CREATIVE SCIENCE

Journal home page: csj.snru.ac.th

# Electrical energy efficiency of dye sensitized solar cells by polymer electrolyte

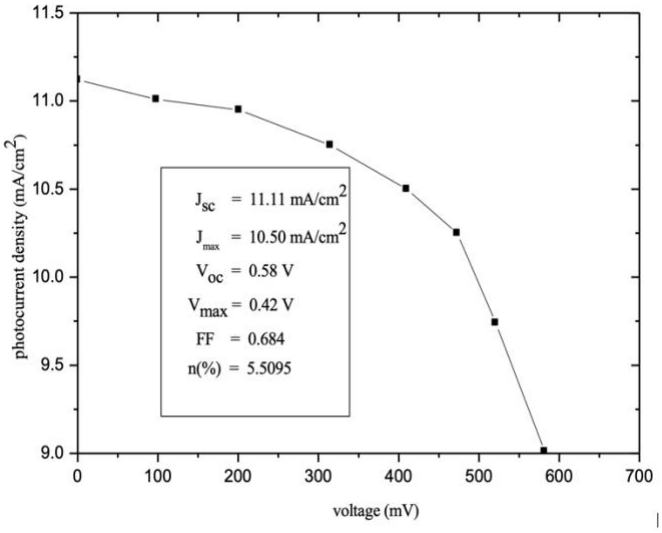
Surasak Santhaveesuk*, Chokchai Kahattha, Witawat Ponhan
Physics Program, Faculty of Science and Technology, Sakon Nakhon Rajabhat University, Sakon Nakhon, 47000 Thailand
*Corresponding Author: surasak31@windowslive.com

DOI: 10.55674/cs.v16i2.254800

**Received:** 18 November 2023; **Revised:** 31 January 2024; **Accepted:** 8 February 2024; **Available online:** 1 May 2024

## Abstract

This research aims to prepare by mixtures method with dope carbon black as a working electrode and the apply it to the dye sensitized solar cells (DSSCs). The thin film of titanium dioxide nanocrystalline semi - conductor with dope carbon black, the cells were coated on to transparent conducting oxide glass sheet by means of the doctor blade technique as a working electrode. But the polymer electrolyte were prepare by adding potassium iodide and iodine salts with a ratio of KI:$I_2$ was 10:1, into a polymer electrolyte composed of poly-ethylene glycol, ethylene carbonate and poly(styrene–co–acrylonitrile). The polymer electrolyte mixtures became homogeneous and stirring at a temperature of 80 °C. Found that efficiency for the DSSCs by polymer electrolyte based on yielded an overall light to electrical energy conversion efficiency ($\eta(\%)$) of the DSSCs was 5.5095%, An open-circuit voltage ($V_{oc}$) of 0.58 V, voltage at the point of maximum power output ($V_{max}$) of 0.42 V, short-circuit current density ($J_{sc}$) of 11.11 mA.cm$^{-2}$, current density at the point of maximum power output ($J_{max}$) of 10.50 mA.cm$^{-2}$ fill factor ($FF$) of 0.684 under an irradiation of 80 mW.cm$^{-2}$. And the long-term stability test of the DSSCs with a polymer electrolyte is evidently superior to the DSSCs with liquid electrolyte based on the observation period lasting for 90 days.




**Keyword:** Dye sensitized solar cells; Polymer electrolyte; efficiency



## 1. Introduction

In between 2000 and 2030 demand for fossil fuels will be increase by about 70%, supplying 80%, of all energy consumed worldwide, are facing rapid resource depletion. The resource reserves of fossil fuels throughout the whole world in 2002 were projected to last 40 years for oil, 60 years for natural gas and 200 years for

coal. Combined with the depletion of fossil fuels resources, global warming, and its associated climate change, there is an urgent need for the environmentally sustainable energy technologies. Among all the renewable energy technologies, photo - voltaic technology utilizing solar energy is considered the most promising one [1]. because of their high energy conversion efficiency (~10 – 13%) and low production cost [2]. Substituting the gel liquid electrolyte [3] is the most efficient way to prevent the leakage and evaporation of electrolytes [4 – 9]. Several types of based on polymers [10] as gelators have been used in gel electrolyte for the dye sensitized solar cells (DSSCs). The concentration of $I^-$ ions is sufficient for reducing the oxidation sensitizer of the DSSCs during operations, if the $I^{3-}$ ions are supplied by only added the lithium iodide or sodium iodide the gel electrolyte.

