



Journal of Nanoscience and Nanotechnology Vol. 16, 7337–7344, 2016 www.aspbs.com/jnn

Photocurrent Enhancement by Employing 2,6-Bis[1-(2,4,6-trimethyl-phenylimino)ethyl]Pyridine as a Co-Sensitizer with Ruthenium in Dye Sensitized Solar Cell

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2,6-bis[1-(2,4,6-trimethyl-phenylimino)ethyl]pyridine (M3) is prepared and employed as a cosensitizer in dye-sensitized solar cells (DSSCs) based on nanostructured TiO_2 electrodes. The prepared co-sensitizer could alleviate the aggregation of ruthenium dye N719 on the nanostructured TiO_2 film, enhance the spectral responses of the co-sensitized TiO_2 film in region from 400 to 750 nm, suppress the electron recombination, prolong the electron lifetime and decrease the total resistance of DSSCs. The optimized cell device co-sensitized by M3/N719 dye gives a short circuit current density of 17.31 mA cm⁻², an open circuit voltage of 0.70 V and a fill factor of 0.61 corresponding to an overall conversion efficiency of 7.30% under standard global AM 1.5 solar irradiation, which is 34% higher than that of device solely sensitized by N719 (5.43%) under the same conditions. The improved overall conversion efficiency is ascribed to the enhancement of photocurrent.

Keywords: Dye Sensitized Solar Cells, Co-Sensitization, Co-Sensitizer, Photocurrent Enhancement.

1. INTRODUCTION

Dye-sensitized solar cells (DSSCs) have attracted much attention due to its low-cost and simple fabrication for conversion of the solar energy into electricity.¹⁻³ Polypyridyl ruthenium compounds have been widely used as the light harvesting units in DSSCs since O'Regan and Grätzel first reported them in 1991.^{4,5} Although the power conversion efficiency above 11% has been achieved by C101 and N719 sensitizers,^{6,7} it is still possible to further improve the efficiency of the cells based on ruthenium sensitizers. Compared with the challenge to design a single ruthenium dye that is able to fulfill all the requirements for obtaining an efficient device,^{8,9} co-sensitization is considered to be a more promising way to combine the spectral responses of co-sensitizers on the film for performance enhancement.¹⁰ For example, Han and Arakawa obtained a high efficiency of above 11.0% by co-sensitization of the black dye with organic compounds, respectively.^{11, 12}

DSSC efficiency of 7.5% has been achieved which exceed those recorded for individual dye devices.¹⁴ Yang reported a co-sensitized system using N719 dye with metal-free organic dye FL. The cell efficiency was optimized to be 5.10%, which was higher than that of the cell soaking only in N719 (4.89%).¹⁵ Ko published a co-sensitization study using Ru-complex JK-142 and organic JK-62 dye. The DSSC efficiency exhibited 10.2% surpassing that of cells using only JK-142 dye (7.28%) or JK-62 dye (5.36%).¹⁶ Sharma obtained a cell efficiency of 7.35% by co-sensitization of zinc-porphyrin and thiocyanate-free ruthenium(II) terpyridind dyes.¹⁷ Wu co-sensitized N719 with an organic dye resulting in a efficiency of 7.91%, 8.6% higher than that of N719 sensitized alone.¹⁸ Chang reported efficient panchromatic light harvesting by cosensitization of a porphyrin molecule and N719 in dye

Dehghani co-sensitized N719 dye with a porphyrin dye ZnTCPP, resulting in the efficiency of 6.35%, which

was higher than that of 4.75% based on N719 alone.13

Holliman co-senstized N719 dye with triarylamine dyes,

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Scheme 1. Molecular structures of M3 and N719.

sensitized solar cells, the co-sensitized devices shows a considerably enhanced power conversion efficiency of 8.89%, higher than individually sensitized by N719.¹⁹ Nath used phenylalkanoic acids as co-adsorbents along with a ruthenium sensitizer N719, the short circuit current density ($J_{\rm sc}$) and the open circuit voltage ($V_{\rm oc}$) of the cells were enhanced.²⁰

