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Short communication

A novel glowing electrolyte based on perylene accompany with spectrum compensation function for efficient dye sensitized solar cells

Sihang Bai [1], Liangliang Liang [1], Changlei Wang, Hadja Fatima Mehnane, Chenghao Bu, Sujian You, Zhenhua Yu, Nian Cheng, Hao Hu*, Wei Liu*, Shishang Guo*, Xingzhong Zhao*

School of Physics and Technology, Key Laboratory of Artificial Micro/Nano Structures of Ministry of Education, Wuhan University, Wuhan, 430072, China

HIGHLIGHTS

- Electrolytes containing perylene shows an increase in the conversion efficiency.
- The increase in the conversion efficiency is more than 11%.
- Device with perylene has excellent down-shifting ability.
- Perylene has unit approached quantum yield and photo-stability.
- Perylene has spectrum compensation function in DSSCs.

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ABSTRACT

Liquid electrolytes employing fluorescent perylene are prepared and applied in dye sensitized solar cells (DSSCs). Due to the excellent down-shifting property of perylene, photons with short wavelength (from about 350 to 440 nm) can be absorbed and then converted to ones with longer wavelength (from 450 nm to 550 nm) which can be more efficiently utilized by DSSCs. As a result, device with optimal concentration of 0.05 M perylene presents an efficient improvement in the short-circuit current density (J_{sc}), leading to an increase of 11.6% in the power conversion efficiency (PCE) compared with the reference DSSC based on control electrolyte.

1. Introduction

As one of the most promising candidates to replace conventional silicon solar cells, DSSCs have attracted a lot of attention, due to their novel concept, ease of fabrication, potential efficiency and low cost [1–3]. The adsorption of dye molecules on the TiO_2 nanoparticles is responsible for electron generation when exposed to sunlight. However, as the molar absorptivity of dyes and the incident photon to current conversion efficiency (IPCE) of DSSC significantly depend on the irradiation spectrum, photons with wavelength from 450 to 550 nm have been demonstrated to be more valuable to DSSCs than that located in the range from 350 nm to 450 nm [4,5]. Therefore, Enhancing the optical density in some certain regions such as from 400 to 500 nm is believed to be a feasible way to improve the performance of DSSCs.

To extend light harvesting and improve the PCE, efforts to improve the molar extinction coefficient of various dyes have been made [6,7]. Nevertheless, synthesis of a new dye or modification of an existing dye may come up with new problem, like the dyes of compatibility with the organic solvents or TiO_2 nanoparticles [6,8–10]. Thus, lots of research efforts focused mainly on modifying the spectral response of DSSCs' photoanode to match the solar spectrum, such as introducing rare-earth-doped oxides into the DSSC. The high-energy photons are absorbed by the rare-earth-doped oxides and the energy is transferred to the sensitizers by spectrum conversion. Wu et al. tried to make use of UV light by mixing a rare-earth-doped oxide (Eu^{3+}-doped Y_2O_3) colloid into

* Corresponding authors.
E-mail addresses: haohu@whu.edu.cn (H. Hu), wliu@whu.edu.cn (W. Liu), gssyhx@whu.edu.cn (S. Guo), xzzhao@whu.edu.cn (X. Zhao).
[1] These authors contributed equally to this work.

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the TiO_2 nanocrystalline film [11]. Gd_2O_3: Eu^{3+} as a luminescence medium and p-type dopant was introduced into the DSSC by Xiao et al. [12] Shen et al. deposited $NaGdF_4$:Eu nanocrystals on the front glass surface of as-prepared DSSC solar cell [13]. When these rare-earth nanoparticles are introduced into DSSCs, the high energy photons in the UV region are absorbed and converted to longer wavelength photons which can be used by the common sensitizer. By this down-converted (DC) method, the usually low utilizing UV photos can be converted to blue or green ones and they effectively used by DSSCs. Unfortunately, due to the lower absorption cross-section of rare-earth ions, inadequate quantum yield, and limited doping concentration (usually lower than 5%) in the TiO_2 film, only a small portion of the photons in the UV region can be used. Thus, other types of DC materials should be explored to satisfy the requirements of high absorption coefficient, suitable absorption region, and high quantum yield. Perylene, a fluorescent molecule, owing to its high absorption coefficient, unit approached quantum yield, tuneable absorption range, and photo-stability, shows promising potential for photovoltaic application [14].

Herein, for the first time, we report the application of fluorescent perylene as an additive in the electrolyte to enhance the performance of DSSCs. The DC function of perylene can effectively convert photons from 350 nm to 440 nm to ones between 450 nm and 550 nm. In this way, photons in the prior region can be made the utmost to contribute the electron generation. By employing the electrolyte with proper amount of perylene, DSSC devices show higher J_{sc}. Besides that, the fill factor (*FF*) and the open-circuit voltage (V_{oc}) were simultaneously improved. The addition of perylene in electrolytes gives excellent performances in DSSCs.

