Vol. **135** (2019) *ACTA PHYSICA POLONICA A* No. 4

Special Issue of the 8th International Advances in Applied Physics and Materials Science Congress (APMAS 2018)

Dye-Sensitized Solar Cell Using Gel Polymer Electrolytes Based on Organic Dye

M.K. Alobaidi*

Department of Physics, College of Science, University of Baghdad, Baghdad, Iraq

DSSCs were fabricated with the structure of FTO/TiO_2-ZnPc-dye/electrolyte/Pt/FTO. The electrolytes containing (PVP-co-VAc)/PMMA and a mixture of KI and TPAI salts were prepared by solution cast method. The cell fabricated with an electrolyte containing 30 wt% TPAI exhibited a higher efficiency of 1.32%. However, the cell with an electrolyte including 25 wt% TPAI/5 wt% KI exhibited the best power conversion efficiency of 1.1% under 1000 W/m^2 light intensity. Field emission scanning electron microscopy images show that the TiO_2 nanoparticles were comparatively well dispersed but are irregularly shaped due to agglomeration.

DOI: 10.12693/APhysPolA.135.643

PACS/topics: dye-sensitized solar cells (DSSCs), gel polymer electrolyte, binary salts, zinc phthalocyanine

1. Introduction

The development of gel polymer electrolytes with high iodide–ion conductivity is necessary to improve the efficiency [1]. The nature of the cation incorporated with the host polymer matrix plays a significant role in the ion transport mechanism in DSSCs [2, 3]. A photosensitizer should have a high absorption cross-section at the wavelength suitable for the specific application [3, 4]. Among the most promising photosensitizers are zinc phthalocyanines (ZnPcs), which are planar aromatic molecules with considerable electron delocalization [5]. The conversion efficiencies below 1% might be due to the poor solubility of the macrocycle in organic solvents, and a strong tendency to aggregate on the surface [6, 7]. The goal of this work is an attempt to enhance the efficiency of a DSSC with gel electrolyte based on ZnPc.

2. Materials and methods

(PVP-co-VAc) and PMMA, with an average molecular weight of 50000, and 996000 respectively, were dissolved using DMSO, TPAI, and KI with a molecular weight of 313.26 and 166, respectively. Iodine with a molecular weight I:126.9 along with all materials mentioned above were purchased from Sigma-Aldrich. GPE assigned as Cs was prepared by solution cast method with different weight ratio as tabulated in Table I. TPAI and KI were dissolved with 5 ml of DMSO in a glass container using stirrer and heated to 70 °C. Then (PVP-co-VAc) and PMMA were added one after another with weight percent 2:1. The mixture was then stirred for 1 h till it became homogeneous. Then iodine I_2 chips were added. Finally, the mixture was left to cool down to room temperature.

In the next step, 0.5 g of Degussa TiO_2 powder was grounded well for about 30 min in an agate mortar, and then HNO_3 ($\approx$ 2 ml) was added. About 0.1 g of Carbowax and few drops of Triton X 100 were added and mixed well with the above-obtained TiO_2 paste solution and cast using a doctor blade method, followed by sintering at ≈ 450 °C for 30 min. After that, 5 mg of ZnPc (Sigma-Aldrich) was dissolved in 10 ml of THF (Merck, Germany) in a glass bottle. The TiO_2 coated electrodes were soaked in ZnPc dye, and then were withdrawn from the dye solution after 24 h. Alcoholic solution of platinum salt (H_2PtCl_6) was spread on FTO and heated in an oven at 385 °C for $\approx$ 20 min as cathode. Field emission scanning electron microscopy (FE-SEM) was performed with JSM-7600F. The J–V characteristics have been measured with a Keithley 2400 source meter under 100 mW cm^{-2} illumination.

TABLE I

Polymer electrolyte Cs with different salts and I_2 weight ratio.

Cs	KI [%]	TPAI [%]	KI [g]	TPAI [g]	KI [mol]	TPAI [mol]	Total [mol]	I_2 [mol]	I_2 [g]
C1	0	30	0	0.642	0.0000	0.0020	0.0020	0.00020	0.0520
C2	5	25	0.107	0.535	0.0006	0.0017	0.0024	0.00024	0.0597
C3	10	20	0.214	0.428	0.0013	0.0014	0.0027	0.00027	0.0674
C4	15	15	0.321	0.321	0.0019	0.0010	0.0030	0.00030	0.0751
C5	20	10	0.428	0.214	0.0026	0.0007	0.0033	0.00033	0.0828
C6	25	5	0.535	0.107	0.0032	0.0003	0.0036	0.00036	0.0905
C7	30	0	0.642	0.000	0.0039	0.0000	0.0039	0.00039	0.0982

3. Results and discussion

FE-SEM images of the TiO_2 nanoporous electrode, shown in Fig. 1a,b, indicates that nanoparticles are relatively well dispersed but are irregularly shaped due to agglomeration [8].