Usually, it is believed that the dye should capture as much incident light as possible, both in the absorption intensity and the absorption breadth, to enhance the performance of the cell. The co-sensitization methods mentioned above were mostly focused on selecting dyes absorbing at different wavelengths from that of ruthenium complexes for panchromatic harvesting. Besides the absorption breadth of dye sensitized film, its absorption intensity also plays an important role in the performance of the cell. However, the optical absorptivity of ruthenium dyesensitized films improved by co-sensitization has attracted little attention. In the previous report, the organic compounds, 2,6-bis[1-(phenylimino)ethyl]pyridines possessing alkyl substituents on the phenyl rings, were found to function as this kind of co-sensitizers, among which the compound possessing two dimethylphenyl groups was the most excellent one,²¹ and the number and position of methyl also has some effect on the performance of DSSCs.²² Therefore, in this context, we introduce three methyl groups to the phenyl rings of the 2,6-bis[1-(phenylimino)ethyl]pyridine, and the compound noted as M3 (Scheme 1) is employed as co-sensitizer in the well-known ruthenium dye N719 (Scheme 1) sensitized solar cell. The effects of this co-sensitizer on the photochemical performances of the cells have been investigated.



2. EXPERIMENTAL DETAILS

The FTO conducting glass (Fluorine-doped SnO₂, sheet resistance 15 Ω per square, transmission 90% in the visible range) was purchased from NSG, Japan, and cleaned by a standard procedure. N719 [Bis-tetrabutylammonium cis-bis(isothiocyanato) bis(2,2-bipyridyl-4,4-dicarbox-ylato)ruthenium(II)] was purchased from Solaronix Company, Switzerland. All of the other solvents and chemicals used in this work were of reagent grade without further purification. And all characterizations were carried out under ambient pressure and room temperature.

The 2,6-diacetylpridine was prepared according to a published procedure.²³ M3 was synthesized according to modified published procedures in a good yield by condensation of 2,6-diacetylpyridine with the corresponding aniline in refluxing absolute methanol in the presence of a catalytic amount of formic acid (Scheme 2).²⁴ The experimental details as well as the products characterization were reported by our group previously.^{25, 26}

Dye-sensitized solar cells were fabricated using the following procedure. The TiO₂ paste was cast onto the FTO substrate by the screen-printing method, followed by drying at 100 °C for 5 min and this process was repeated for six times, then followed by sinterings at 500 °C for 15 min in air to obtain a transparent TiO₂ photoelectrode with the thickness of *ca*. 10 μ m. The co-sensitized electrodes were prepared by immersing the obtained mesoporous TiO₂ photoelectrode into 0.3 mM M3 solution in absolute ethanol for 2 h and washed with ethanol and dried with blower, then further immersing the electrodes in 0.3 mM N719 solution in absolute ethanol for 12 h, and then washed with ethanol and dried with blower again. The single N719 sensitized electrodes were prepared by



Scheme 2. Synthesis process of 2,6-bis[1-(2,4,6-trimethyl-phenylimino)ethyl]pyridines.

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Figure 1. UV-visible absorption spectra of M3 and N719 in ethanol.

only immersing TiO₂ photoelectrode into 0.3 mM N719 solution in absolute ethanol for 14 h. The electrolyte used in this work was 0.5 M LiI+0.05 M I₂+0.1 M tert-butyl pyridine in a 1:1 (volume ratio) of acetonitrile-propylene carbonate. The platinum counter electrode was prepared by depositing H₂PtCl₆ paste onto the FTO glass substrates and then sintered at 450 °C for 30 min. The cells were assembled by sandwiching the electrolyte between the dye sensitized photoanode and the counter electrode and assembly was held together using mini-binder clips.

UV-visible absorption spectra in ethanol solution were recorded on SPECORD S600 UV-visible spectrophotometer (Jena, Germany), and absorption spectra of TiO₂ films were recorded on UV-2250 spectrophotometer (Shimadzu, Japan). Fluorescence properties of the synthesized dyes were obtained using an FLS920 spectrometer equipped with a peltier-cooled R928 photomultiplayer tube (Hamamatsu). A Xe900 450 W Xenon arc lamp was used as exciting light source. Time-dependent density functional theory (TD-DFT) calculations were conducted by using the B3LYP/6-31G basis set. The theoretical molecular orbital levels of HOMO and HUMO in ethanol were achieved with the B3LYP/6-31G basis set implemented in the Gaussian 03 package. The cyclic voltammetry (CV) were measured with a electrochemical workstation (CHI660d, Chenhua, Shanghai) using a three-elctrode cell with a Pt working electrode, a Pt wire auxiliary electrode, and a saturated calomel reference



Figure 2. UV-visible absorption spectra of different photoelectrodes.

electrode in saturated KCl solution. The supporting electrolyte was 0.1 M teterabutylammonium hexafluorophosphate (TBAPF₆, Fluka, electrochemical grade) in ethanol as the solvent. Photocurrent-photovoltage (I-V) curves were recorded by Keithley model 2400 digital source meter using a mask with an aperture area of 0.16 cm². The irradiance of AM1.5 global sunlight from a filtered 500 W xenon lamp light source was set at 100 mW cm⁻² and was calibrated by a standard silicon solar cell (NO. NIMMS1123, calibrated by National Institute of Metrology, P. R. China). Based on I-V curve, the fill factor (FF) is defined as: $FF = (J_{\text{max}} \times V_{\text{max}})/(J_{\text{sc}} \times V_{\text{oc}})$, where J_{max} and V_{max} are the photocurrent density and photovoltage for maximum power output; $J_{\rm sc}$ and $V_{\rm oc}$ are the shortcircuit photocurrent density and open-circuit photovoltage, respectively. The overall energy conversion efficiency η is defined as: $\eta = (FF \times J_{sc} \times V_{oc})/P_{in}$ where P_{in} is the power of the incident light. IPCE was measured on an EQE/IPCE spectral response system (Newport). The SPS instrument was assembled by Jilin University, in which monochromatic light was obtained by passing light from a 500 W xenon lamp through a double-prism monochromator (SBP300, China), and the signal were collected by a lock-in amplifier (SR830, Stanford). EIS were recorded by CHI660D Electrochemical Analyzer (Chenhua, China), and the measurements were taken over a frequency range of 0.1-100 kHz under standard global AM1.5 solar irradiation by applying a forward bias of -0.75 V. Open-circuit

Table I. Experimental data for spectral and electrochemical properties of co-sensitizers.

Dyes	$\lambda_{\mathrm{abs}}~(\mathrm{nm})^a$	$\varepsilon \; (\mathrm{M}^{-1}\mathrm{cm}^{-1})^a$	$\lambda_{\rm em}~({\rm nm})^{a,b}$	$E_{0-0} ({\rm eV})^c$	$E_{\rm HOMO}~({\rm eV})^d$	$E_{\rm LUMO}~({\rm eV})^d$	HOMO (eV) ^e	LUMO (eV)
M3	279	26435	438	3.00	-5.20	-2.20	-5.22	-2.52

Notes: ^{*a*} Absorption and emission spectra were recorded in ethanol solution $(3 \times 10^{-4} \text{ M})$ at room temperature. ^{*b*} Dyes were excited at their absorption maximum value. ^{*c*} Optical band gap calculated from intersection between the absorption and emission spectra. ^{*d*} The values of E_{HOMO} and E_{LUMO} were calculated with the following formula:

 $E_{\text{HOMO}} = -(E_{\text{onset}}^{\text{ox}} + 4.4) \text{ (eV)}; \quad E_{\text{LUMO}} = E_{\text{HOMO}} + E_{0.0}$

where $E_{0.0}$ is the absorption edge of co-sensitizers. ^{*e*}B3LYP/6-31G calculated values.



