



# Improving the durability of dye-sensitized solar cells through back illumination

Lu-Yin Lin<sup>a</sup>, Chuan-Pei Lee<sup>a</sup>, R.Vittal<sup>a</sup>, Kuo-Chuan Ho<sup>a,b,\*</sup>

<sup>a</sup> Department of Chemical Engineering, National Taiwan University, Taipei 10617, Taiwan

<sup>b</sup> Institute of Polymer Science and Engineering, National Taiwan University, Taipei 10617, Taiwan

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## ABSTRACT

Highly efficient and stable back illumination dye-sensitized solar cell (BIL-DSSC) is developed using its Pt-counter electrode (Pt-CE) as the light-irradiating surface. Photovoltaic parameters are measured for DSSCs with Pt-CEs obtained with different sputtering periods of platinum layer. By optimizing the transmittance and catalytic property of the platinum layer on the counter electrode, a light-to-electricity conversion efficiency ( $\eta$ ) of 7.54% is achieved with back illumination at  $100 \text{ mW cm}^{-2}$ , when the platinum deposition time is 30 s. The effects of platinum layers with different sputtering periods on the photovoltaic characteristics of the respective DSSCs are explained in terms of transmittance and catalytic activity of the layers. A comparative study is also made on the durability of the DSSCs with BIL and front illumination (FIL), in which the respective DSSCs are previously subjected to UV-soaking for different periods of time under simulated conditions of back and front illuminations; at-rest stability tests for such UV-soaked DSSCs carried out through BIL and FIL suggest a far higher stability in favor of the BIL-DSSC, compared to that of the FIL-DSSC. Explanations are substantiated with transmittance spectra, cyclic voltammetry (CV), electrochemical impedance spectroscopy (EIS), and absorption spectra.

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## 1. Introduction

It is well known that a typical dye-sensitized solar cell (DSSC) consists of three adjacent thin layers: a mesoporous  $\text{TiO}_2$  film, dye molecules such as ruthenium bipyridyl derivatives on the  $\text{TiO}_2$  film, which are sensitive to sunlight, and an organic liquid electrolyte, essentially containing iodide and triiodide ions as a redox couple. These three layers are sandwiched together between two conducting glasses, one covered with a thin layer of  $\text{TiO}_2$  and the other with a platinum layer. Mesoporous  $\text{TiO}_2$  is an active photocatalyst for various degradation reactions of organic molecules [1–5] and can decompose them under ultraviolet (UV) ray irradiation, facilitated by its large band gap (3.2 eV) [6–19]. In the case of a DSSC,  $\text{TiO}_2$  can degrade the dye through its photocatalytic activity under UV radiation of sunlight, and can thus deteriorate the functioning of the cell in long-term operations. Fortunately, iodine, which has been added to produce the redox couple ( $\text{I}^-/\text{I}_3^-$ ) in the electrolyte, has an excellent ability to absorb ultraviolet (UV) rays [20]. To exploit this ability of iodine advantageously and to cope with the problem of decomposition of dye molecules from  $\text{TiO}_2$ , back illumination (BIL) of DSSCs can be a strategy to be adopted; a success of this

strategy of BIL implies improvement of the stability of the DSSC. In the case of a front-illuminated DSSC (FIL-DSSC), the sunlight passes through the transparent working electrode instead of non-transparent Pt-CE; the advantage for this FIL is that light can excite more dye molecules due to higher transmittance of the working electrode (FTO) than that of the counter electrode (ITO + platinum) and that light can directly strike the dye molecules, which is not possible with BIL. The disadvantage with FIL is that UV part of light can degrade the dye molecules, catalyzed by  $\text{TiO}_2$ . In the case of BIL, light passes through the Pt-CE and electrolyte layer, in which the electrolyte enables absorption of UV rays and thereby reduces the decomposition probabilities of dye molecules. Although in sunlight the ratio of UV rays is only 6% [21], it is still necessary to minimize the effect of UV rays on the performance of a DSSC, in order to develop a more stable device.

Platinum coated counter electrode is very important in determining the performance of a BIL-DSSC. The counter electrode in a DSSC should have the following characteristics for high performance of the cell: (1) high conductivity for transporting electrons, (2) excellent catalytic activity for triiodide reduction, and (3) high transparency for the penetration of light through the counter electrode. According to previous reports, the catalytic abilities of platinum layers deposited for different periods above 7 s are almost the same for DSSCs with FIL [22]. This needs not be the case with BIL, as the thickness of a platinum layer can play a great role, owing to the fact that light-transmittance is not the same at different thicknesses. Fabrication of Pt-CE with high transmittance and catalytic

\* Corresponding author at: National Taiwan University, Department of Chemical Engineering, No. 1, Sec. 4, Roosevelt Rd., Taipei 10617, Taiwan.  
Tel.: +886 2 2366 0739; fax: +886 2 2362 3040.

