by measuring the J-V (current density-voltage) characteristic curves. White light Xenon arc lamp was used as a source and the intensity of the incident light was 80 mW/cm^2. The active areas of the cells are about 0.25 cm^2.

The photocurrent performance, i.e. fill factor and overall light to electrical energy conversion efficiency (η), were calculated by the following equations [7]:

$$FF = \frac{V_{\max} J_{\max}}{V_{oc} J_{sc}} \quad (1)$$

$$\eta(\%) = \frac{V_{\max} J_{\max}}{P_{in}} \times 100$$

$$= \frac{V_{oc} J_{sc} FF}{P_{in}} \times 100 \quad (2)$$

Where J_{sc} is the short-circuit current density (mA/cm^2), V_{oc} is the open-circuit voltage (V), P_{in} is the incident light power. $J_{\max}$ (mA/cm^2), $V_{\max}$ (V) are the current density and voltage at the point of maximum power output on the $J-V$ curve, respectively.

3. Results and Discussion

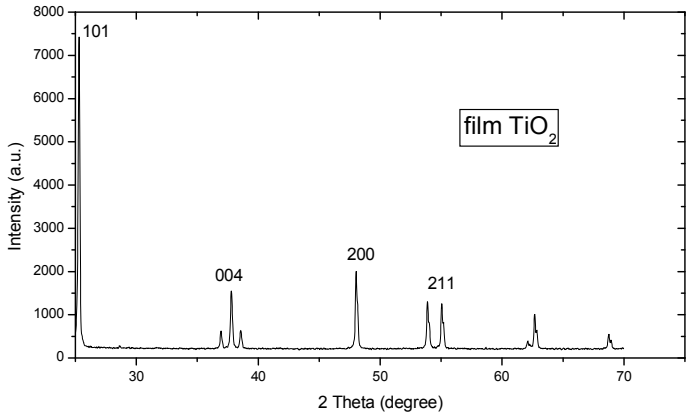

Fig. 1 X-Ray diffraction pattern of nanocrystalline thin film TiO_2.

The photovoltaic test of the dye-sensitized solar cells (DSSC) composed of solid state polymer electrolytes series of mixtures were prepared by adding 0.5 g iodide salts potassium, 0.05 g iodine, 1.0 ml propylene carbonate (PC), 1.0 ml 1–methyl–3–propylimidazolium iodide (MPI), and 0.1 g 1,2,4,5–tetrakisbromomethylbenzene (TB), 1.5 g ethylene carbonate (EC) into 1.5 g poly(styrene – co – acrylonitrile) (P(S-A)) as a mixture solvent. The mixture with the ratio of potassium /iodine (KI : I_2) of 10:1 were measured. The experimental results were summarized in (Table 1.). XRD was used to identify the phase formation. It was found that the phase of TiO_2 was anatese structure and peaks were observed at 2θ= 19°, 28.6°, 36.3° and 48.5° show in Fig. 1.

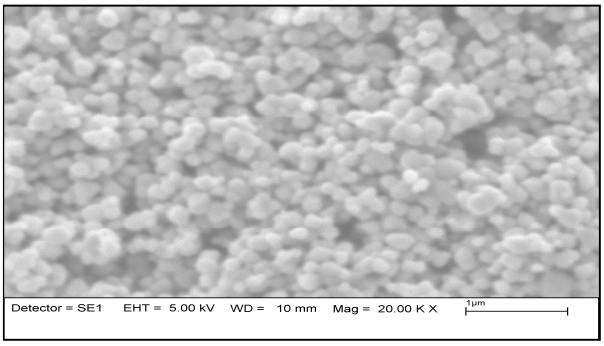

Fig. 2 Scanning electron microscopy (SEM) image of nanocrystalline thin film TiO_2

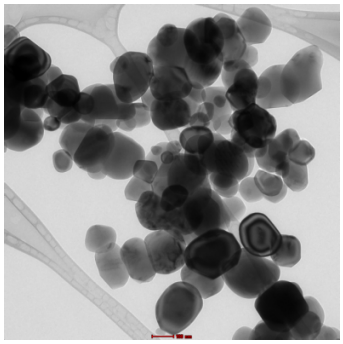

Fig. 3 Transmission electron microscopy (TEM) image of nanocrystalline thin film TiO_2

Scanning electron microscopy (SEM) magnification of 20,000 and transmission electron microscopy (TEM) images of the thin film nanocrystalline and solid state polymer electrolytes structure with the size of 100-200 nanometer (nm) are shown in Fig. 2, 3 and 4. Fig. 5 and table 1 show the photocurrent-voltage characteristics curves (J-V) of dye-sensitized solar cell (DSSC) based on the solid state polymer electrolyte. The open-circuit voltage (V_{oc}), the short-circuit current density (J_{sc}), fill factor (FF) and overall light to electrical energy conversion efficiency (η) value of the dye-sensitized solar cell (DSC) with the solid state polymer electrolyte of KI are 0.582 V, 6.31 mA/cm^2, 0.542, 2.49 %, respectively.

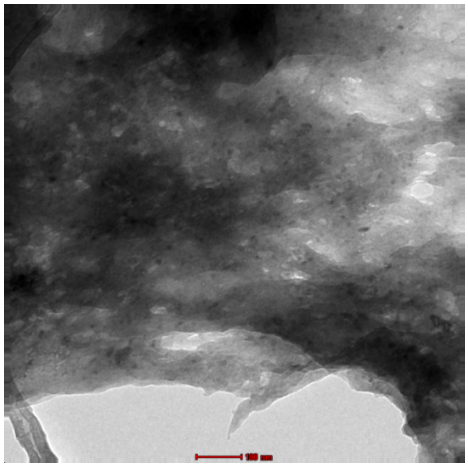

Fig. 4 TEM micrograph of the solid state polymer electrolyte

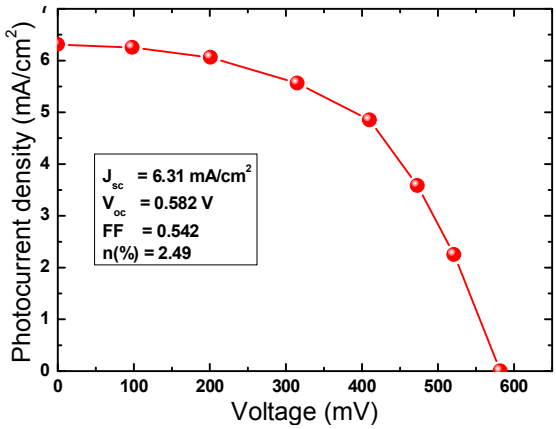

Fig. 5 Current density and voltage curves (J-V) for the dye-sensitized solar cells (DSSC) fabricated by using the solid state polymer electrolyte containing the iodide salt potassium

Table 1 Photoelectrochemical data of the dye sensitized solar cell

Electrolyte	J_{sc} (mA/cm^2)	V_{oc} (V)	FF	η (%)
solid state	6.31	0.582	0.542	2.49

4. Conclusion

In this work, we have synthesized TiO_2 by sol-gel method with doctor blade technique for dye sensitized solar cells (DSSC). XRD data show that the phase structure is anatese and peaks were observed at 2θ = 19°, 28.6°, 36.3°and 48.5°. SEM and TEM images reveal that the nanocrystalline thin film and solid state polymer electrolyte structure size are 100-200 nanometers (nm). The results showed that energy conversion efficiency from light to electricity was 2.49 % under irradiation of 80 mW/cm^2.

5. References

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