Figure 3. The emission spectra of M3 and N719 in ethanol solution.

voltage decay curves (OCVD) and dark current were also recorded by CHI660D Electrochemical Analyzer.

3. RESULTS AND DISCUSSION

The absorption spectrum of M3 in ethanol is shown in Figure 1 and its absorption data are listed in Table I. It can be seen that M3 displays a strong absorption peaks at *ca*. 279 nm with a weak shoulder absorption band at 335 nm. In comparison with that of N719 dye in ethanol solution (Fig. 1), M3 could only compensate for the absorption of N719 dye in the UV region in principle, but not for that in the visible region. However, the spectra response of the TiO₂ films co-sensitized by N719 and M3 was still explored. As shown in Figure 2, the two clear absorption bands of N719 in ethanol solution at 383 and 525 nm are broadened into both sides when it attached to TiO₂ film, indicating the formation of Herrings-bone aggregates by N719 on the TiO₂ film is co-sensitized with M3, the intensities



Figure 4. Energy levels of M3 and of the other materials used for DSSCs fabrication.



Figure 5. The HOMO and LUMO frontier molecular of M3 calculated with B3LYP/6-31G.

of the two absorption bands both increase a lot, and as shown in Figure 2, the two absorption bands at 554 and 367 nm attributed to N719 move to 547 and 375 nm, respectively, suggesting the aggregation degree of N719 on the TiO₂ film is decreased. The alleviation of aggregates adjusts the arrangement of N719 molecules toward a more uniform orientation. Apparently, the change of the absorption of N719 on the TiO₂ film after co-sensitization will contribute to the spectra response of the sensitized film as well as the power conversion efficiency of the DSSCs.

The emission spectra of M3 and N719 are illustrated in Figure 3. M3 exhibits strong luminescence in the region of wavelength 350–600 nm. It is worth to note that the emission spectra of M3 overlap with the spectrum of the excitation spectrum of N719 inordinately, which indicates that N719 could synchronously accept the energy input from the incident light and the emission of M3, which will further improve the spectra response of N719 in the region of wavelength 300–700 nm.

To estimate the energy level of M3, cyclic voltammetry (CV) experiments were carried out, and the data from CV experiments are summarized in Table I. Based on their first oxidation potentials, the HOMO value for M3 is -5.20 eV.^{27} As calculated from the edge of absorption spectra, the excitation transition energy ($E_{0.0}$) for M3 is 3.00 eV. Therefore, the LUMO levels of M3, calculated from $E_{\text{HOMO}} + E_{0.0}$, is -2.20 eV. For better electron injection, this LUMO level should lie above



Figure 6. SPS of co-sensitized photoelectrodes and N719 sensitized photoelectrode.



Figure 7. J-V curves for DSSCs based on different photoelectrode.

the conduction band (CB) of the TiO₂ semiconductor (-4.0 eV vs. vacuum) and for effective dye regeneration, the HOMO energy level should lie below the I^-/I_3^- redox electrolyte (-4.6 eV vs. vacuum) which is further improved negatively about 0.3 V by adding additives such as 4-tert-butyl pyridine (TBP) to the I^-/I_3^- redox electrolyte.²⁸ Hence, as shown in Figure 4, the energy levels of M3 are suitable for electron injection and dye regeneration thermodynamically.²⁹

In order to further understand the energy band structure in M3, ab initio calculations for the molecular orbitals based on the time-dependent density functional theory (TD-DFT) with B3LYP/6-31G basis set were performed. The geometric structures were fully optimized in conjunction with the solvent model. The electronic distributions of the frontier molecular orbitals of M3 in ethanol are shown in Figure 5. The highest occupied molecular orbital (HOMO) of M3 contributes to the mehyl-substituted phenyl rings (Donor) and the lowest unoccupied molecular orbital (LUMO) contributes to the pyridyl rings (Acceptor). The two imino functional groups with conjugated C=N bridge work as a π conjugated bridge, so M3 is donor- π -conjugated-acceptor (D- π -A) type metal free cosensitizers. The HOMO and LUMO energy levels of M3, estimated from DFT calculations are -5.22 and -2.52 eV, respectively. It is consistent with the CV results that the energy levels of M3 are suitable for electron injection and dye regeneration thermodynamically.