E-mail address: [kcho@ntu.edu.tw](mailto:kcho@ntu.edu.tw) (K.-C. Ho).

ability is also very important with respect to a flexible DSSC in view of its design, which needs a non-transparent flexible substrate, such as titanium metal, for its photoanode. Almost all the previous studies have adopted BIL for research on flexible DSSCs. In this research we adopted BIL to study the stability aspect of the DSSCs in general.

In this study, we have optimized the optical and catalytic properties of the counter electrode by varying the sputter-deposition time of platinum layer on the electrode. We have shown that a BIL-DSSC is about six times more stable against UV-soaking than a FIL-DSSC and shows an  $\eta$  of 7.54%, when its front-illuminated version shows an  $\eta$  of 7.87%. Fan et al. have studied front-illuminated DSSCs and the  $\text{TiO}_2$  used was commercial P25 [22]. In our case, the DSSCs are back-illuminated and the  $\text{TiO}_2$  used is commercial ST-21. Their best efficiency was 4.90% with 2 s as Pt deposition time, and our best efficiency is 7.54% with 30 s as Pt deposition time and 20 mA as sputtered current. Khelashvili et al. have studied catalytic effects of platinum layers for DSSCs, without measuring the photovoltaic parameters of the cells [23]. They did not measure the photovoltaic parameters of the pertinent cells and focused on the study of the catalytic performance of the counter electrodes. They achieved the best charge transfer resistance value of  $0.93 \Omega \text{ cm}^2$  with 3% platinum. In terms of deposition time of platinum, i.e., for 180 s, we obtained the best charge transfer resistance of  $8.56 \Omega \text{ cm}^2$ .

The meager decrease in efficiency and remarkable increase in durability against UV-light in favor of the BIL-DSSC assumes importance to this research. The novelty of this study lies on the grounds that this is a comparative study on the performances of a BIL-DSSC and a FIL-DSSC with sputtered platinum layers on the electrodes, in which the durability tests were directly performed under UV-soaking. It is also the first comprehensive study on the detrimental effects of UV radiation on the performance of a DSSC. The cell efficiency of 7.54% is one of the best reported for any BIL-DSSC. The study on BIL-DSSCs can also throw more light on flexible DSSCs which often require a flexible non-transparent photoanode substrate, e.g., titanium metal, which cannot be front-illuminated.

## 2. Experimental

Lithium iodide (LiI), iodine ( $\text{I}_2$ ), poly(ethylene glycol) (PEG, M.W. = 20,000), and propyl-methyl-imidazolium iodide (PMII) were obtained from Merk. 4-tert-Butylpyridine (TBP) and tert-butyl alcohol were obtained from Acros. Acetonitrile, acetylacetone, ethanol, neutral cleaner, guanidine thiocyanate (GuSCN), 1-ethyl-3-methylimidazolium thiocyanate (EMISCN), titanium(IV) isopropoxide (TTIP), and isopropyl alcohol (IPA) were obtained from Aldrich.

Commercial titanium dioxide (ST-21,  $50 \text{ m}^2 \text{ g}^{-1}$ , 6.0 g, Ya Chung Industrial Co. Ltd., Taiwan) was added slowly into a solution of acetylacetone (500  $\mu\text{l}$ ) in DI-water (11.0 g), and the contents were thoroughly mixed and stirred for 3 days; 1.8 g of PEG was then added to the well-dispersed colloidal solution. The final mixture was stirred for an additional 2 days to obtain the desired  $\text{TiO}_2$  paste. A fluorine-doped  $\text{SnO}_2$  conducting glass (FTO,  $15 \Omega \text{ sq.}^{-1}$ , Solaronix S.A., Aubonne, Switzerland) was first cleaned with a neutral cleaner and then washed with DI-water, acetone, and IPA sequentially. The conducting surface of the FTO was treated with a solution of TTIP (0.028 g) in ethanol (10 ml) for obtaining a good mechanical contact between the conducting glass and the  $\text{TiO}_2$  film, as well as for isolating the conducting glass surface from the electrolyte. A 10- $\mu\text{m}$ -thick film of  $\text{TiO}_2$  was coated by doctor blade method onto the treated conducting glass, and a portion of  $0.4 \text{ cm} \times 0.4 \text{ cm}$  was selected as the active area by removing the side portions by scrapping. The  $\text{TiO}_2$  film was gradually heated to  $500^\circ\text{C}$  in an oxygen atmosphere, and subsequently sintered at that temperature for 30 min. After sintering at  $500^\circ\text{C}$  and cooling