It is interesting that the organic iodine salts containing large cations, such as N-methyl pyridine iodide [11]. or 1, 3–dimethyl–3 - imidazolinium iodine are also added to gel electrolyte to supply parts of $I^-$ ions. The same strategy was adopted for the DSSCs based on liquid electrolytes [12, 13]. It implies that large cations in gel electrolytes contribute to improving the performance of aquasi-solid-state the DSSCs. In addition, lithium iodide commonly used for the DSSCs is deliquescent and more expensive than other alkali metal iodine salts, such as sodium iodide (NaI), and potassium iodide (KI) [14].

The DSSCs by modifying low molecular weight polyethylene glycol at both chains ends with functional groups having quadruple hydrogen bonding sites [15]. The overall conversion efficiency of the DSSCs was 3.34% at 100 mW $cm^{-2}$.

In this work, the polymer electrolyte was prepared by adding potassium iodide and iodine salts with the ratio of $KI:I_2$ 10:1, into polymer electrolyte composed polyethylene glycol, ethylene carbonate, and poly (styrene–co–acrylonitrile). And use them for the DSSCs devices. I have fabricated DSSCs using the titanium dioxide nanocrystalline, with dope carbon black as working electrode thin films, using the sol-gel method. The DSSCs were tested yielded an overall conversion efficiency ( $\eta(\%)$ ) of the DSSCs under an irradiation with 80 W.$cm^{-2}$. And the long-term stability test of the DSSCs with the based on polymer electrolyte is evidently superior to the DSSCs based on liquid electrolyte with the observation period lasting for 90 days.

## 2. Materials and Methods

*Preparation nanocrystalline $TiO_2$*

The titanium dioxide nanocrystalline semiconductors with dope carbon black as working electrode thin films were prepared as the following procedure. A sol-gel processing of the titanium dioxide nanocrystalline were prepared using by mixed powder of 79.90%, into 0.1 M nitric acid aqueous solution, in an iso-propanol solution, 0.05 g carbon black and distilled water were added for adjusted of value pH 3 – 4.

A conducting glass substrate (TCO glass sheet resistance 8 Ω/sq) was coated onto the titanium dioxide nano- crystalline with dope carbon black on the working electrode thin film with the doctor blade technique. Finally, the titanium dioxide nanocrystalline porous with dope carbon black as a working electrode thin film was sintering by firing the transparent conducting oxide glasses of sheet at 450 °C for 30 minutes and was used as the anode. After that, a titanium dioxide ($TiO_2$) with dope carbon black as working electrode porous thin film electrode was immersed to absorb in the sensitizing dye bis (tetrabutylammonium) -*cis*- di (thiocyanato) -*N*,*N*- bis (4-carboxylato-4-carboxylic acid-2,2-bi pyridine) ruthenium (II) (commercial name is N719 dye). Other solvents and reagents were used as received, adequately and then the other impurities were used as received, for 24 h. washed up with anhydrous ethanol and dried in moisture-free air.

*Polymer electrolyte*

A series of mixtures were prepared based on the polymer electrolyte by adding these potassium iodide mixture iodide salts. The mixture with the ratio of $KI:I_2$ was 10:1., adding 0.5 g potassium iodide, 0.05 g iodine salts, into

a consisting, 1.5 g polyethylene glycol, 1.5 g ethylene carbonate 98%, and 10 mL poly (styrene–co–acrylonitrile).

The polymer electrolyte was obtained when the mixtures became homogenous and could not flow under stirring at a temperature of 80 °C. Finally, the based on polymer electrolyte was obtained.

*Conversion efficiency*

Tested yielded an overall conversion efficiency of the DSSCs under an irradiation with 80 W $cm^{-2}$ by I – V test can be measured such as the equipment model EDAQ (ET 030), automatical computer control.

