

## Photoelectrochemical Characteristic of ZnO Dye-sensitized Solar Cell with Platinum Nanoparticle as a Counterelectrode

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### ABSTRACT

*Photoelectrochemical characteristic of ZnO dye-sensitized solar cell (DSSC) with platinum nanoparticle as a counterelectrode was studied. The structure of the DSSC was FTO/ZnO/dye/electrolyte/Pt nanoparticle counterelectrode. For types of dye, Eosin-Y, Rhodamine B and Crystal Violet were examined as sensitizers for ZnO DSSC. The photoelectrochemical characteristics were measured under illumination of simulated sunlight came from a solar simulator with the radiant power of 100 mW/cm<sup>2</sup> using xenon lamp as a light source with AM-1.5 filter. The photocurrent density versus photovoltage characteristics was measured with dc voltage and current source which interfaced and controlled by personal computer. It was found that ZnO DSSC with Eosin-Y exhibited the best photoelectrochemical characteristics with an energy conversion efficiency ( $\eta$ ) of 0.42% compared with those of Rhodamine B and Crystal Violet that exhibited an energy conversion efficiency of 0.18% and 0.08%, respectively. Moreover, two solvents of acetone and ethanol were used as a solvent for the dyes. It was found that acetone gave the better photoconversion performance.*

**Key words:** Photoelectrochemical characteristic, Zinc oxide, Dye-sensitized solar cell, nanoparticle

### INTRODUCTION

Dye-sensitized solar cells (DSSCs) are attracting interest for a new type of solar cell due to their high efficiency and low cost (O'Regan et al., 1991). Since the work of Regan and Grätzel, DSSCs with nanocrystalline TiO<sub>2</sub> as a semiconductor and [Ru(dcbp)<sub>2</sub>(NCS)<sub>2</sub>] or N3 as a sensitizer has given a high energy conversion efficiency of 10% (Nazeeruddin et al., 1993). Thus, TiO<sub>2</sub> has been a popular wide band gap metal oxide in DSSCs. However, an alternative metal oxide semiconductor is ZnO. Recent reports have shown that ZnO and TiO<sub>2</sub> exhibit the similar electron injection process from excited dyes in DSSCs. (Bauer et al., 2001) Also,

N3 dye was applied as sensitizer with a porous ZnO electrode and the conversion efficiency was about 5% (Keis et al., 2002). However, organic dye has many advantages such as low cost, higher absorption coefficient, ease of recycling and so on (Lee et al., 2006). Recently photovoltaic devices with some organic dye such as coumarin (Hara et al., 2003), indoline (Horiuchi et al., 2003), merocyanine (Sayama et al., 2002), and hemicyanine dyes (Ya et al., 2003) have been reported to act as good sensitizers.

In this study, ZnO DSSCs with three organic dyes (Eosin Y, Rhodamine B and crystal violet) were fabricated. The photoconversion performance was compared. Moreover, acetone and ethanol were used as a solvent for the dyes.

### MATERIALS AND METHODS

ZnO film electrodes were prepared on fluorine tin oxide-coated glass (FTO glass) by the screening technique. The ZnO paste was prepared by mixing ZnO powder (ALDRICH Chemical Company, Germany) in a solution of polyethylene glycol in water (6% by mass). After screening on FTO glass, the electrode was sintered for 1 hr at 400°C in air. Eosins Y, Rhodamine B and Crystal Violet were used as sensitizers. The dyes were dissolved in acetone at concentrations of 0.5 mM. The electrodes were immersed at room temperature for 1 hr in the solutions of dyes. Also, the ZnO photoelectrode were immersed in the solution of dye (Eosin Y) in acetone at room and higher temperature (40°C and 55°C) and that in ethanol at room and higher temperature (40°C, 55°C, 80°C). After that, the dye sensitized ZnO electrode was incorporated into a thin-layer sandwich-type solar cell with a spacer. The counter electrode was thin platinum film coated on FTO glass. The electrolyte solution was a mixture of 0.3 M LiI and 0.03 M I<sub>2</sub> in an ethylene carbonate. The photocurrent and photovoltage (J-V curve) were measured under solar stimulation AM 1.5 and light intensity of 100 mWcm<sup>-2</sup>. Based on J-V curve, the fill factor (FF) and the energy conversion efficiency (η) are defined as

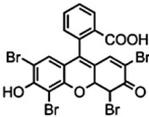
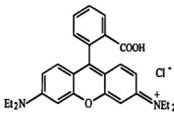
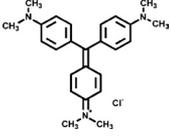
$$FF = \frac{J_{\max} V_{\max}}{J_{SC} V_{SC}} \quad \text{and} \quad \eta = \frac{J_{\max} V_{\max}}{P_{in}} \quad (1)$$

where  $J_{\max}$  and  $V_{\max}$  are the photocurrent and voltage for maximum power output ( $P_{\max}$ ),  $J_{SC}$  and  $V_{OC}$  are the short-circuit photocurrent and open-circuit voltage, respectively, and  $P_{in}$  is the light intensity.