to  $80^\circ\text{C}$ , the  $\text{TiO}_2$  electrode was immersed in a  $3 \times 10^{-4} \text{ M}$  solution of N719 (Solaronix S.A., Aubonne, Switzerland) in acetonitrile and tert-butyl alcohol (volume ratio of 1:1) at room temperature for 24 h. Transparent Pt-CEs were prepared by sputtering Pt on conducting glass (ITO,  $10 \Omega \text{ sq.}^{-1}$ , uni-onward, Taiwan) for 10, 20, 30, 55, 80, 130, and 180 s (under sputter current: 20 mA). The  $\text{TiO}_2$  electrode prepared as described was coupled with a platinum counter electrode (Pt-CE); these two electrodes were separated by a 25- $\mu\text{m}$ -thick Surlyn (SX1170-25, Solaronix S.A., Aubonne, Switzerland) and sealed by heating. A mixture of 0.1 M LiI, 0.6 M DMPII (Solaronix S.A., Aubonne, Switzerland), 0.05 M  $\text{I}_2$ , and 0.5 M TBP in 3-methoxypropionitrile (MPN, Fluka) was used as the electrolyte. The electrolyte was injected into the gap between the two electrodes by capillarity; the electrolyte-injecting hole was previously made in the counter electrode with a drilling machine, and the hole was sealed with hot-melt glue after the electrolyte injection.

The surface of the DSSC was illuminated by a class A quality solar simulator (PEC-L11, AM1.5G, Peccell Technologies, Inc.) and the incident light intensity ( $100 \text{ mW cm}^{-2}$ ) was calibrated with a standard Si cell (PECSI01, Peccell Technologies, Inc.). The photoelectrochemical characteristics of the DSSCs were recorded with a potentiostat/galvanostat (PGSTAT 30, Autolab, Eco-Chemie, the Netherlands). The film thickness was determined using a surface profilometer (Sloan Dektak 3030). UV-vis spectrophotometric data (V-570, Jasco, Japan) and cyclic voltammetry (CV) measurements were used to investigate, respectively, the transmittance properties and the catalytic abilities of the Pt-CEs. Electrochemical impedance spectra (EIS) were obtained by the above-mentioned potentiostat/galvanostat equipped with an FRA2 module, under a constant light illumination of  $100 \text{ mW cm}^{-2}$ . The frequency range explored was 10 mHz to 65 kHz. The applied bias voltage was set at the open-circuit voltage of the DSSC, between the ITO/Pt-CE counter electrode and the FTO/ $\text{TiO}_2$ /dye working electrode, starting from the short-circuit condition; the corresponding ac amplitude was 10 mV. The impedance spectra were analyzed using an equivalent circuit model [24,25]. For the durability test with UV rays soaking, the working electrodes were put in an airtight container with dryers and UV-light (Long wave UV-365 nm, 115 V–60 Hz, 0.16 A, Upland, CA, USA). For UV-absorption spectra, dyes were dissolved from their  $\text{TiO}_2$  films into aqueous 0.1 M NaOH solutions and the corresponding spectra were obtained using these solutions.

## 3. Results and discussion

Pt-counter electrodes were prepared by sputtering method, and the deposition times of platinum were varied from 10 to 180 s. As transparency of the counter electrode is very important for the passage of light through it to the dye molecules, transparency data of the platinum films collected at various sputtering periods are obtained in the wavelength range from 400 to 800 nm, which covers the essential part of light absorbed by dye molecules in a DSSC. Fig. 1 shows that the transmittance of a Pt-CE decreases with the increase in the sputtering time of platinum; in other words the transmittance decreases with the increase of thickness of platinum layer. Although high transparent Pt-CE is favorable for a BIL-DSSC, the catalytic ability of the platinum film is also to be taken into consideration from the efficiency viewpoint of the cell. To obtain the catalytic abilities of the platinum films deposited at different sputter periods, cyclic voltammograms (CVs) of the films were obtained. Fig. 2 shows overlaid CVs recorded for various deposition periods of platinum films; the absolute cathodic peak currents ( $I_{\text{pc}}$ ) represent the electrochemical activities of Pt-CEs [26]. The absolute  $I_{\text{pc}}$ 's in the CVs show increases with increasing deposition times of platinum until 30 s, and the peak heights remain almost the same with further deposition times. These results suggest that the catalytic ability of

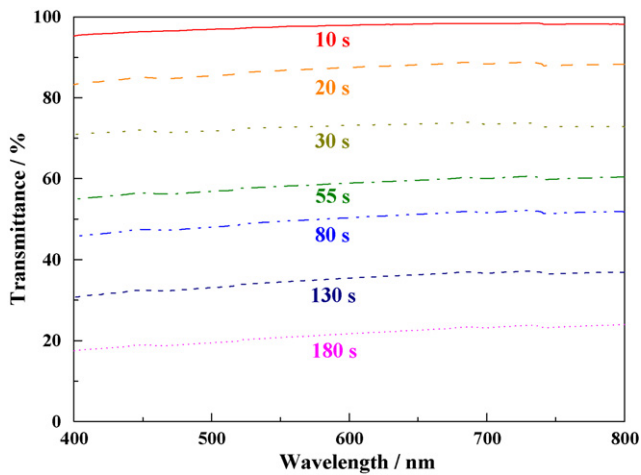


Fig. 1. Transmittance spectra obtained with platinum counter electrodes with different deposition times of platinum layers (baseline at the top of all with bare ITO electrode).

the platinum layer for  $I_3^-$  reduction increases with the increase of deposition time up to 30 s, and then remains the same with further deposition times. In addition, the CE with bare ITO presents  $J_{PC}$  value close to zero, revealing that a bare conducting glass (without a catalytic layer) has no catalytic ability for the reduction of  $I_3^-$ .

Fig. 3 shows photocurrent–voltage curves of DSSCs with different deposition times of platinum layers, measured at  $100 \text{ mW cm}^{-2}$  light intensity and illuminated from the counter electrode side (back illumination), except in one case where it is front illumination. The back illumination was intended to improve the durability of the cells under ultraviolet (UV) radiation, because it is this radiation which plays a role in the degradation of dye molecules in a conventional DSSC with front illumination, i.e., illumination from the  $\text{TiO}_2$  side, as mentioned already [6–19]. Table 1 gives the open-circuit voltage ( $V_{OC}$ ), short-circuit current density ( $J_{SC}$ ), fill factor (FF) and cell efficiency ( $\eta$ ) of DSSCs with platinum layers of different deposition periods and with back illumination. Obviously, the  $J_{SC}$  values increase steadily with increasing deposition time up to 30 s and then decrease with further deposition time. For the deposition times from 30 to 180 s, the steady decrease of  $J_{SC}$  may be attributed to the decrease in transmittance with increasing Pt thickness. On the other hand, the lesser values of  $J_{SC}$  for deposition times

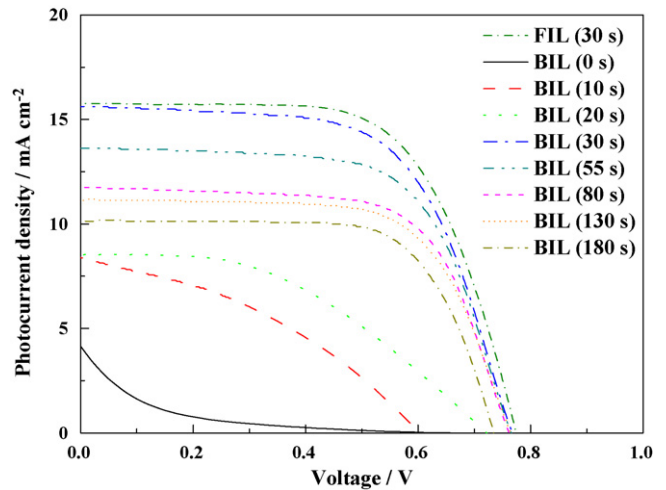


Fig. 3. Photocurrent–voltage curves of DSSCs with different deposition times of platinum layers, measured at  $100 \text{ mW cm}^{-2}$  light intensity and illuminated from the counter electrode side. One curve is also included for front illumination.

less than 30 s may be attributed to the insufficient catalytic ability of the platinum layers, notwithstanding their high transmittance. When the sputtering time is lesser than 30 s, the cell performance decreases dramatically. The best cell efficiency of 7.54% is achieved, when the sputtering time is set at 30 s.

EIS technique was also used to study the charge transfer resistances in the case of BIL-DSSCs, with platinum layers of different deposition times; these results are found to be in consistency with the results obtained from the photovoltaic characteristics. Fig. 4 shows the EIS data of the solar cells with various deposition times of their platinum layers. The equivalent circuit is illustrated in the inset of Fig. 4. In general, the impedance spectra of a DSSC show three semicircles in the frequency range of 10 mHz to 65 kHz. The ohmic serial resistance ( $R_s$ ) corresponds to the overall series resistance. The first, second and third semicircles correspond to the charge-transfer resistances at the counter electrode ( $R_{CT1}$ ), at the  $\text{TiO}_2/\text{dye}/\text{electrolyte}$  interface ( $R_{CT2}$ ) and to the resistance of Warburg diffusion process of  $I^-/I_3^-$  in the electrolyte ( $R_{diff}$ ), respectively. A very thin spacer was used in our device. Therefore, the  $R_{diff}$  is not obvious, and it is overlapped by  $R_{CT2}$ . The corresponding values of  $R_{CT1}$  and  $R_{CT2}$  are showed in Table 1. The  $R_{CT1}$  shows drastic decreases with increases in deposition time up to 30 s, indicating