## 3. Results and Discussion

The photoelectronic execution [i.e. fill factor ($FF$) and an overall conversion efficiency ($\eta(\%)$)] of the DSSCs were calculated by the following equation [16]. :

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

$$\eta(\%) = \frac{V_{max} J_{max}}{P_{in}} \times 100 \quad (2)$$

$$= \frac{V_{oc} J_{sc} FF}{P_{in}} \times 100 \quad (3)$$

Where $J_{sc}$ is the short-circuit current density (mA.$cm^{-2}$), $V_{oc}$ is the open-circuit voltage (V), 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.

Were used to identify the phase formation by X-ray diffraction (XRD). It was found that the phase of the titanium dioxide nanocrystalline were anatese structure and diffraction peaks on the observation at $2\theta$ = 25.28°, 37.80°, 48.04°, 55.06°, 62.68°, 70.30°, and 75.02°. Correspond to the reflection from 101, 004, 200, 211, 204, 220, and 215. And the carbon black structure and diffraction peaks were observed at $2\theta$ = 26.44°, and 37.74°, shown in (Fig. 1). Scanning electron microscopy (SEM) with magnification sizes of as × 20,000 and × 30,000. And transmission electron microscopy (TEM) images of the thin film nanocrystalline and structure with the sizes of as 100 nanometres are shown in Fig. 2 (a), (b) and Fig. 3 (a),(b). Which indicated a very small the titanium dioxide nanocrystalline. And an analysis by energy dispersive X-ray microanalysis (EDX), the resulting energy dispersive phase of the titanium dioxide nanocrystalline with dope carbon black as a working electrode element consisting of titanium (Ti), carbon (C), and oxygen (O) were 63.11, 5.59 and 31.29 wt %, respectively, are shown in Fig. 4.

