J-V Characteristics of Dye-sensitized Solar Cell Based on ZnO Nanobelts with Different Buffer Layer

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ABSTRACT

Characteristics of dye-sensitized solar cells based on ZnO nanobelts with different buffer layer as a photoelectrode were studied. The structure of the DSSC was Fluorine-doped tin oxide (FTO)/buffer layer/ZnO nanobelts/Eosin-Y/iodine-iodide /Pt nanoparticle counterelectrode. The photoelectrode of ZnO nanobelts and buffer layers were prepared by rf sputtering technique. The photoelectrochemical characteristics were measured under the illumination of simulated sunlight from a solar simulator with the radiant power of 100 mW/cm^2 using a xenon lamp as a light source with the AM-1.5 filter. The photocurrent density versus photovoltage (J-V) characteristics was measured with dc voltage and current sources which were interfaced and controlled by personal computer. It was found that types of buffer layer had effect on the J-V characteristics of DSSC. The obtained photoelectrochemical results will be discussed by the equivalent circuit model of solar cell.

Key words: Zinc oxide, ZnO, Nanobelts, Dye sensitized solar cell

INTRODUCTION

The dye-sensitized solar cell (DSSC) is one of the most promising organic solar cells. It exhibits high power conversion efficiency up to 10.8% by using TiO_2 nanostructures as reported several years ago (Hagfeldt et al., 1995; Chiba et al., 2006). Thus, the DSSC based on TiO_2 has been extensively investigated.

ZnO is a promising metal oxide semiconductor that can be used as an alternative photoelectrode in DSSC because its band gap, electron affinity, and electron injection efficiency are nearly the same as TiO_2. Recently, the research work on ZnO as an alternative photoelectrode has been intensively done. However, the photoconversion efficiencies of DSSCs based on ZnO are quite low compare to TiO_2 DSSCs. The DSSC based on ZnO has in recent year reached power conversion efficiencies in the 5%, range which make them suited for many applications provided that they are stable (Baxter et al., 2006; Chen et al., 2006; Lee et al.,

2004).

One of the parameters that enhance the efficiency of ZnO DSSC is the charge recombination at the interface in DSSC as show in Figure 1.

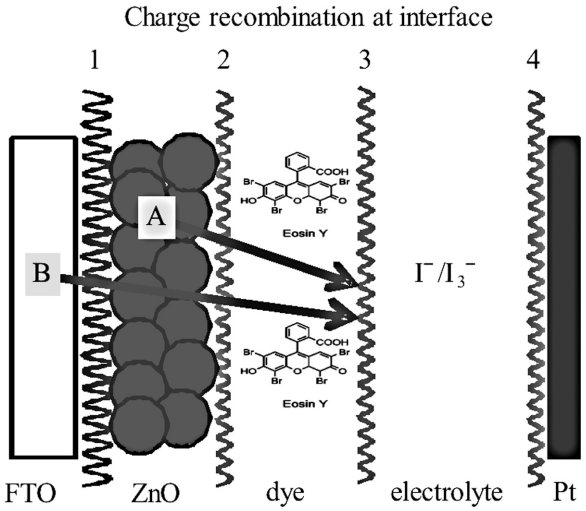

Figure 1. Charge recombination transfer processes of the dye-sensitized solar cell.

Charge recombination transfer processes of the dye-sensitized solar cell are shown in Figure 1. When the dye sensitizer absorbs a photon and transform to excited state, an electron of dye injects to the conduction band of ZnO as charge recombination at interface number 2 and given by equation

$$D + \text{photon} \rightarrow D^* \rightarrow D^+ + e_{ZnO}^- \quad (1)$$

where D*, and D^+ are an excited dye molecule, and an oxidized dye molecule, respectively. After that, injected electron diffuse through FTO as charge recombination at interface number 1 and flow through the load via the external circuit and then reach the Pt counterelectrode. At the Pt counterelectrode, the oxidized redox species (R^+) is subsequently reduced back to R by accepting electron at the charge recombination interface number 4. Finally, R^+ is generated from the charge recombination at interface number 3 as in chemical equation