2. Experimental section

2.1. Preparation of electrolytes

Electrolytes were prepared by dissolving LiI (0.05 M) and I_2 (0.03 M) in the mixture of acetonitrile (ACN) and propylene carbonate (PC) (vol: vol = 1: 1) with different concentrations of perylene (0.02 M, 0.05 M, 0.10 M, and 0.15 M), besides 0.1 M 1-propy-3-methylimidazolium iodide (PMII), 0.1 M guanidinium thiocyanate (GuSCN), and 0.5 M 4-tert-butylpridine (TBP) were used as additives. The same electrolytes were also used for the tests in dummy cells.

2.2. Fabrication of DSSCs

The FTO glass was pretreated with $TiCl_4$ solution in a traditional way [17]. Photo-electrodes were prepared on the glass by doctor-blade method and sintered at 500 °C for 30 min according to our previous work [15]. Then a scattering layer was added on the prepared photoanode films using doctor-blade method, followed by annealing at 500 °C for 30 min [16]. For dye adsorption, the TiO_2 photoanodes were immersed in a 0.5 mM N719 ethanol solution, heated at 60 °C for 12 h, rinsed with ethanol and then dried. The DSSC devices were fabricated by assembling the dye-loaded mesoporous TiO_2 films with platinum-sputtered FTO counter electrodes. Dummy solar cells were assembled in the same method with the common DSSCs, by replacing the photoanodes with another platinum electrodes and with hot-melt Surlyn film (25 μm thickness, Geao Tech) as spacer. The electrolytes above were injected into the cells. Fig. 1 shows the schematic design of DSSC device based on electrolytes containing fluorescent perylene.

2.3. Characterization of DSSCs

Photovoltaic measurements were performed by applying external potential to devices under AM 1.5 simulated illumination (Newport, 91192) with a power density of 100 mW cm^{-2}. The irradiated area of each cell was kept at 0.25 cm^2 by using a light-tight metal mask. EIS measurements of dummy cells were obtained in the frequency range from 100 KHz to 0.01 Hz at 0 V bias. The power of the simulated light was calibrated to be 100 mW cm^{-2} using a standard silicon cell (Newport Corporation, Irvine, CA). IPCE measurements on DSSCs were performed from 300 to 800 nm in wavelength with a 300 W xenon lamp (Newport, 66984). Their optical properties were determined using UV–vis spectrophotometry (Shimadzu, Japan). Diffuse reflectance and transmittance spectra were measured on Carry 5000. The reflectance spectra appeared to abide by the Mie scattering theory, which stated that pores with a comparable size to the light wavelength can act as effective light scattering centers [18], then was calculated a numerical solution of the radiative transfer equation [19]. Excitation and emission spectra were recorded by a spectrometer (Spectrapro 2500i, Acton) with a liquid nitrogen-cooled CCD (SPEC-10, Princeton).

3. Results and discussion

Fig. 2a shows the room-temperature photoluminescence (PL) excitation and emission spectra of electrolyte with 0.05 M perylene. It is obvious that photons in the range from 350 nm to 440 nm can be absorbed and effectively converted to ones with wavelength between 450 nm and 550 nm although with some overlap around

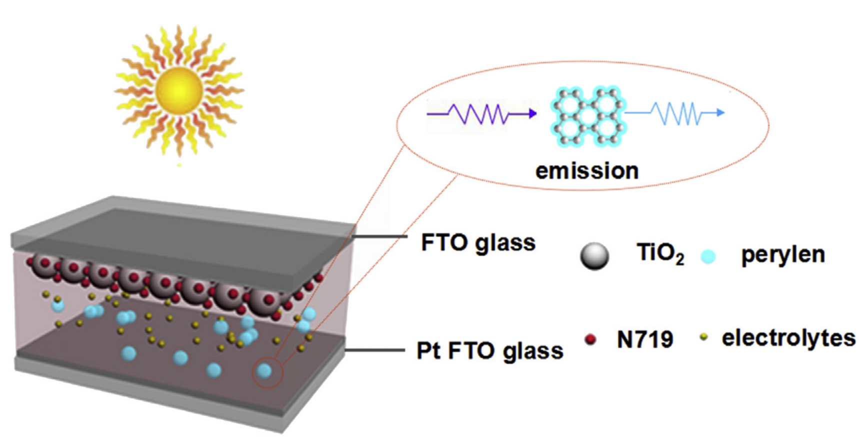

Fig. 1. Structure of DSSCs based on electrolytes containing fluorescent perylene.