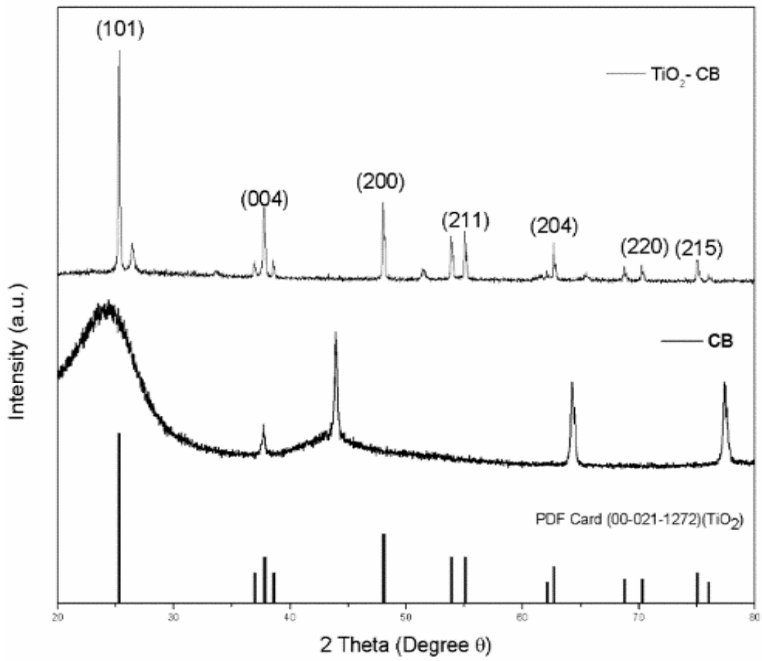
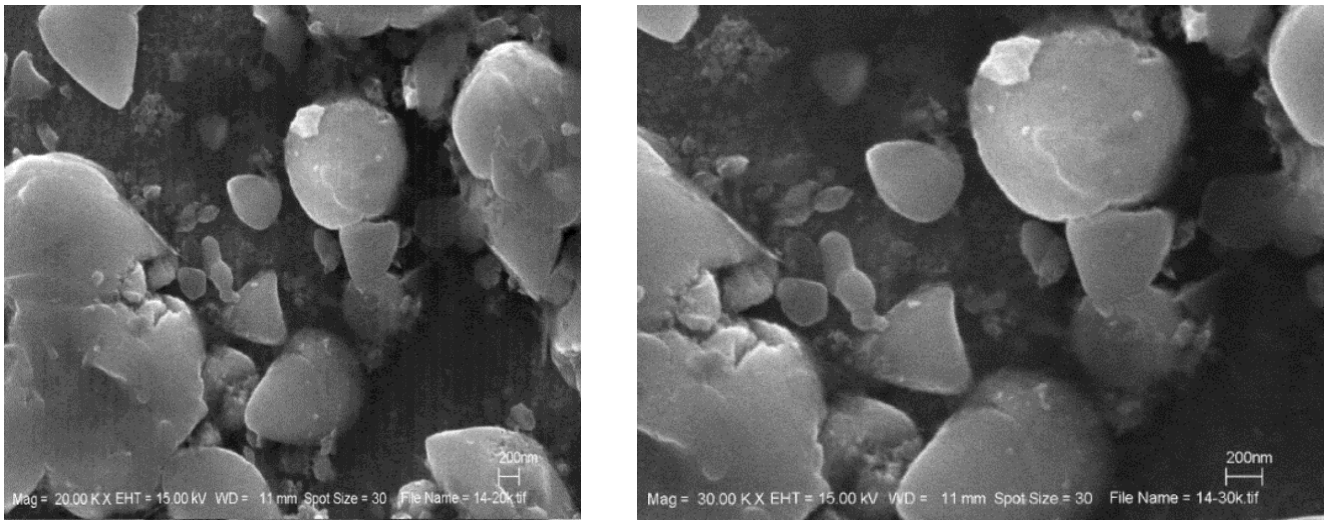
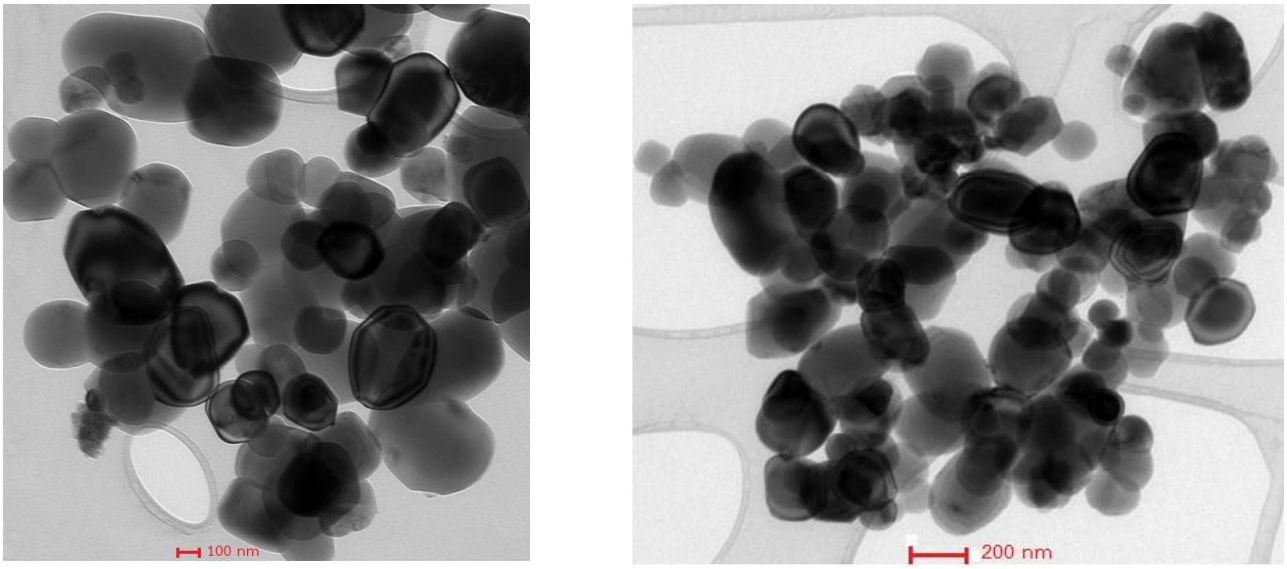