$$D^+ + R \rightarrow D + R^+ \quad (2)$$

where D, R, and R^+ is an original dye molecule, redox species, and oxidized redox species, respectively. This equation is usually called the dye regeneration process. The oxidized dye is quickly reduced back to its original state by reduce redox species (R) in the electrolyte for a complete cycle of electron transfer. On the other hand, a charge recombination back transfer is also shown in Figure 1. Path A and path B represent charge transfer from ZnO layer to electrolyte and from FTO to

electrolyte, respectively. Therefore, the interface between ZnO and FTO glass is playing an important role for back transfer. Recently, the interface between FTO and semiconductor was studied by using Nb_2O_5 blocking layer deposited between fluorine-doped tin oxide (FTO) and nanocrystalline TiO_2 (Xia et al., 2007). The remarkable improvements of VOC and fill factor for the DSSCs suggested that the thin Nb_2O_5 layer is an effective blocking layer at the FTO and TiO_2 interface.

In this work, the effect of the buffer layer on the photoconversion performance of the ZnO DSSC was investigated. The buffer layers were used in order to control the interface between ZnO and FTO glass and they were prepared by rf sputtering technique.

MATERIALS AND METHODS

ZnO nanobelts were prepared by rf sputtering technique on the copper substrate (Choopun et al., 2005). The white ZnO products were extracted from a substrate and dissolved in a polyethylene glycol (PEG) solution 10% by weight for ZnO nanobelt paste. The three different buffer layers (no buffer layer, ZnO thin films layer, and ZnO:Al thin films layer) were prepared on FTO glass by rf sputtering technique. For sputtering conditions, the base pressure was lower than 10^{-5} Torr and the deposition pressure was 20 mTorr under argon atmosphere with RF power of 200 W. The deposition times were 10 min. A photoelectrode was fabricated by screen-painting the ZnO nanobelt paste on the conductive glass with different buffer layer, followed by calcinations at 450°C for 1 h. The photoelectrode were soaked in Eosin-Y organic dye solution (0.04 g of Eosin Y, $C_{20}H_6Br_4Na_2O_5$, in acetone 100 cm^3) for 1 h. The dye-loaded ZnO as photoelectrode and the Pt counterelectrode (0.5 mM Hydrogen hexachloroplatinate (IV) Hydrate, Cl6H2Pt.aq, in acetone solution) were assembled into a sealed device using a hot-melted double layer parafilm (50 μm thick/sheet). The redox electrolyte (0.3 M LiI + 0.03 M I2 in Polyethylene carbonate) was introduced into the inter-space between the photoelectrode and the counterelectrode through two predrilled holes on the side of the device. The photoelectrochemical characteristics of ZnO DSSCs were tested under the simulated sunlight AM 1.5 from a solar simulator with the radiant power of 100 mW/cm2. The incident light intensity was calibrated with a standard Si solar cell. J-V characteristic were measured with a dc voltage and current sources which were interfaced and controlled by a computer.

Table 1. Summary of the photoelectrode with different buffer layer for ZnO DSSCs.

Devices	Layer1	Layer2
A	ZnO thin film	ZnO nanobelt
B	ZnO:Al thin film	ZnO nanobelt
C	-	ZnO nanobelt
D	-	ZnO nanobelt*

*The ZnO nanobelt was deposited on FTO glass by rf sputtering.

RESULTS AND DISCUSSION

Figure 2 shows J-V characteristics of ZnO DSSCs with different buffer layers. All samples can generate photocurrent in the order of mA under solar simulated sunlight as solar cell. The photoelectrochemical parameters such as the short current density (J_{sc}), the open circuit voltage (V_{oc}), the fill factor (FF) and the overall photoconversion efficiency (η) determined from the measured J-V curves was summarized in Table 2. Clearly, ZnO nanobelt DSSC with ZnO thin films layer exhibits high short current density (J_{SC} = 2.15 mA cm^{-2}) and finally, higher photoconversion efficiency (η = 0.65%).

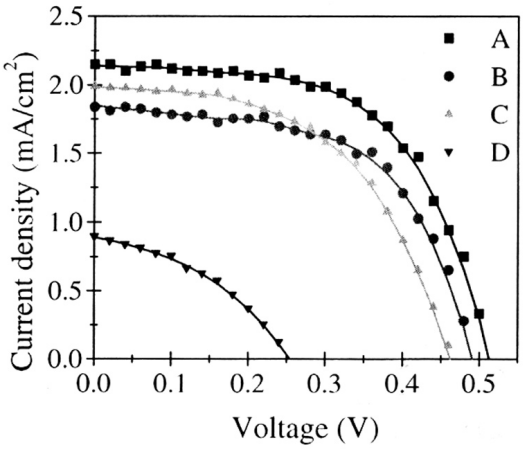

Figure 2. J-V characteristic of ZnO nanobelts as a photoelectrode with Eosin Y sensi-tized solar cell.