From FE-SEM images (Fig. 2a and b) of the surface of TiO_2 photoanode immersed in ZnPc, it can be clearly seen that the dye aggregates due to low solubility, which affects on the amount of dye adsorbed by non-porous TiO_2. The solar conversion efficiency depends on the amount of dye loading [9].

---

*e-mail: `mohamedkadhom@yahoo.com`

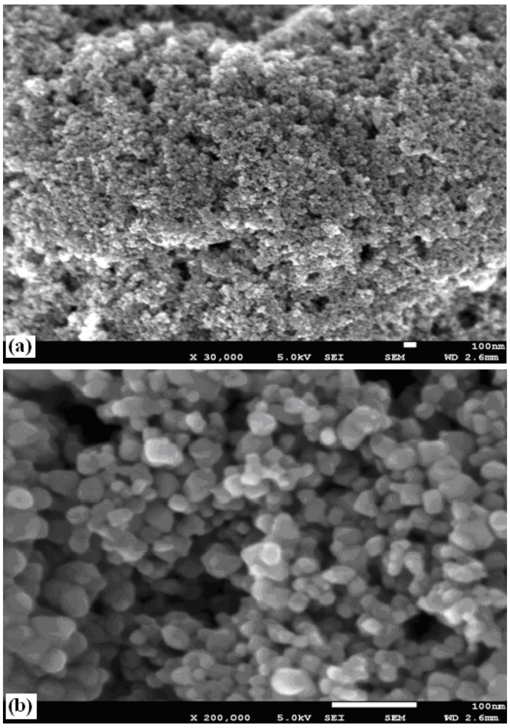

Fig. 1. FE-SEM photograph of nanoporous TiO_2 films showing the surface morphology with a magnification of (a) 30,000 and (b) 200,000 under 5.0 kV accelerating voltage of electron beam.

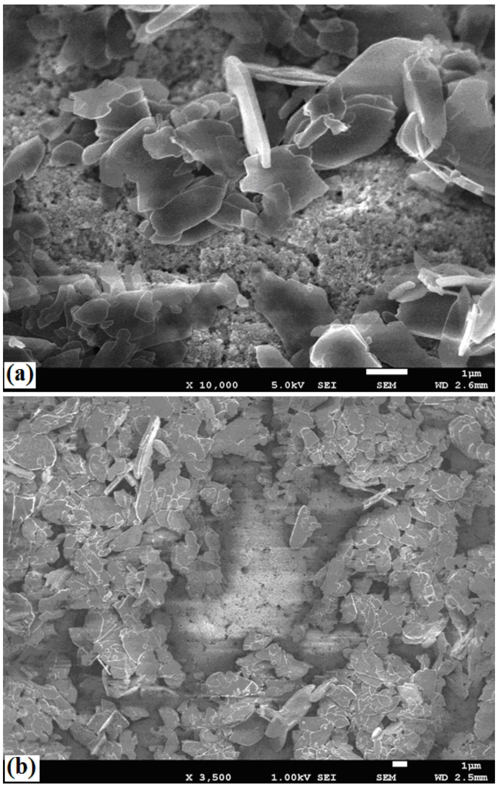

Fig. 2. FE-SEM images of the surface morphologies of ZnPc dye-based TiO_2 nanoparticles with a magnification of (a) 10,000 under 5.0 kV, (b) 3,500 under 5.0 kV, accelerating voltage of electron beam.

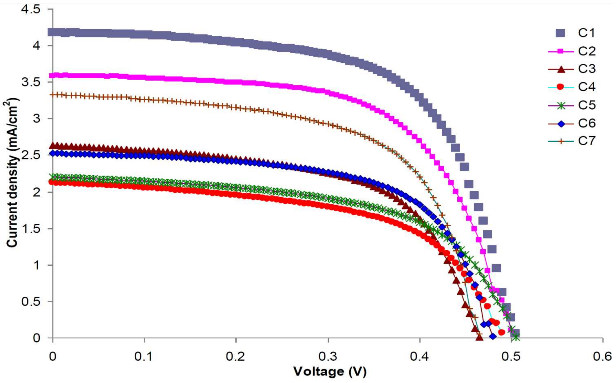

Fig. 3. The photocurrent–photovoltage (J–V) characteristics of solar cells with electrolytes Cs.

