Inverted Organic Photovoltaic With Dye

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Abstract: Bulk heterojunction organic solar cells based on ZnO nanorod coated with Eosin-Y has been reported to be as one of the challenging study in order to increase the cell performance. The low band-gap polymer PCPDTBT as electron donor material and PCBM as electron acceptor material introduced to the device structure in order to enhance the rate of charge transfer in the active layer. This low band-gap polymer helps to harvest more sunlight in a wider range of the solar spectrum leading to the improvement in photovoltaic efficiency.

Key-Words: bulk-hetrojunction polymer solar cell, ZnO nanorod, Eosin-Y, PCPDTBT, PCBM.

1 Introduction

Organic solar cell have known as a promising device due to the great potential and its flexibility at relatively low costs and easy-preparation [25,26].Nano-based bulk-heterojunction polymer solar cell has received so much attention because it can provide a large surface area per unit volume for efficient light absorption.Previous studies have shown by applying nanostructures in the device structure, it can improve electronmobility as well as device efficiency due to wide absorption of light and unwanted hole leakage into cathode. Wide band gap (3.37 eV), large exciton binding energy (60 meV) [9] and high electron mobility (115-155 cm² V⁻¹ S⁻¹) of ZnO has improved the electron transportation in inverted type hybrid organic solar cell [18-20].Takanezawa et al. [1] have shown that ZnO nanorods lead to the improvement of electrontransport in bulk-heterojunction solar cells. However, poor power conversion efficiency ranging from 0.04% to 0.53% [21-23] of inverted type hybrid organic solar cells on ZnO nanorods/poly(3-hexylthiophene-2,5-diyl) (P3HT) bulk heterojunction, leads to the urgent work on surface modification of the device.

In polymer solar cell, the active layer of bulk-heterojunction solar cell consists of different conjugated polymer, which acts as an electron donor and blends with an electron acceptor based on fullerene derivatives such as PCBM, PC₇₀BM and PC₇₁BM. By tuning the morphology of this layer, the potential of device efficiency can be obtained. In addition, the type of material used as an active layer should be closely matched to the maximum peak of the solar spectrum which is ~ 670 nm in order to get high power conversion efficiency (PCE) [2]. The first low bandgap polymer was used in polymer solar cell was PCPDTBT [3], [4]. PCPDTBT is a subclass of π-conjugated polymers which has an alternating carbon single and double bonds has gained much attention for photovoltaic applications since the discovery of their conductive properties by Shirakawa, Mac Diarmid and Heeger [5]. PCPDTBT become a great choice recently due to its low bandgap ~1.5 eV as an organic material. This compound can extend its spectral absorption into the infrared region, which can increase the overall photovoltaic performance of solar cells. The active layer composed of PCPDTBT and PCBM has shown to give rise to power conversion efficiency of 3.2% [6].
Many works are being done to develop metal-free organic dyes as an alternative to the Ru complexes. The reasons are because, the molecular structures of organic dyes are in diverse form and can be easily designed and synthesized. The interesting property of organic dye in term of higher molar extinction coefficient compared to Ru complexes, making them attractive for thin film and solid-state dye-sensitized solar cells (ss-DSCs) applications. The advantage of higher extinction coefficient is the organic dye do not need thick mesoporous films as Ru for complete light harvesting [7]. Besides that, this type of metal free organic dyes produces less environmental effects and cost saving [8].

One way to improve the efficiency of the dye based solar cell is to reduce the energy gap of the dyes so that it can absorb the spectral range of 650-940 nm. But to find the dye which can absorb in the range of 350-940 nm is not that straightforward [9]. Eosin-Y is an organic dye that could match this wavelength because in an aqueous solution, the molecules of Eosin-Y exists in a monomer form with peak absorption at 515 nm. In contrast with other dye, Eosin-Y gives the good solubility in water and lots cheaper than ruthenium bipyridyl complex dyes [10]. Eosin-Y also can be easily absorbed into the ZnO surface to form a unique pore structure such as a wall or a sponge depending on the Zn in the electrolyte.

2 Working Principal of the Device

Herein, the device structure and operating mechanism of solid state dye solar cell will be discussed further. The basic processes of this kind of solar cells need at least four key components, which are light absorption (dye), exciton diffusion, exciton dissociation and electron transport to anode and cathode. In an organic solar cell van der Walls forces attach the molecules. When the cell absorbs light, photons are generated and form excitons. Due to electrostatic interactions of excitons, they will not easily dissociate to electron-hole pair unless the excitons gain sufficient energy to dissociate them. After the dissociation process, the electron is transferred to the lowest unoccupied molecular orbital (LUMO), leaving behind a hole. Within that time, the electric field causes the electron to move to the electrode. The final electric current yield from solar cell depends on the total number of the collected charges in the electrode. This number corresponds to the fraction of photons absorbed, the fraction of electron-hole pairs that are dissociated and the total charges that reach the anode and cathode respectively. The charge carriers need a net driving force in order to reach the electrodes. This force produces by the gradient in the electrochemical potentials of electrons and holes [11].