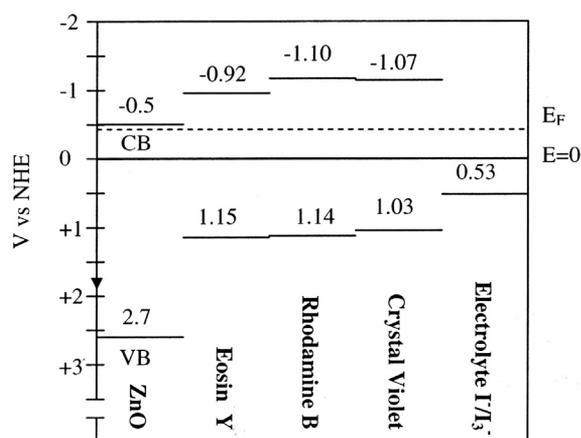
### RESULTS AND DISCUSSION

Table 1 shows electrochemical properties of all three types of dyes and the energy level diagram of DSSCs were shown in Figure 1.

**Table 1.** LUMO, HOMO energy level, molecular structure, absorption maximum of Eosin Y, Rhodamine B and Crystal Violet.

Dye	Eosin Y	Rhodamine B	Crystal Violet
Molecular structure			
$E_{\text{LUMO}}^a$ (V vs NHE)	-0.92	-1.10	-1.07
$E_{\text{HOMO}}^a$ (V vs NHE)	1.15	1.14	1.03
Excitation Energy (eV)	2.07	2.24	2.10
Absorption maximum(nm)	514	543	590

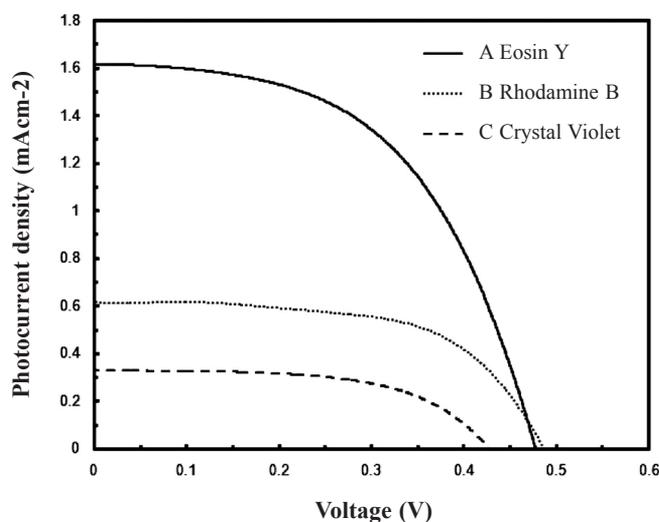
<sup>a</sup> Potentials converted from SCE to NHE scale by addition of +0.24 V (Frebortová et al., 2004)


**Figure 1.** The energy level diagram of ZnO, Eosin Y, Rhodamine B, Crystal Violet and electrolyte ( $I^- / I_3^-$ ).

The ELUMO of Eosin Y, Rhodamine B and Crystal Violet were negative enough to inject electron into ZnO which has the conduction band edge minimum at -0.5 (vs NHE) (Katoh et al., 2004). Moreover, the potential of the redox couple in the  $I^- / I_3^-$  electrolyte ( $E_{\text{redox}} = 0.53$  V vs NHE (Wang et al., 2005)) were higher than EHOMO of all three dyes. The photovoltaic performance of Eosin Y, Rhodamine B and Crystal Violet in DSSCs were shown in Table 2 and the photocurrent-voltage curves (J-V curves) were illustrated in Figure 2.

**Table 2.** The performance of DSSCs sensitized with Eosin Y, Rhodamine B and Crystal Violet under AM 1.5 radiation and 100 mWcm<sup>-2</sup> light intensity.

Dye	$E_{\text{HOMO}} - E_{\text{redox}}$	VOC (V)	$J_{\text{SC}}$ (mAcm <sup>-2</sup> )	FF	$\eta$ (%)
A Eosin Y	0.62	0.48	1.62	0.53	0.41
B Rhodamine B	0.61	0.49	0.62	0.60	0.18
C Crystal Violet	0.50	0.43	0.33	0.58	0.08