The surface photovoltage spectrum (SPS) method is commonly applied to TiO_2 for DSSCs, which is a well-established contactless technique for surface state distribution.^{30,31} The SPS of photoanodes sensitized with single N719 sensitizer and co-sensitized with N719 and

Table II. Performances of DSSCs based on different photoelectrodes.

Photoelectrode	$J_{\rm sc}~({\rm mA/cm^2})$	$V_{\rm oc}~({ m V})$	FF	η (%)
N719/TiO ₂	12.61	0.71	0.61	5.43
M3/N719/TiO ₂	17.31	0.70	0.61	7.30

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Figure 8. IPCE spectra of DSSCs based on different photoelectrodes.

M3 are shown in Figure 6. As show in Figure 6 cosensitization could enhance the photovoltage signals of the sensitized films between 300 and 750 nm, which indicates that the separate efficiency of electrons and holes correlate strongly with M3. Combined the results of UV-visible absorption spectra and SPS, it is easy to find that the spectra response of the N719 sensitized TiO₂ photoelectrodes is enhanced by co-sensitizing with M3.

To investigate the effect of M3 on the photovoltaic properties of DSSCs, M3/N719 co-sensitized DSSCs was fabricated followed a stepwise co-sensitization procedure by sequentially immersing the TiO₂ electrode (with thickness of *ca.* 10 um) in separate solution of M3 and N719. For comparison purpose, device sensitized by the individual dye of N719 was also fabricated under the same experimental conditions. This two type DSSCs were denoted as M3/N719/TiO₂ and N719/TiO₂, respectively. Figure 7 shows the photocurrent–voltage (J-V) curves of the devices sensitized by M3/N719 and N719 under illumination (AM 1.5 G, 100 mW cm⁻²) and the results are summarized in Table II. The device based on M3/N719 shows



Figure 9. Nyquist plots of different DSSCs measured under standard AM1.5 G solar irradiation.



Figure 10. Equivalent circuit used to represent interface in DSSCs consisting of FTO glass substrate/TiO₂/Dye/ I_3^-/I^- ||Pt/FTO glass substrate.

a short-circuit photocurrent density (J_{sc}) of 17.31 mA cm⁻² which is 37% higher than that of device sensitized by individual N719 (12.61 mA cm⁻²), and for other photo-voltaic parameters such as V_{oc} and *FF*, it is comparable for devices based on N719 ($V_{oc} = 0.71$ V, *FF* = 0.61). As a result, the device based on M3/N719 obtained a 34% higher overall conversion efficiency (η) than that of device individually sensitized by N719, which is 7.30% and 5.43%, respectively.

Obviously, the higher η value of co-sensitized solar cell compared with the individually N719 sensitized devices, is attributed to the enhanced photovoltaic parameters of J_{sc} . Since J_{sc} and IPCE are related by the equation:

$$J_{\rm sc} = \int e\phi_{\rm ph.AM1.5G}(\lambda) \, d\lambda$$

where *e* is the elementary charge and $\phi_{ph,AM1,5G}$ is the photon flux at AM 1.5 G,^{1,32} the enhanced J_{sc} value is ascribed to the enhanced IPCE response of the co-sensitized cell. Figure 8 collected the IPCE spectra of the two devices. It is found that co-sensitized with M3 could enhance the spectral response of N719 on TiO₂ film in the whole visible region and consequently enhance the photocurrent performance. This means the co-sensitization of N719 and M3 has a significant synergy effect on light harvesting, electron injection and electron collection on TiO₂. Based on the IPCE and the absorption spectra, it could be conclude that the cell's higher J_{sc} in the case of co-sensitization is ascribed to the decreased aggregation degree of N719 on the TiO₂ film and its enhanced spectra response.

EIS was employed to analyze the charge carrier dynamics in the interfacial regions of solid–liquid layers in DSSCs. The Nyquist plots of EIS for DSSCs sensitized only with N719 and co-sensitized with N719 and M3 measured under standard AM1.5 G solar irradiation are shown in Figure 9. Three semicircles in the Nyquist plots are observed. The small and large semicircles located in the high and middle frequency regions are assigned to the charge transfer at Pt/electrolyte and TiO₂/dye/electrolyte interface, respectively. Another small semicircle assigned to the Nernst diffusion in the electrolyte, which should have appeared at the low frequency region, is not clear due to overlap with the middle frequency large semicircle. Under light illumination, the radii of the large semicircle located in middle frequency regions in the Nyquist plot decreases after co-sensitized with M3, suggesting a decrease of the electron transfer impedance and an increase of charge transfer rate at this interface.

In order to further understand the complex charge transfer process in DSSCs, a physical model has been proposed,33 and the equivalent circuit represented in Figure 10, $R_s[C_1(R_1O)](R_2Q_2)$, is used to model this system, representing interfaces in composite solar cells. The symbols R and C describe a resistance and a capacitance, respectively, R_s is series resistance, R_1 and R_2 are the charge transfer resistance, O, which depends on the parameters $Y_{o,1}$ and B, accounts for a finite-length Warburg diffusion (Z_w) and Q is the symbol for constant phase element (CPE, its parameters are $Y_{o,2}$ and n). The parameters obtained by fitting the impedance spectra of co-sensitized solar cells measured under standard AM1.5 G solar irradiation using the equivalent circuit are listed in Table III. The series resistance R_s does not obviously change; the resistance R_1 which is estimated from the middle frequency range semicircle in Nyquist plots decreases with the introduction of M3, and the resistance R_2 which is estimated from the high frequency range semicircle of Nyquist plots also decreases with the introduction of M3, and the total resistance of co-sensitized DSSCs decreases compared with single N719 sensitized DSSCs. The total resistance decrease is beneficial for electron transfer and further improving the photocurrent of DSSCs. This suggests that the high performances in DSSCs sensitized with M3/N719 are also due to decrease of internal cell resistance and better charge transfer.

Suppressing the back electron transfer in DSSC is especially important to enhance the photocurrent. Recently, dark current measurement of DSSCs has been considered as a qualitative technique to describe the extent of the back electron transfer.^{34, 35} It could provide useful information regarding the back electron transfer process by making a comparison of dark current between the investigated cells. Therefore, dark current of cells based on N719 and M3/N719 were measured and are shown in Figure 11. By comparing the curves in Figure 11, it is found that the onset of the dark current for individual N719 sensitized

Table III. Parameters obtained by fitting the impedance spectra of solar cells measured under standard AM1.5 G solar irradiation using the equivalent circuit.

				0			Q_2	
DSSC samples	$R_{s}\left(\Omega ight)$	$C_1 (10^{-4}F)$	$R_1(\Omega)$	$Y_{O,1}$ (10 ⁻¹ S)	$B(S^{1/2})$	$R_2(\Omega)$	$Y_{O,2} (10^{-5} \mathrm{S}^{1/2})$	п
N719/TiO ₂	25.60	6.24	15.56	1.38	0.50	14.10	9.03	0.76
M3/N719/TiO ₂	26.38	7.37	11.11	1.14	0.47	11.70	7.40	0.75



Figure 11. Dark current of the DSSCs based on different photoelectrodes.

DSSC is at a bias about +0.40 V, and then the dark current increase remarkably with the increase of potential. In contrast, for the M3/N719 co-sensitized DSSCs, the onset potential shifted to about +0.50 V; furthermore, the dark current of the co-sensitized DSSCs increased much slower than that of N719 sensitized DSSC when potential was greater than +0.50 V. In other words, under the same potential bias, when the potential was \geq 0.40 V, the dark current for the co-sensitized DSSCs was noticeably smaller than that for the N719 sensitized DSSC. The increase of the onset potential and the reduction of the dark current demonstrated that M3 successfully suppress the electron back reaction with I₃⁻ in the electrolyte by forming a compact layer with N719. This is critical to reduce the current leakage in DSSC and enhance its photocurrent.

The OCVD technique has been employed as a powerful tool to study interfacial recombination processes in the TiO₂ DSSCs between injected electrons and the electrolyte. It can provide some quantitative information on the electron recombination velocity in DSSCs.^{36, 37} The OCVD decay curves of the DSSCs based on different photoelectrodes are shown in Figure 12(a). It was observed that the OCVD response of the DSSC with co-sensitized photoelectrode was much slower than that individually sensitized by N719, especially in the shorter time domain (within 12 s). Since the decay of the V_{oc} reflects the decrease in the electron concentration, which is mainly caused by the charge recombination,³⁸ the cell sensitized by M3/N719 has a lower electron recombination rate than that of the cell individually sensitized by N719.

Under the present dark and open-circuit state conditions, electron lifetime (τ_n) was used to quantify the extent of electron recombination with the redox electrolyte. τ_n was calculated with the OCVD results in Figure 12(a) according to the following equation:

$$\tau_n = -\frac{k_{\rm B}T}{e} \left(\frac{dV_{\rm oc}}{dt}\right)^{-1}$$

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Figure 12. (a) Open-circuit voltage decay curves of the DSSCs based on different photoelectrodes. (b) Comparison of electron lifetime as a function of open-circuit voltage of DSSCs based on different photoelectrodes.

where $k_{\rm B}$ is the Boltzmann constant, T is absolute temperature, e is the electronic charge, and dV_{oc}/dt is the derivative of the transient open-circuit voltage.³⁹ Figure 12(b) compares the results of the dependence of τ_n on the open-circuit voltage for DSSCs sensitized by N719 and M3/N719. It can be clearly seen that the electron lifetime of the co-sensitized cell was longer than that of the cell individually sensitized by N719 at any given $V_{\rm oc}$ value. The difference in OCVD was mainly due to the blocking effect of the compact layer made by M3 and N719. This suggests that the electrons injected from excited dye can survive longer and hence can facilitate electron transport without undergoing losses at the bare FTO surface. Therefore, employ M3 as a co-sensitizer is able to reduce the photoelectron recombination speed and prolong the lifetime of the photoelectrons, which are favorable for improving photocurrent.

4. CONCLUSION

In conclusion, We have developed and investigated 2,6bis[1-(2,4,6-trimethyl-phenylimino)ethyl]pyridine (M3) as co-sensitizers in ruthenium dye N719 based solar cell. The co-sensitization could enhance the spectral response of the N719 dye sensitized nanostructured TiO_2 film, suppress the electron recombination, prolong the electron lifetime and decrease the total resistance of DSSCs. These all help to improve the photocurrent of DSSCs. The device co-sensitized by M3/N719 yields the overall efficiency of 7.30%, which is 34% higher than that of the devices in this work were fabricated without scatterings layers, TiCl_4 treatment, or antireflecting coatings, but could improve the performance of the devices by only simple co-sensitization. This way of simple co-sensitization is a potential method that deserves to be further developed for high efficient DSSC fabrication.

Acknowledgments: This work was supported by National Natural Science Foundation of China (Grant 21171044, 21371040 and 21571042), the National key Basic Research Program of China (973 Program, No. 2013CB632900), the Fundamental Research Funds for the Central Universities (Grant No. HIT. IBRSEM. A. 201409), and Program for Innovation Research of Science in Harbin Institute of Technology (PIRS of HIT No. A201418, A201416 and B201414).

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Received: 11 March 2015. Accepted: 2 September 2015.