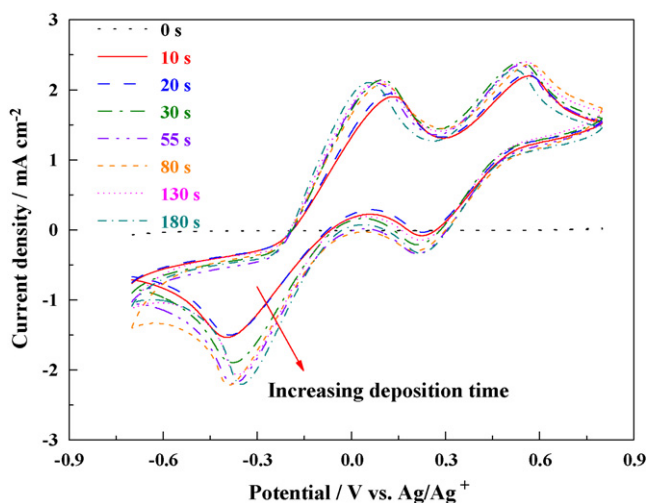


Fig. 2. Cyclic voltammograms obtained with platinum counter electrodes with different deposition times of platinum layers (bare ITO electrode shows zero current).

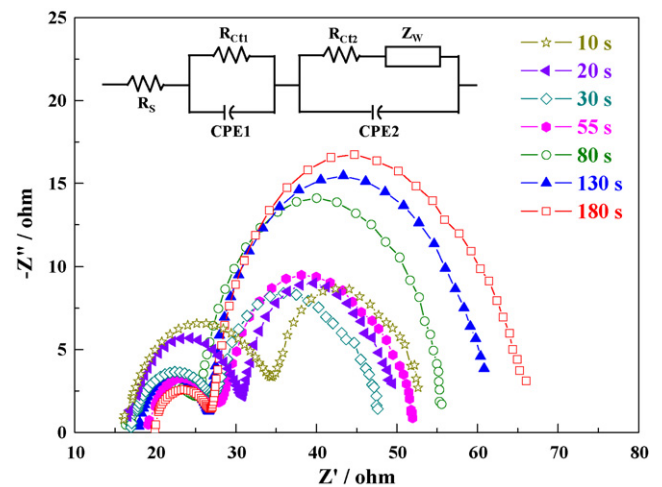


Fig. 4. Electrochemical impedance spectra of the DSSCs with different deposition times of platinum layers, measured at  $100 \text{ mW cm}^{-2}$  light intensity under open-circuit voltage. The frequency range was from 10 mHz to 65 kHz.

**Table 1**  
Photovoltaic characteristics and electrochemical impedance data (only  $R_{\text{Ct1}}$  and  $R_{\text{Ct2}}$ ) of the DSSCs with different deposition times of platinum layers on counter electrodes, measured at  $100 \text{ mW cm}^{-2}$  light intensity and illuminated from the counter electrode side.

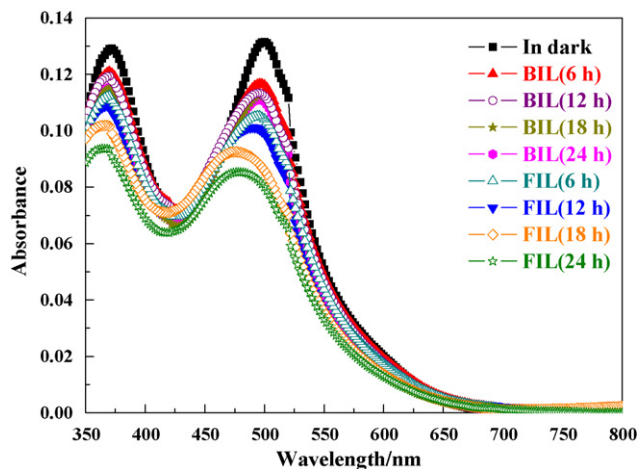
Deposition period (s)	$V_{\text{OC}}$ (V)	$J_{\text{SC}}$ ( $\text{mA cm}^{-2}$ )	$\eta$ (%)	FF	$R_{\text{Ct1}}$ (ohm)	$R_{\text{Ct2}}$ (ohm)
0	0.68	1.86	0.09	0.07	–	–
10	0.61	8.44	1.90	0.37	21.92	21.59
20	0.72	8.50	2.76	0.45	16.75	21.57
30	0.76	15.63	7.54	0.63	12.82	23.19
55	0.76	13.69	6.87	0.66	10.81	26.32
80	0.76	11.75	6.01	0.68	10.21	33.39
130	0.76	11.13	5.74	0.68	10.18	37.72
180	0.76	10.38	5.58	0.71	8.56	42.52

drastic enhancement in catalytic ability of the platinum layers; after 30 s and up to 180 s, the  $R_{\text{Ct1}}$  shows moderate decreases, which indicate that the catalytic ability of the platinum layers increases modestly. With regard to  $J_{\text{SC}}$  values, up to 30 s their increases are well in consistency with the corresponding decreases in  $R_{\text{Ct}}$  values. This means that the catalytic ability of the platinum layers deposited up to 30 s, or of the thinner layers plays a dominant role in deciding the  $J_{\text{SC}}$  and thereby the efficiency of the corresponding DSSCs. Even though there is decrease in  $R_{\text{Ct1}}$  values for deposition periods of over 30 s, the  $J_{\text{SC}}$  values do not show any increases and on the contrary they decrease considerably leading to the decrease of the efficiencies of the corresponding DSSCs; this phenomena can be explained considering that the moderate beneficial effect of increased catalytic ability of the platinum layers deposited at periods of more than 30 s is nullified by the detrimental effect of reduced transmittance due to the thick platinum layers formed at longer periods of over 30 s. Thus, the transmittance of the platinum layers deposited above 30 s, or of the thicker layers plays the dominating role in deciding the  $J_{\text{SC}}$  and thereby the efficiency of the corresponding DSSCs. It can also be seen in Fig. 4 and Table 1 that the longer the deposition time of a platinum layer, the larger the charge transfer resistance at the  $\text{TiO}_2/\text{dye}/\text{electrolyte}$  interface ( $R_{\text{Ct2}}$ ); this observation is in consistency with the corresponding decreased values of  $J_{\text{SC}}$  (Table 1). Increase in the thickness of Pt implies reduced transparency for the light from the platinum layer which means reduced dye excitation and fewer injected electrons to the conduction band of  $\text{TiO}_2$ ; this causes an increase in  $R_{\text{Ct2}}$  (note that the electrolyte is the same). Though the transmission of the Pt electrode with the Pt deposition time of 30 s is nearly twice that of the Pt electrode with deposition time of 130 s (Fig. 1), this did not reflect in the corresponding values of  $J_{\text{SC}}$ , i.e., the  $J_{\text{SC}}$  in the case of 30 s of deposition is not twice larger than that in the case of 130 s of deposition (Table 1). This can be explained based on the facts that the catalytic abilities are almost the same for these deposition times (see Fig. 2) and the charge transfer resistance  $R_{\text{Ct2}}$  for the deposition time of 30 s is not half of that for the deposition time of 130 s; in fact the charge transfer resistance at the counter electrode, i.e.,  $R_{\text{Ct1}}$  for 30 s is higher than that for 130 s (Table 1). In other words, the short-circuit photocurrent cannot be directly proportional to the transmittance of the platinum coated counter electrode, and catalytic ability and charge transfer resistances at the electrodes also influence it greatly.

For BIL-DSSCs, the sunlight penetrates through the Pt-CE and electrolyte before reaching the  $\text{TiO}_2$  layer; in this situation, the electrolyte can absorb UV rays and this can reduce the catalytic ability of  $\text{TiO}_2$  to degrade the dye. Reducing degradation of dye implies increasing the durability of the corresponding DSSC. We conducted durability tests with DSSCs illuminated both from the front side and back side, i.e., the cells underwent these tests were FIL-DSSCs and BIL-DSSCs. We expected performance decay for both types of cells, however, with a difference in degree of decay. In order to amplify the effect of performance decay in the case of DSSCs with BIL and FIL, we placed them directly under UV rays in an airtight container

instead of placing them under normal light. After this exposure, we used the working electrodes to study the dye desorption properties. Fig. 5 shows the absorption spectra of dyes, desorbed from the working electrodes with BIL and FIL after 6, 12, 18 and 24 h. The figure shows that the absorption spectra decrease with the increase in the UV-soaking time for front illumination; this decrease is far smaller for back illumination, as compared to that with front illumination. These results suggest that the dye degradation is much more less in the case of back-illuminated photoanodes, compared to that in the case of front-illuminated ones. This reduced dye degradation in the case of back illumination can lead to higher durability for BIL-DSSCs than that for FIL-DSSCs. The curve for 6 h of UV-soaking, when compared with that obtained for dark condition, indicates that even for 6 h of UV-soaking there is considerable degradation of dye on  $\text{TiO}_2$ .