Table 2. Summary of the photoelectrochemical parameters such as short current density (J_{sc}), open circuit voltage (Voc), fill factor (FF) and the overall photo- conversion efficiency (η) of ZnO DSSCs.

Devices	VOC (V)	J_{SC} (mA/cm^2)	FF	η (%)
A	0.52	2.15	0.58	0.65
B	0.49	1.85	0.60	0.54
C	0.46	1.99	0.53	0.48
D	0.25	0.88	0.41	0.09

Usually, J_{SC} is directly related to an amount of dye-sensitizer adsorbed on the ZnO photoelectrode surface. The higher short circuit current density in ZnO nanobelt DSSC sample indicates that larger amount of dye adsorbed on surface. Sample D was exhibited lowest J_{SC} indicating the least amount of dye adsorbed on surface. This may be due to the density of ZnO nanobelt prepared by sputtering is lower than ZnO nanobelt prepared from paste (Choopun et al., 2005). The DSSCs which were fabricated from ZnO nanobelt paste showed high J_{SC} of about 2 mA, depending on the type of buffer layer.

Normally, the maximum open circuit voltage, VOC, of ZnO DSSC depends on the difference of the energy level between redox potential of electrolyte and Fermi-level of ZnO. Thus, the VOC of ZnO DSSCs is independent with morphology and dye adsorption surface area of ZnO. But VOC is dependent on a photoelectrode thickness, an inter-space thickness between the photoelectrode and the counterelectrode, and an interface area between electrolyte and FTO glass (Xia et al., 2007). Our results showed the drop of VOC in sample D which has the highest photoelectrode thickness. Moreover, the fill factor also shows a similar value for each sample.

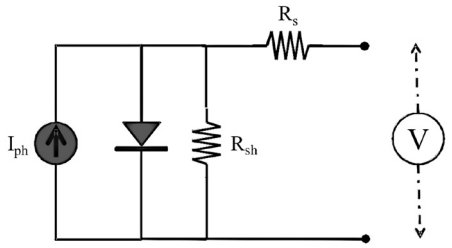

Figure 3. Simple equivalent circuit model for conventional solar cells

In addition, the equivalent circuit of solar cell is shown in Figure 3, a shunt resistance (R_{sh}) is in parallel with a diode and a constant-current source (I_{ph}) which are in series with series resistance (R_s). The series resistance is mainly caused by the bulk resistance of semiconductor materials, metallic contacts, and interconnections, and the contact resistance between the metallic contacts and the semiconductor. The shunt resistance is due to leakage across the interface between photoelectrode and dye, and the presence of crystal defects and/or impurities in the interface region. The source Iph results from the excitation of excess carriers by solar radiation. Typically, the DSSC with high R_{sh} and low R_s would exhibit the best performance of solar cell. Shunt resistance and series resistance of ZnO DSSC with different buffer layers are shown in Table 3. For our results, ZnO nanobelts with ZnO thin films buffer layer showed the best performance of DSSC, which is in agreement with higher Rsh and lower R_s.

Table 3. Shunt resistance and series resistance of ZnO DSSC with different buffer layers.

Devices	Rsh ($\Omega.cm^2$)	Rs ($\Omega.cm^2$)
A	3,451	23
B	1,609	56
C	2,917	52
D	742	115

CONCLUSION

We presented the effect of the different buffer layer on the photoconversion performance of the ZnO DSSC. It was found that types of buffer layer had an effect on the J-V characteristics of DSSC. The DSSCs based on ZnO nanobelts with ZnO thin films buffer layer exhibited the best performance with photoconversion efficiency of 0.65% (J_{SC} = 2.15 mA cm^{-2}, V_{OC} = 0.52, FF = 0.58). The DSSC with buffer layer exhibited better photoconversion performance than DSSC without a buffer layer due to the improvement of interface between ZnO and FTO.

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