**Fig. 1** XRD patterns of the thin film titanium dioxide nanocrystalline with dope carbon black as a working electrode



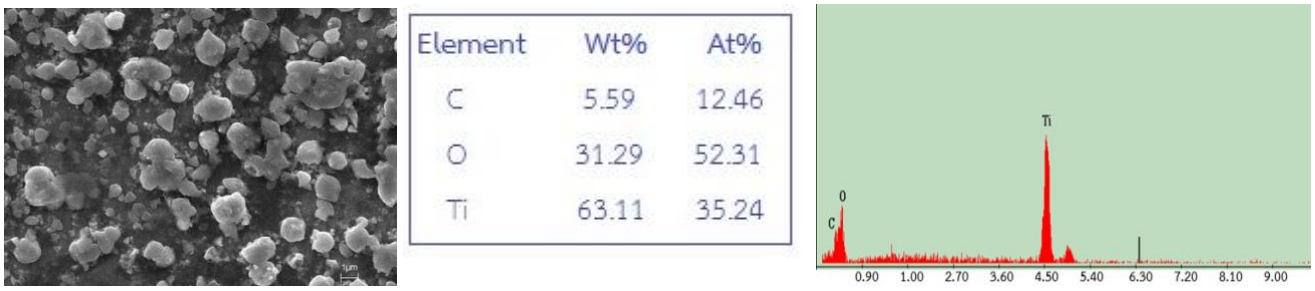

(a) (b)

**Fig. 2** SEM micrograph (a) and (b) of the thin film titanium dioxide nanocrystalline with dope carbon black as working electrode




(a) (b)

**Fig. 3** TEM image (a) and (b) of the thin film titanium dioxide nanocrystalline with dope carbon black as working electrode




(a) (b) (c)

**Fig.4** (a),(b) and (c) EDX of the thin film titanium dioxide nanocrystalline with dope carbon black as working electrode

**Table 1** The photocurrent density-voltage data of the DSSCs with dope carbon black as working electrode

| $J_{sc}$ (mA cm$^{-2}$) | $V_{oc}$ (V) | $FF$ | $\eta$ (%) |
|---|---|---|---|
| 11.11 | 0.58 | 0.684 | 5.5095 |

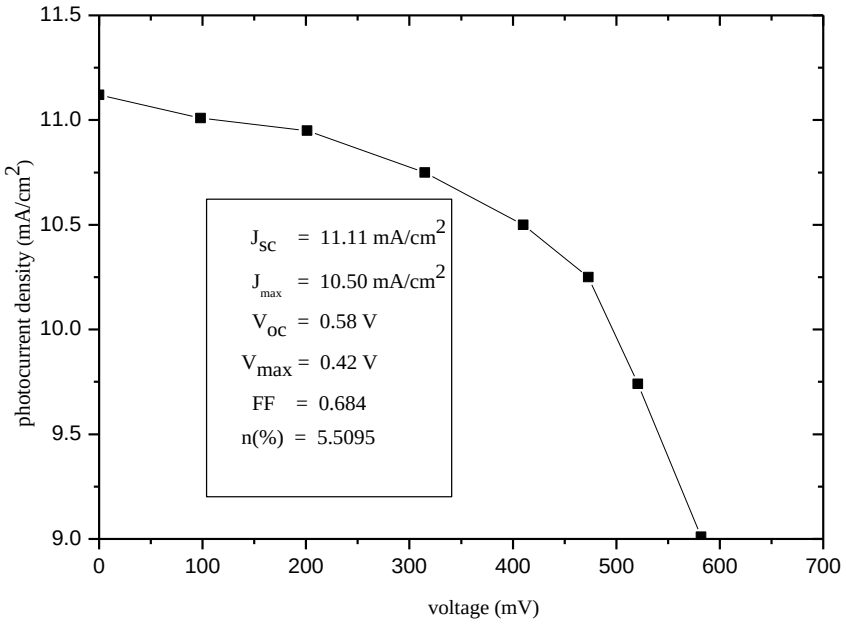



**Fig. 5** J-V curve for the DSSCs under an irradiation with 80 mW.cm$^{-2}$

Fig. 5 and (Table 1). Shows the photocurrent density-voltage characteristics J-V curve of the efficiency of the DSSCs with dope carbon black as a working electrode, based on an electrolyte by added these potassium iodide mixture iodine salts. The mixture with the ratio of KI:$I_2$ was 10:1. Had an overall conversion efficiency ($\eta(\%)$) of the DSSCs was 5.5095 %, an under irradiation with 80 mW cm$^{-2}$.