After exposure of the electrodes to UV rays for 6, 12, 18, and 24 h, the photovoltaic parameters of the corresponding cells were measured for both back and front illuminations, at AM 1.5 solar light with an intensity of  $100 \text{ mW cm}^{-2}$ , and the data are shown in Table 2. It can be seen in Table 2 that the efficiencies of BIL-DSSCs were higher than those of corresponding FIL-DSSCs in all the cases of exposure to UV radiation. This can be explained as follows: in the case of a BIL-DSSC the photoanode was exposed to UV radiation through the electrolyte and thus the corresponding dye degradation was less, because the electrolyte absorbed UV radiation and virtually nullified its detrimental effect on the dyes. In the case of FIL-DSSC, the photoanode was directly exposed to UV radiation, leaving the dye molecules unprotected by the electrolyte. In other words the dyes used in the case of BIL-DSSCs were not or less degraded and the dyes used in the case of FIL-DSSCs were more degraded. This led to the better performance of the BIL-DSSCs over



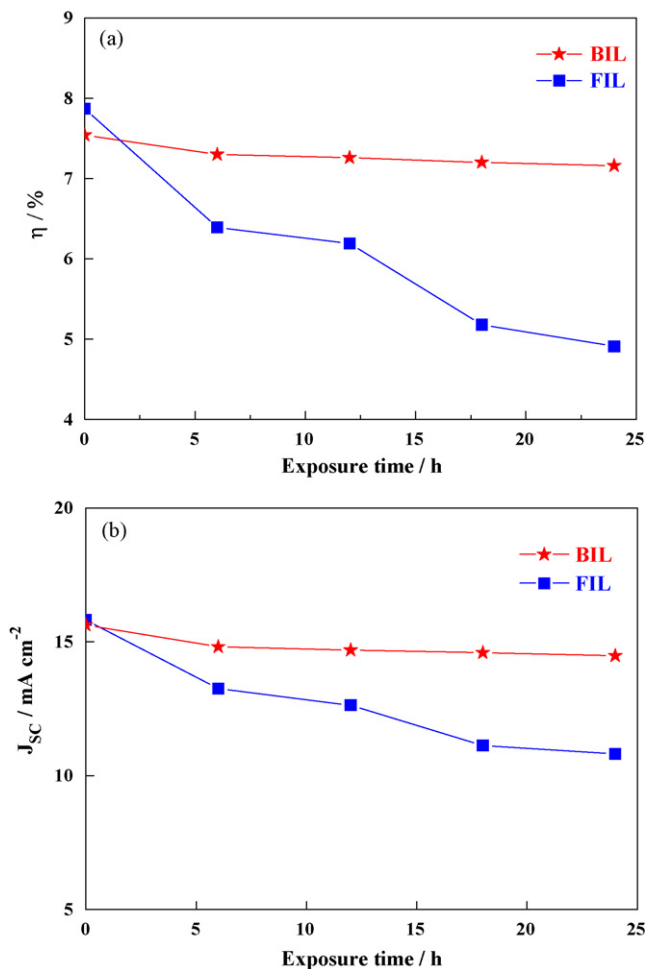
**Fig. 5.** Absorption spectra of dyes, desorbed from  $\text{TiO}_2$  electrodes of DSSCs soaked for 6, 12, 18 and 24 h under UV-light. The spectra were obtained for cells with BIL and FIL. The spectral data also includes a spectrum for electrode exposed to the dark.

**Table 2**

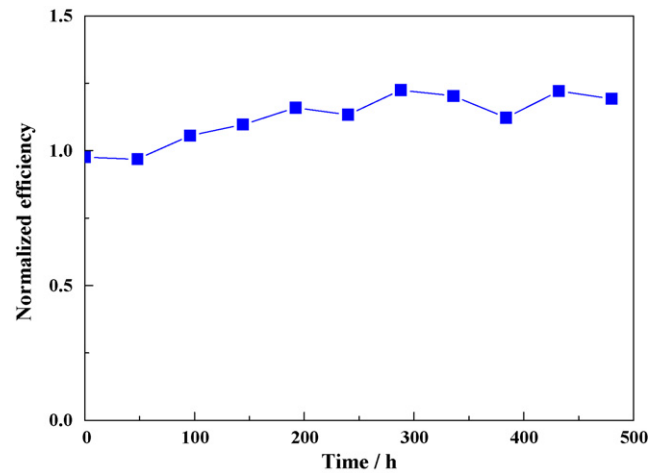
Photovoltaic parameters and  $R_{Cl2}$  values of the DSSCs soaked under UV-light for 6, 12, 18, and 24 h, measured at  $100 \text{ mW cm}^{-2}$  light intensity. The data were obtained for both front and back illuminations.