The current density–photovoltage characteristic curves (J–V) for seven various cells that were fabricated are shown in Fig. 3. The following equation defines the fill factor:

$$ff = \frac{J_{\max} V_{\max}}{J_{sc} V_{oc}}, \tag{1}$$

where $J_{\max}$ and $V_{\max}$ are the photocurrent and photovoltage for maximum power output and J_{sc} and V_{oc} are the short-circuit photocurrent density and open-circuit photovoltage [7]. The solar conversion efficiency η can be obtained from the following equation:

$$\eta = \frac{J_{sc} V_{oc} ff}{I_0} \times 100, \tag{2}$$

where I_0 is the photon flux (in W m^{-2}), J_{sc} is in mA/cm^2, V_{oc} is in V. The low η of ZnPc adsorbed onto TiO_2 is due to the solubility, aggregation, and poor electron injection from the excited state of phthalocyanine into the conduction band of TiO_2 [10]. ZnPc without anchoring groups will result in very low cell performance, with efficiency $< 1\%$ [11, 12]. Also, it could be ascribed to the fast recombination reaction between the injected electrons and the parent cations [7, 10]. The factors J_{sc}, V_{oc}, ff, and η are listed in Table II. The highest values of η and short-circuit current J_{sc}, were obtained for cells with electrolytes (C1, C2, and C7) (η, 1.324, 1.1, and 0.948) (J_{sc}, 4.17, 3.58, and 3.328) respectively. The rise in η of cell in the presence of TPA^+ larger cations can be assigned to the firm interaction between blend and the positive charges [13].

TABLE II

Photovoltaic parameters of DSSC fabricated with ZnPc dye.

Electrolyte	J_{sc} [mA/cm^2]	V_{oc} [V]	Fill factor (ff)	η[%]
C1	4.17	0.505	0.629	1.324
C2	3.58	0.5	0.619	1.108
C3	2.631	0.465	0.594	0.726
C4	2.12	0.49	0.563	0.585
C5	2.19	0.505	0.575	0.639
C6	2.526	0.48	0.619	0.7516
C7	3.328	0.465	0.613	0.948

4. Conclusion

The effect of electrolyte composition and photoanode morphology on the performance of DSSCs was studied. The morphology characterization by FE-SEM confirms the porous property of the TiO_2 thin film. The low conversion efficiency of ZnPc adsorption onto TiO_2 was due to the solubility, aggregation, and poor electron injection. The highest values of η and J_{sc} were obtained for cells with electrolytes (C1, C2, and C7) (η, 1.324, 1.1, and 0.948) (J_{sc}, 4.17, 3.58, and 3.328), respectively.

Acknowledgments

The author would like to thank the University of Malaya, Center for Ionics, for their support.

References

[1] S. Lu, R. Koeppe, S. Gunes, N.S. Sariciftci, *Solar Energy Mater. Solar Cells* **91**, 1081 (2007).

[2] T.M.W.J. Bandara, M.A.K.L. Dissanayake, W.J.M.J.S.R. Jayasundara, I. Albinssone, B.E. Mellander, *Phys. Chem. Chem. Phys.* **14**, 8620 (2012).

[3] G.W. Park, C.G. Hwang, J.W. Jung, Y.M. Jung, *Bull. Kor. Chem. Soc.* **33**, 4093 (2012).

[4] G. Liu, A. Klein, A. Thissen, W. Jaegermann, *Surf. Sci.* **539**, 37 (2003).

[5] S. Senthilarasu, S. Velumani, R. Sathyamoorthy, A. Subbarayan, J.A. Ascencio, G. Canizal, P.J. Sebastian, J.A. Chavez, R. Perez, *Appl. Phys. A* **77**, 383 (2003).

[6] D. Sharma, A. Huijser, J. Savolainen, G. Steena, J.L. Herek, *Faraday Discuss.* **163**, 433 (2013).

[7] D. Zhang, X.J. Zhang, L. Zhang, L.J. Mao, *Bull. Kor. Chem. Soc.* **33**, 1225 (2012).

[8] M.S. Akhtar, J.M. Chun, O.B. Yang, *Electrochem. Commun.* **9**, 2833 (2007).

[9] E.M. Jin, K.H. Park, J.Y. Park, J.W. Lee, S.H. Yim, X.G. Zhao, H.B. Gu, S.Y. Cho, J.G. Fisher, T.Y. Kim, *Int. J. Photoenergy* **2013**, 296314 (2013).

[10] A.K. Sarker, M.G. Kang, J.D. Hong, *Dyes Pigments* **92**, 1160 (2012).

[11] Y. Amao, T. Komori, *Langmuir* **19**, 8872 (2003).

[12] C.S. Chou, R.Y. Yang, M.H. Weng, C.H. Yeh, *Adv. Powder Technol.* **19**, 541 (2008).

[13] S. Lu, R. Koeppe, S. Günes, N.S. Sariciftci, *Solar Energy Mater. Solar Cells* **91**, 1081 (2007).