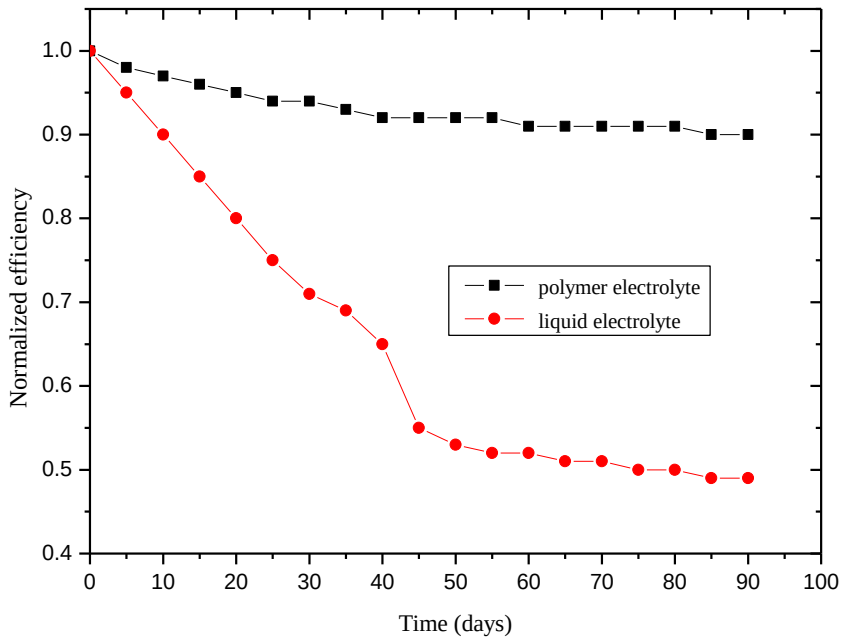



**Fig. 6** Long-term stability test of the DSSCs with dope carbon black as working electrode with the based on polymer electrolyte compared with liquid electrolyte

And Fig. 6, the result showed that the long-term stability test of the DSSCs with dope carbon black as working electrode, based on the polymer electrolyte by adding these potassium iodide mixture iodine salts. The mixture with the ratio of KI : $I_2$ was 10:1. The result shows that on polymer electrolyte compared with liquid electrolyte. Based on the duration of 90 days of observed, the long-term stability test of the DSSCs with the polymer electrolyte is evidently superior to the DSSCs with liquid electrolyte as shown in Fig. 6.

## 4. Conclusion

In this work, efficiency for the DSSCs by polymer electrolyte based on yield an overall light to electrical energy conversion efficiency for the DSSCs, by using the yielded of an open-circuit voltage $(V_{oc})$, of 0.58 V, voltage at the point of maximum power output $(V_{\max})$, of 0.42 V, the short-circuit current density $(J_{sc})$, of 11.11 mA.cm$^{-2}$, the current density at the point of maximum power output $(J_{\max})$ of 10.50 mA.cm$^{-2}$ fill factor $(FF)$ of 0.684, and an overall conversion efficiency $\eta(\%)$ of the DSSCs was 5.5095 %, under an irradiation of 80 mW.cm$^{-2}$. Its the long-term stability test of the DSSCs with the on polymer electrolyte is evidently superior to the DSSCs with liquid electrolyte based on the duration of 90 days of observation.

## 5. Acknowledgment

The authors wish to thank Assoc.Prof. Dr. Supakorn pukird, Department of Physics, Faculty of Science, Ubonrajathanee University and Faculty of Science, Sakon Nakhon Rajabhat University.

## 6. References

[1] B. Li, L. Wang, B. Kang, P. Wang, Y. Qiu, Review of recent progress in solid-state dye-sensitized solar cells, Sol. Energy Materials Solar. 90 (2006) 549 – 573. 10.1016/j.solmat.2005.04.039.

[2] B. O'Regan, M. Grätzel, A Low-Cost, High-Efficiency solar cell based on dye-sensitized colloidal $TiO_2$ Films, Nature. 353 (1991) 737 – 740. 10.1038/353737a0.

[3] Y.J. Kim, J.H. Kim, M.S. Kang, M.J. Lee, Y. Won, J.C. Lee, Y.S. Kang, Supramolecular electrolytes for use in highly efficient dye-sensitized solar cells. Adv. Mater. 16 (2004) 5250. 10.1002/adma.200306664.