UV-soaking time	$V_{OC}$ (V)	$J_{SC}$ ( $\text{mA cm}^{-2}$ )	$\eta$ (%)	FF	$R_{Cl2}$ (ohm)
BIL (0 h)	0.76	15.63	7.54	0.63	29.98
BIL (6 h)	0.76	14.81	7.30	0.65	31.65
BIL (12 h)	0.75	14.69	7.26	0.66	32.08
BIL (18 h)	0.76	14.59	7.20	0.65	33.53
BIL (24 h)	0.76	14.48	7.16	0.65	33.6
FIL (0 h)	0.77	15.81	7.87	0.64	25.8
FIL (6 h)	0.74	13.25	6.39	0.66	36.11
FIL (12 h)	0.73	12.63	6.19	0.67	36.29
FIL (18 h)	0.72	11.13	5.18	0.64	38.47
FIL (24 h)	0.72	10.81	4.91	0.63	39.23

against the FIL-DSSCs in all the cases of exposure to UV radiation. The cell efficiency of FIL-DSSC with zero exposure period to UV radiation (7.87%) is just a little higher than that of BIL-DSSC with zero exposure period to UV radiation (7.54%). The nearly same efficiency for BIL-DSSC and FIL-DSSC without exposure to UV radiation implies that the UV radiation does not have effect on efficiency of a DSSC for an instant measurement of the cell efficiency, but causes a great detrimental effect, if the cells are exposed to it for longer periods of 6 h to 24 h. The lower  $\eta$  of the BIL-DSSC than that of the FIL-DSSC, both without exposure to UV-light, may be attributed to the slightly lower transmittance of the substrate for back illumina-



**Fig. 6.** At-rest stabilities of BIL-DSSC and FIL-DSSC against UV-exposure times of 6 h to 24 h: (a) with respect to efficiency ( $\eta$ ) and (b) with respect to short-circuit photocurrent ( $J_{SC}$ ).



**Fig. 7.** Long-term stability test (500 h) for a BIL-DSSC. The data was obtained once per 2 days, and the normalized data was divided by the average value of the first 6 days.

tion, due to its platinum layer, than that of the FIL substrate. Though the transmission of the Pt electrode with 30 s of Pt deposition (about 85%) is less than that of the bare substrate of photoanode (about 95%), the catalytic ability and conductivity of the counter electrodes of front-illuminated and back-illuminated DSSCs are the same for both the cells at the same Pt deposition time, i.e., 30 s. Thus the better transmission of bare substrate of photoanode is the meager advantage to the FIL-DSSC, and the consequent difference in the efficiencies of FIL-DSSC and BIL-DSSC is meager (the difference in the efficiencies of FIL-DSSC and BIL-DSSC at 0 h of UV-soaking is  $7.87 - 7.54 = 0.33\%$ , Table 2).

Fig. 6 shows at-rest stabilities of BIL-DSSC and FIL-DSSC against UV-exposure times of 6–24 h, both in terms of efficiency ( $\eta$ ) and short-circuit photocurrent ( $J_{SC}$ ). Although the cell efficiency of the DSSC with BIL has decreased by about 6%, the cell efficiency of the DSSC with FIL has decreased by about 38%, both after being exposed to UV rays for 24 h; the cell efficiencies of FIL-DSSC and BIL-DSSC are 7.16% and 4.91%, respectively, after 24 h of UV-soaking (Table 2). As compared with BIL-DSSCs, the FIL-DSSCs suffered from a far higher dye degradation under UV conditions for the time more than 24 h. This is because  $I^-/I_3^-$  couple in the electrolyte exhibited strong absorption of light of UV region for BIL-DSSCs, thereby protecting them from dye-degrading and favoring them for better cell efficiency and durability than those of FIL-DSSCs. Fig. 7 shows long-term stability of a BIL-DSSC for 500 h; the data was obtained once per 2 days, and the normalized data was divided by the average value of the first 6 days. The curve is nearly a flat straight line which means a good durability of the BIL-DSSC under continuous illumination of  $100 \text{ mW cm}^{-2}$  light intensity.

#### 4. Conclusions

From the photovoltaic parameters of back-illuminated DSSCs with sputter deposited platinum layers, it is established that the efficiency of the cells increase dramatically with increasing deposition times up to 30 s and decrease steadily with further deposition times up to 180 s. A cell efficiency of 7.54% was achieved with back illumination, when the platinum deposition time was 30 s, which was close to the value of 7.87% in the case of front illumination. The cell performance depends on the transmittance and catalytic property of the platinum layer in the case of a back-illuminated DSSC. It is established, with respect to platinum layers that catalytic ability is the cell efficiency-determining factor with sputter-deposition times of platinum up to 30 s, and transmittance is the efficiency-

determining factor with sputter-deposition times above 30 s up to 180 s. As compared with BIL-DSSCs, the FIL-DSSCs suffered from higher dye degradation under UV-soaking over a period of 24 h. The cell efficiency had decreased by about 6% and 38% for BIL-DSSC and FIL-DSSC, respectively, after they were exposed to UV rays for 24 h, suggesting that BIL-DSSCs have better durability against UV-soaking.

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