The concept of bulk-heterojunction solar cells are introduced to improve the performance of bilayer organic solar cells that can collect only a small amount of excitons at the interface layer [12]. In bulk-heterojunction solar cell, the electron donor and electron acceptor are blended together to form an active layer. The selection of suitable materials to be the donor and acceptor is important because it has a great impact for the charge mobility. In this study, electrons are transported to the electron acceptor material (PCBM) and the holes are transported to the electron donor material, which is PCPDTBT. Eosin-Y help to cover the defect in ZnO nanorods by injecting more electrons to the ZnO nanorods and prevent charge recombination. Then, electrons and holes are move to the anode (Ag) and cathode (FTO) and finally generate electricity.
2.1 Charges Transfer at Donor-Acceptor Interface

The conversion of photon to electron to generate current, undergo the first step that is the absorption of light by the electron donor material to generate exciton. The binding energy of exciton called Frenkel exciton is very strong due to the Coulomb interaction. This very strong interaction should be split in order to generate photocurrent. The solutions to surmount this binding energy are by high thermal energy kBT, high intrinsic electric field and dissociation at the metal contacts. However, the above solutions yield poor efficiency as the temperature is not high enough to split them in ambient condition and normally thickness of the sample is too thick than exciton diffusion length. In bulk-heterojunction solar cells, there are so called donor-acceptor interface. After light absorption, Frenkel exciton diffuses from donor to the acceptor material at this interface to dissociate them into an electron-hole pair. The charge transfer process is depicted in figure 3 whereas the band energy diagram of the device is shown in figure 4. (1) HOMO\(_D\) and LUMO\(_D\) of donor molecule. (2) excited donor molecule gain ionization potential energy, IP\(_D\) and ready to be transferred to LUMO\(_A\) (3) electron is transferred in a picosecond timescale by gaining an electron affinity, EA\(_A\) (4) additional binding energy, EB between the electron on the acceptor and the hole on the ionized donor need to be surmounted to hinder recombination.

Fig. 4: The corresponding energy diagram of the cell

2.2 Strategies to Improve Organic Solar Cell Performance

The working principle of the device has been discussed and they include light absorption, exciton dissociation, charge transport, and charge collection. In order to maximize the performance of an OPV cell, the nanostructured OPV cell was designed to reduce the charge recombination and maintain exciton dissociation[14][15]. This alternative approach needs the design principles of nanostructured OPV cells, which is important for excellent performance of the device. A 10 nm to 40 nm period pattern expected to dissociate excitons efficiently since they travel 5 nm to 20 nm. Other than that, the height has to be tuned to absorb sufficient photons without losing charges by recombination. For instance, 200 nm thick P3HT absorbs over 90 % of incident light at the maximum absorption peak wavelength. Therefore, it means that, the pattern height should be more or around 200 nm thick. If it is thicker than 200 nm, the film absorbs almost 100 % of incident photons, but some of the photons may recombine due to longer distance travel. Higher series resistance and lower shunt resistance occur in thicker film. On the contrary, thinner film < 200 nm, the film absorbs less than 90 % of photon charges. In this case, lower resistance and higher shunt resistance are beneficial [12] ZnO is one of the first semiconductors used in DSSC. Similar to TiO\(_2\) (anatase), ZnO has the same bandgap and conduction band edge, but has higher electron mobility than TiO\(_2\). In recent years, ZnO the use of ZnO in DSCs has increased dramatically in term of number of publications to beat TiO\(_2\). One of the reason is mainly because easy synthesizing
crystalline ZnO in wurzite structure. Much research had been conducted by using different morphology of ZnO such as nanoparticles, nanowires, nanorods, nanotubes, nanoflowers, nanosheets and branched nanostructures via a wide range of techniques [8].

3 Future Suggestion

Since photovoltaic technology has become an alternative to non-renewable energy source, a number of organics photovoltaic materials have been designed, synthesized and applied in many solar cell applications. Tailoring the active layer materials by considering the band gap, mobility, solubility, morphology, molecular energy level, photon absorption and so on are the keys to boost the efficiency. Future study and development to optimize and balance all of these parameters is required for higher solar cell performance. In principle, organic based solar cell not only can improve power-conversion efficiency, but also can produce an affordable cost per generated power for commercialization. The common reason of low efficiency of OPV device is due to the mismatch between absorption spectra of conjugated polymers and the solar irradiance spectrum. The low bandgap polymer is an approach to enhance light harvesting, however, to choose a polymer which can have broad overlap with the solar emission spectrum is not an easy task. PCPDTBT: PCBM blend extends its spectral sensitivity to 900 nm (infrared region) [16]. Additionally, one of the promising strategies to realize absorption enhancement was based on dye sensitized. Organic dyes as Eosin-Y is considered as a cheaper sensitizer than the commonly used ruthenium bipyridyl complexes. However, serious precaution has to be taken since the direct release of waste water containing Eosin-Y will cause an environmental problem due to its toxicity [17]. By creating ordered nanostructures, faster electron transport can improve current density as well as other parameters.

4 Conclusion

To conclude, this article proposed a type of device structure and materials for efficient photons absorption and charge collection in solar cells. The device performance can be further enhanced after considering a match energy level of each material. Extensive efforts and studies are carrying out by researchers in order to create promising low bandgap polymers, dyes and semiconducting materials in order to increase the power conversion efficiency. This step is very important and can be considered as a stepping-stone for large-scale productions.

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References:


