

Increasing Efficiency of Dye-sensitized Solar Cells through Co-sensitization of Organic Dyes LEG4 and DN-F10 as Light Absorber

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Abstract

Organic dyes LEG4/DN-F10 as efficient co-sensitized dye system were introduced in dye-sensitized solar cell. With attribution of broaden spectral absorption, the LEG4/DN-F10 co-sensitized dye system could improve the photovoltaic performance of devices in combination with Co(II/III) electrolyte. The photo-transition energy gap of LEG4/DN-F10 system is 1.81 eV. In the present work, power conversion efficiency (PCE) of 4.47% were achieved for device based on LEG4/DN-F10 with short circuit current density, J_{sc} of 6.87 mA/cm², V_{oc} of 0.76 V and FF of 56.78 while PCE of device with single dye are 3.41% for LEG4 dye and 3.76% for DN-F10 dye. The co-sensitization is a simple and effective strategy to improve the photovoltaic performance of the device. Further optimization steps are needed to enhance power conversion efficiency and it is under way.

Keywords: LEG4, DN-F10, DSSC, broaden absorption spectra and co-sensitization

1. Introduction

With break through results, dye-sensitized solar cells (DSSCs) based on dye sensitized TiO₂ electrode are extensively studied since three decades ago [1]. In consideration of low production cost compared to other inorganic photovoltaic devices and simple device layout, DSSC called Gratzel solar cells has been realized for manufacturing [2]. A DSSC is basically composed of a working electrode (WE), counter electrode (CE) and in between is electrolyte solution consisting of a redox couple. Dye molecules (photosensitizer) attached to TiO₂ working electrode absorb photons and injected excited electrons into titanium oxide and these electrons are collected at back contact of TiO₂ through the external load. The role of photosensitizer is, therefore, vital to decide quality of a device. Metal based dyes such as black dye and porphrin has been developed [3,4]. However synthetic organic dyes were more popular for device application in terms of higher extinction coefficient, cheap and colorful [2]. So far, the weakness of utilizing single dyes is their narrow spectral regions and could not absorb light over the whole visible region. Therefore, it is essential to develop strategy or new dyes since the task of photosensitizers is ensure photons to be absorbed sufficiently from solar spectrum for converting incoming photon into electrons. Few reports have suggested that using two or more dyes together is more efficient [5,7].

According to Minoru Hanaya group, 2015, it is evident that using two or more dyes together is efficient strategy to achieve broader absorption spectra from solar spectrum which enhance power conversion efficiency of devices [8]. The approach, mixing two or more dyes and used as photosensitizer is referred as co-sensitization strategy. Enhancing photocurrent density is the advantages of employing co-sensitizers in device application.

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In this frame work, DN-F10 dye was considered as broaden absorption spectra and LEG4 dye was selected as complementary system to harvest light from the whole visible spectra. By using Uv-vis spectroscopy, absorption properties of single dyes LEG4, DN-F10 and LEG4/DN-F10 were analyzed. Eventually correlating between absorption properties of dyes and an increased photocurrent density of device employed co-sensitized dye system were investigated in comparison with device based on single dyes LEG4 and DN-F10.

2. Experimental Section

Materials

Fluorine-doped tin oxide glasses from Nipon (Japan), Dyes and redox mediators from Dyenamo (Sweden), TiO₂ paste from Dyesol (Australia) were utilized in the present work. All other chemicals were purchased from Sigma Aldrich.

Preparation of Dye Solutions

In order to get the single dye solutions, 0.2mM of LEG4 dye and 0.025mM of DN-F10 dye were prepared in acetonitrile (ACN): tert-butanol (T-BuOH) (1:1 v/v) mixture. For co-sensitized dye system, the 0.2 mM of LEG4 dye solution and 0.025 mM DN-F10 dye solutions were mixed and utilized as prepared.

Solar cell Assembly

Before screen printing TiO₂ films, fluorine-doped tin oxide (FTO) glass substrates and counter electrodes (TEC8) were rinsed in an ultrasonic cleaner with detergent for 15 minutes. Then the substrates were washed and dried under airflow and followed Uv-ozone treatment for 15 minutes. Then transparent TiO₂ films with an area of 0.25 cm² were prepared by screen printing method from the colloidal TiO₂ paste (Dyesol DSL 30NRT). Then a scattering layer was added as the same procedure using opaque TiO₂ paste (Dyenamo DN-GPS-22OS). The film thickness was measured by surface profilometer. Then the electrodes were heated in an oven (Digital Muffle furnace DMF-05) until at 500 °C, following the temperature gradients (at 180°C (10min), 320°C (10min), 390°C (10min) and 500°C (15min)). After that, the electrodes were cooled down to 90 °C, the electrodes were immersed in respective dye baths containing 0.2 mM LEG4, 0.025 mM DN-F10, LEG4/DN-F10(0.2mM:0.025mM), in ACN: T-BuOH (1:1 v/v) and then left for 16 hours. The films were then rinsed in ethanol to remove excess dyes and dried under air. The platinized counter electrodes were prepared by depositing 10 µl per cm, 5mM H₂PtCl₆, chloroplatinic solution on 1 x 1 cm² area by the amount of ~10 µl followed by heating at 400 °C for 15 minutes. For investigation of absorption properties of dyes onto TiO₂ films, the transparent TiO₂ films with ~2.5 µm thickness were prepared. To assemble solar cell, 25 µm thermoplastic Surlyn frame was used to firm photoanode and counter electrode together with hot press sealing machine. Electrolyte was prepared using 0.3M Co(bpy)₃(PF₆)₂, 0.04M Co(bpy)₃(PF₆)₃, 0.25M LiTFSI, lithium perchlorate and 0.4 M 4-tert-butylpyridine, TBP in acetonitrile (All chemical were purchased from Sigma Aldrich). An electrolyte solution was injected through the predrilled hole in the counter electrode in the vacuum chamber and then the cell was sealed with thermoplastic Surlyn cover and a thin glass plate by using hot gun.

3. Characterization Method

UV-vis Spectroscopy

The absorption properties of dye solutions and sensitized TiO₂ films were investigated UV-visible spectrophotometer (Thermo, Genesys 10S). For the measurement of dye solutions, a normal quartz cuvette (1 cm path length) was utilized. For measurements of dye onto TiO₂ films, FTO substrates were used as reference.

Current-voltage (J-V) measurements

Current-voltage (J-V) characteristics were measured using a Newport solar simulator in combination with a computer controlled digital source meter under illumination of AM 1.5 G spectra. By using certified Si solar cell (Fraunhofer ISE), the light intensity was adjusted to 1000 W m⁻². A black mask with a window (0.5 × 0.5 cm²) was placed on top of the cell.

4. Results and Discussion

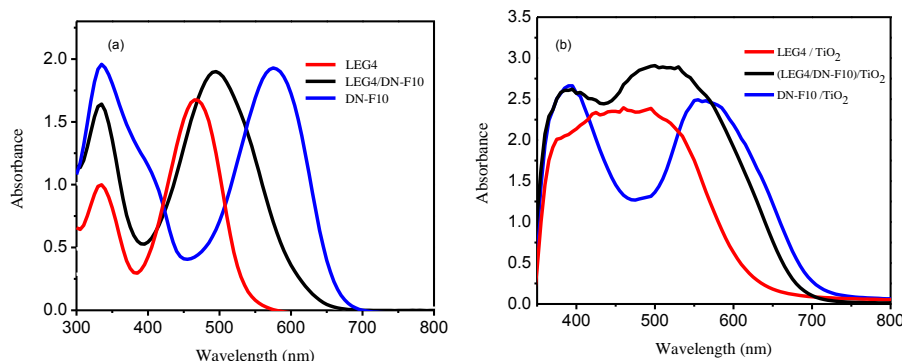


Figure 1.(a) UV-vis absorption spectra of DN-F10, LEG4 and (LEG4/DN-F10)dyes solutions.(b) UV-vis absorption spectra of DN-F10, LEG4 and (LEG4/DN-F10) dyes on TiO₂.

As the first step, the absorbance spectra of LEG4, DN-F10 dye and LEG4/DN-F10 co-sensitized system in solvent tert-ButOH:ACN(1:1) volume ratio were characterized by Uv-vis spectroscopy and shown in Figure 1 (a).The absorption maximum at wavelength 450 nm and 610 nm for LEG4 and DN-F10 were observed. The result pointed out that the broader absorption spectra were received upon mixing LEG4 and DN-F10 with absorbance maximum peak at wavelength 530nm. On the study of dye adsorbed onto TiO₂ films, it was found that utilizing LEG4 and DN-F10 with co-sensitization strategy was successful on filing the weak narrow spectral region (between 420 nm and 600nm) of DN-F10 dye by the LEG4 dye and significantly broader absorption spectra were yielded. The absorption spectra of dye sensitized TiO₂ films: LEG4 sensitized TiO₂ film, DN-F10 sensitized TiO₂ film and LEG4/DN-F10 sensitized TiO₂ film were exhibited in Figure 1 (b).

The photo transition energy (optical band gap) (E_{0-0}) of co-sensitized dye system, LEG4/DN-F10 were estimated by using following formula, $E = 1240 / \lambda_{\text{onset}}$ (eV) from observed the dyes adsorbed onto TiO_2 films. By taking the wavelength maximum from absorption spectra onset carefully and substituting λ_{onset} values in aforementioned formula, E_{0-0} values of dyes, LEG4, DN-F10 and LEG4/DN-F10 co-sensitized dye system, 1.93 eV, 1.75 eV and 1.81 eV could be provided as shown in Table 1.

Table 1. Photo-transition energies of single dyes and co-sensitized dye on TiO_2 films (thickness $\sim 2.5 \mu\text{m}$).

Dye	λ_{onset} (nm)	E_{0-0} (eV)
LEG4	643	1.93
LEG4/DN-F10	686	1.81
DN-F10	708	1.75

Photovoltaic performances of devices in this present work were recorded with a Newport solar simulator. The AM 1.5 light illumination were calibrated with Frenhofer silicon solar cell and the black mask with area 0.25 cm^2 were utilized. Current voltage curve of devices with co-sensitized dye system LEG/DN-F10 compared to devices with individual dyes LEG4 and DN-F10 employing cobalt (II/III) based electrolyte and pt deposited counter electrodes were exhibited in Figure 2. The results from Figure 2 revealed that devices employing LEG4/DN-F10 co-sensitized dye system could achieve significantly higher photocurrent density compared to devices utilizing single dyes LEG4 and DN-F10 while fill factor, FF values and open circuit potential, V_{oc} values were observed more or less similar.

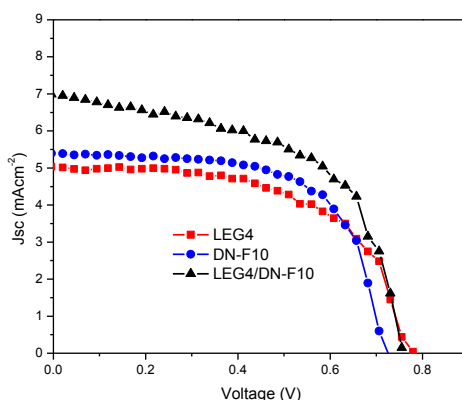


Figure 2. Current-voltage characteristics of devices employing individual dyes, LEG4, DN-F10 and co-sensitizer, LEG4/DN-F10 based on electrolyte, Co(II/III)electrolyte (0.3M Co(II) and 0.04M Co(III), 0.25M LiFSI and 0.4M 4-tert-butylpyridine in acetronitrile).

Sandwich cells area, 0.25cm^2 with meso TiO_2 + scattering layer ($3.5 + 3.5\mu\text{m}$) and pt counter electrode.

The power conversion efficiency (PCE) 4.47% were received for device with LEG/DN-F10 co-sensitized system with short circuit current density, $J_{sc} = 6.87 \text{ mA/cm}^2$, $V_{oc} = 0.76 \text{ V}$ and $FF = 56.78$. On the other hand, we received PCE =3.41% for device based on LEG4 dye with $V_{oc}=0.78 \text{ V}$, $J_{sc}= 4.97\text{mA/cm}^2$ and $FF= 57.93$ and PCE =3.76% for device based on DN-F10 dye with $V_{oc}= 0.72 \text{ V}$, $J_{sc}= 5.37\text{mA/cm}^2$ and $FF= 59.60$. The photovoltaic parameters of devices with co-sensitized system and device with individual dyes were described in Table 2.

Table 2. Photovoltaic performance of devices employing individual dyes, LEG4, DN-F10 and co-sensitizers LEG4/DN-F10 based on electrolyte, CO(II/III)electrolyte (0.3M CO(II) and 0.04M CO(III)), 0.25M LiIFSI and 0.4M 4-tert-butylpyridine in acetronitirle). Sandwich cells area, 0.25cm^2 with meso TiO_2 + scattering layer ($\sim 3.5 + \sim 3.5\mu\text{m}$) and pt counter electrode.

Cell	V_{oc}	J_{sc}	FF	PCE
LEG4	0.78	4.97	57.93	3.41
DN-F10	0.72	5.37	59.60	3.76
LEG4/DN-F10	0.76	6.87	56.78	4.47

Obviously, there were two reasons why higher PCE for devices employing LEG4/DN-F10 co-sensitized dye system were received. Achieving broader absorption spectra could provide an increase short circuit current density of devices utilizing LEG4 and DN-F10 dyes with co-sensitization strategy and it led to improve PCE of devices. Furthermore, by mixing LEG4 and DN-F10, the photo-transition were tunable properly and it might be supportive to get a change in energetics of dye in agreement with this study [9,10].

5. Conclusion and Outcome

In this research, a complementary absorption from two organic dyes, LEG4 and DN-F10 were exploited as efficient co-sensitizer in dye sensitized solar cells (DSSCs). So far, there has been no report using LEG4 and DN-F10 dyes with co-sensitization strategy in DSSCs. The power conversion efficiency (PCE) of DSSCs with co-sensitized dye system is as high as 4.47% with J_{sc} of 6.87 mA/cm^2 , V_{oc} of 0.76 V and FF of 56.78 which is higher than those with single dye, 3.41% for LEG4 and 3.76% for DN-F10 dye. Further optimization studies focusing on the varying the molar ratios of two constituent dyes should be carried out to enhance the device performance.

References

- [1] B. O'Regan and M. Grätzel. (1991). A low cost, highly efficient solar cell based on dye-sensitized colloidal TiO₂ film. *Nature*. (353).737–739.
- [2] A. Hagfeldt, G. Boschloo, L. Sun, L. Kloo and H. Pettersson. (2010). Dye-sensitized solar cells. *Chemical Reviews*. (110)6595-6663.
- [3] L. Wei, Y. Yang, R. Fan, P. Wang, L. Li, J. Yu, B. Yang and W. Cao. (2013) Enhanced the performance of dye-sensitized solar cells by co-sensitization of 2,6-bis (iminoalkyl) pyridine and N719. *RSC Advances* (3) 25908–25916.
- [4] G. D. Sharma, S.P. Singh, R. Kurchania and R. J. Ball. (2013) Cosensitization of dye sensitized solar cells with a thiocyanate free Ru dye and a metal free dye containing thienylfluorene conjugation. *RSC Advances* (3) 6036–6043.
- [5] M. Singh, R Kurchania, A Pockett, R J Ball, E N Koukaras, P J Cameron and G D Sharma. (2015) Characterization of metal-free D-(p-A)₂ organic dye and its application as cosensitizer along with N719 dye for efficient dye-sensitized solar cells. *India journal of Physics*.(89). 1041–1050.
- [6] S. Zhang, X. Yang, Y. Numata and L. Han. (2013) Highly efficient dye-sensitized solar cells: progress and future challenges. *Energy and Environmental Science*. (6,5)1443-1465.
- [7] S.H. Aung, Y. Hao, T.Z. Oo, and G. Boschloo. (2017). 2-(4-Butoxyphenyl)-N-hydroxyacetamide: An Efficient Pre-adsorber for Dye-Sensitized Solar Cells. *ACS Omega*.(2)1820-1825.
- [8] K. Kakiage, Y. Aoyama, T. Yano, K.J. Fujisawa and M. Hanaya. (2015). Highly-efficient dye-sensitized solar cells with collaborative sensitization by silyl-anchor and carboxy-anchor dyes *Chemistry Communication*. (10) 1039.
- [9] S. Mathew, A. Yella, P. Gao, R.H. Baker, B.F. E. Curchod, N. A. Astani, I. Tavernelli, U. Rothlisberger, S.K. Nazeeruddin and M. Grätzel. (2014). Dye-sensitized solar cells with 13% efficiency achieved through the molecular engineering of porphyrin sensitizers. *Nature Chemistry*. (6) 242-246.
- [10] M. Pazoki, P.W. Lohse, N. Taghavinia, A. Hagfeldt and G. Boschloo. (2014) The effect of dye coverage on the performance of dye-sensitized solar cells with a cobalt-based electrolyte. *Physical Chemistry, Chemical Physics*. (16). 503-8508.