**Figure 2.** J-V curves of device A-C.

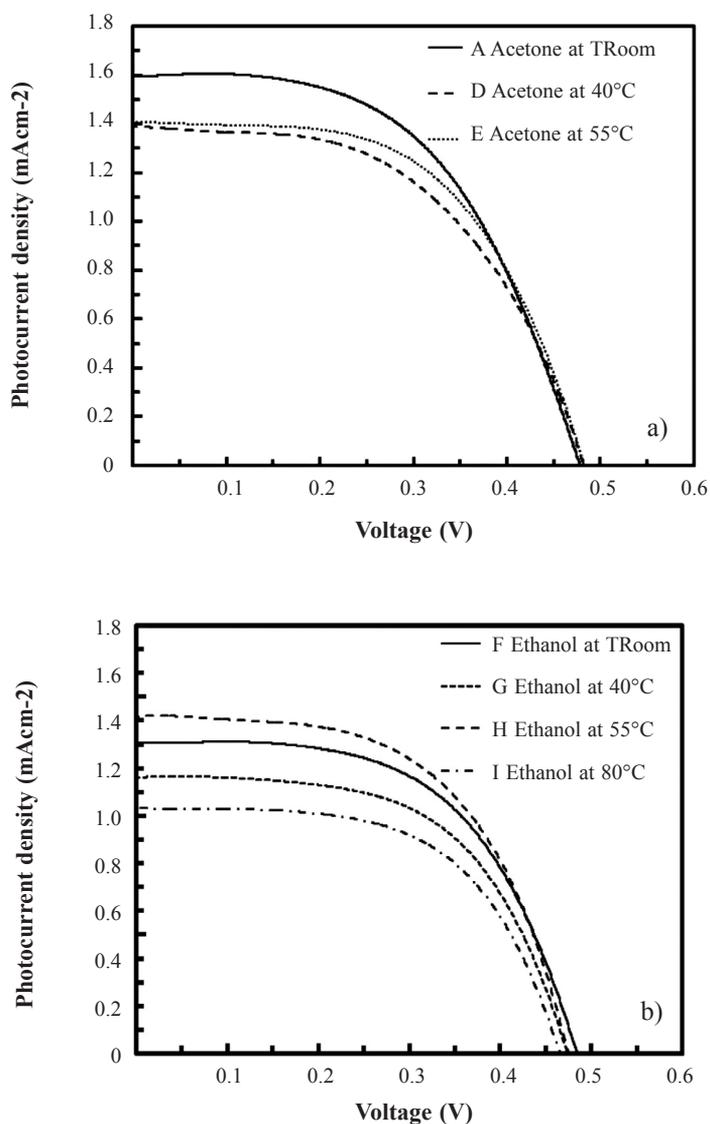
From Table 2 and Figure 2, the  $V_{\text{OC}}$  of devices A, B and C were 0.48, 0.49 and 0.43 V, respectively. These values were independent of the type of dyes because  $V_{\text{OC}}$  depended on the difference of  $E_f$  and  $E_{\text{redox}}$ .

The  $J_{\text{SC}}$  of devices A-C were 1.62, 0.62 and 0.33 mAcm<sup>-2</sup>, respectively. The Eosin Y sensitized solar cell (device A) produced photocurrent more than that of Rhodamine B (device B) and Crystal Violet (device C) sensitized solar cell. The higher  $J_{\text{SC}}$  of devices A may be caused by the surface structure of the electrode, the amount of dyes on the surface, or the electron injection ability.

Moreover, ZnO DSSCs with Eosin Y were also studied with different dye solvent. The dye solvent was in acetone at room (27°C) and higher temperature (40°C and 55°C) and in ethanol at room (27°C) and higher temperature (40°C, 55°C, 80°C). The photovoltaic performance at different dye solvent was shown in the Table 3 and Figure 3. It can be seen that DSSCs with Eosin Y in acetone at room temperature gave the highest short current density and thus, highest photo conversion efficiency. The  $V_{\text{OC}}$  and FF values were about the same values for all samples of A-I.

**Table 3.** The performance of DSSCs with Eosin Y in acetone and ethanol at different temperature.

Device	$V_{oc}$ (V)	$J_{sc}$ ( $mAcm^{-2}$ )	FF	$\eta$ (%)
A Acetone at room temp.	0.48	1.62	0.53	0.41
D Acetone at 40°C	0.48	1.39	0.53	0.35
E Acetone at 55°C	0.48	1.41	0.56	0.38
F Ethanol at room temp.	0.48	1.31	0.58	0.37
G Ethanol at 40°C	0.47	1.16	0.58	0.32
H Ethanol at 55°C	0.47	1.42	0.57	0.38
I Ethanol at 80°C	0.47	1.04	0.59	0.28



**Figure 3.** J-V curve of a) devices A, D and E and b) devices F, G, H and I.

## CONCLUSION

Eosin Y, Rhodamine B and Crystal Violet were examined as sensitizers for zinc oxide solar cells and all three types of dyes were able to promote the light harvesting and the electron injection into the semiconductor conducting band. Eosin Y acted as sensitizer better than Rhodamine B and Crystal Violet and their photo conversion efficiency were 0.41%, 0.18% and 0.08%, respectively. Moreover, acetone acted as the solvent of Eosin Y dye solution better than ethanol.

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