[4] A.F. Nogueira, C. Longo, M.A.D. Paoli, Polymers in dye sensitized solar cells:overview and perspectives, Coordin Chem. Rev. 248(13 – 14) (2004) 1455 – 1468. 10.1016/j.ccr.2004.05.018.

[5] P. Wang, S.M. Zakeeruddin, P. Comte, I. Exnar, M. Grätzel, Gelation of ionic liquid-based electrolytes with silica nanoparticles for quasi solid- state dye-sensitized solar cells, J. Am. Chem. Soc. 25 (2003) 1166. 10.1021/ja029294+.

[6] J.B. Xia, F.Y. Li, C.H. Huang, J. Zhai, L. Jiang, Improved stability quasi-solid-state dye sensitized solar cell based on polyether framework gel electrolyte, Sol. Energ. Mat. Sol. C. 90(7 – 8) (2006) 944 – 952. 10.1016/j.jpowsour.2008.09.034.

[7] Y.J. Ren, Z.C. Zhang, S.B. Fang, M.Z. Yang, S.M. Cai, Application of PEO based gel network polymer electrolytes in dye sensitied photoelectrochemical cells, Sol. Energ. Mat. Sol. C. 71 (2002) 253 – 259. 10.1016/S0927-0248(01)00084-8.

[8] X. Zhang, H. Yang, H.M. Xiong, F.Y. Li, Y.Y. Xia, A quasi solid state dye-sensitized Solar cell based on the stable polymer-grafted nanoparticle composite electrolyte. J. Power Sources. 160 (2006) 1451 – 1455. 10.1016/J.JPOWSOUR.200 6.03.008.

[9] Z. Lan, J.H.Wu, D.B. Wang, S.C. Hao, J.M. Lin, Y.F. Huang, Quasi-solid- state dye-sensitized solar cells based on a sol–gel organic– inorganic composite electrolyte containing an organic iodide salt, Sol. Energy. 81(1) (2007) 117 – 122. 10.1016/j.solener.2006.05.003.

[10] J.H. Wu, Z. Lan, J.M. Lin, M.L. Huang, S.-C Hao, T. Sato, S. yin, A Novel

thermosetting gel electrolyte for stable quasi solid-state dye-sensitized solar cell. Adv.Mater. 19(22) (2007) 4006 – 4011. 10.1002/adma.200602886.

[11] F.J. Li, F.Y. Cheng, J.F. Shi, F.S. Cai, M. Liang, J. Chen, Novel quasi-solid electrolyte for dye-sensitized solar cells, J. Power Source. 165 (2007) 911 – 915. 10.1016/j.jpowsour.2007.01.005.

[12] S. Ito, S.M. Zakeeruddin, R. Humphry-Baker, P. Liska, R. Charvet, P. Comte, M.K. Nazeeruddin, P. Pechy, M. Takata, H. Miura, S. Uchida, M. Grätzel, High efficiency organic dye sensitized solar cells controlled by nanocrystalline $TiO_2$ electrode thickness. Adv. Mater. 18 (2006) 1202. 10.1002/adma.200502540.

[13] T. Horiuchi, H. Miura, K. Sumioka, S. Uchida, High efficiency of dye-sensitized solar cells based on metal free indoline dyes, J. Am. Chem. Soc. 126 (2004) 12218. 10.1021/ja0488277.

[14] X. Shen, W. Xu, J. Xu, G. Liang. H. Yang, M. Yao, Quasi-solid-state dye-sensitized solar cells based on gel electrolytes containing different alkali metal iodide salt. Solid State Ionics. 179(35 – 36) (2008) 2027 – 2030. 10.1016/j.ssi.2008.06.027.

[15] T. Stergiopoulos, M.C. Bernard, A.H.L. Goff, Fararas, P. Resonance, Review resonance micro-Raman spectrophoto electrochemistry on nanocrystalline $TiO_2$ thin film electrodes sensitized by Ru(II) complexes. Coord Chem Rev. 248(13 – 14) (2004) 1407 – 1420. 10.1016 /j.ccr.2004.03.023.

[16] M. Grätzel, Perspectives for dye sensitized nanocrystalline solar cells. Prog Photovolt Res. 8 (2000) 171. 10.1002/(SICI)1099-159X(200001/02)8:1<171::AID-PIP300> 3.0.CO;2-U