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Review

Polymer solar cells: Recent development and possible routes for improvement in the performance

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ABSTRACT

The development of polymer solar cells is rapidly accelerating as the need of new clean energy sources. Polymer solar cells are attractive because they can be manufactured on plastic substrates by a variety of printing techniques. In this article, we provided an overview on basic operational principles and recent development of polymer solar cells. The possible routes for improvement in power conversion efficiency, stability, and the effects toward manufacturing of polymer solar cells were summarized and highlighted.

Contents

1. Introduction

Polymer solar cells have certain attractive features [1]. Because the active materials used for fabrication devices are soluble in most of common organic solvents, polymer solar cells have potentials to be flexible and to be manufactured in a continuous printing process like printing newspapers. Various printing and coating technologies have been proven their compatibility with semiconducting polymer processing [2]. Fig. 1 illustrated that polymer solar cells can be manufactured using standard printing processes [3].

Power conversion efficiency (PCE) beyond 6% [4,5] was reported recently, but this value is far away for daily applications. Deep investigation of operating mechanism and creative synthesis

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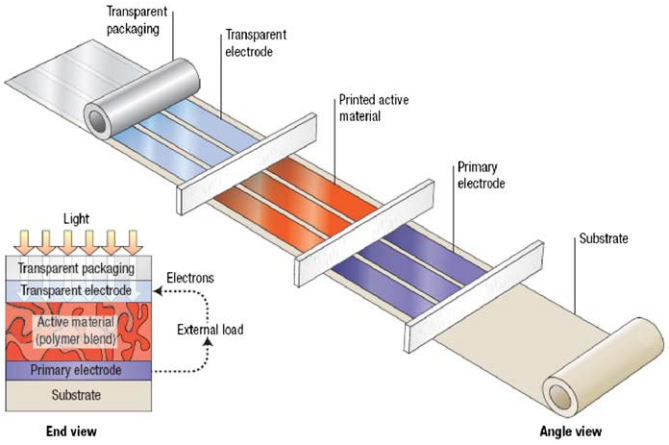

Fig. 1. Schemtic illustration of polymer solar cells can be manufactured by standard printing rocesses [3].

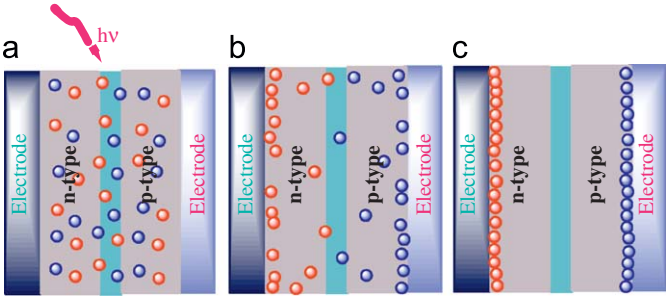

Fig. 2. Schematic illustration of operational mechanisms in polymer solar cells. (a) Absorption of light, (b) charge separation and (c) charge collection.

of novel materials for approaching high performance polymer solar cells are summarized in the literature [6]. Improving PCE is the first aim of the current investigation. At the same time, some visionary scientists have already paid their attention to the lifetime of these flexible solar cells [7]. So far the best lifetime reported by Konarka Technology was more than one year [8].

This article overviewed recent development of polymer solar cells and discussed the possible routes for improvement in the performance of polymer solar cells. We started with an introduction of basic operational principles and polymer solar cells materials. We highlighted current most prominent materials system, a mixture of poly(3-hexylthiophene) (P3HT):1-(3-methoxyxarbonyl) propyl-1-phenyl [6,6] C_{61} ($PC_{60}BM$). The recent development in polymer solar cells is summarized in Section 3. In Section 4, we discussed the possible routes for improvement in the performance of polymer solar cells, i.e. improving absorption, enlarging open circuit voltage, towards a controllable morphology, using new device structures. We also discussed the stability of polymer solar cells, ITO-free solar cells and the effects toward to manufacturing polymer solar cells. We finished this article with conclusion and outlook.

2. Operational principles

The process of conversion of light into electricity by polymer solar cells can be illustrated in Fig. 2. There are three operational mechanisms determined that polymer solar cells have capability to generate electricity: absorption of a photon either by electron donor and/or electron acceptor, leading to the formation of an excited state, that is, the bound electron–hole pairs creation; exciton diffusion at the interface between the electron donor and

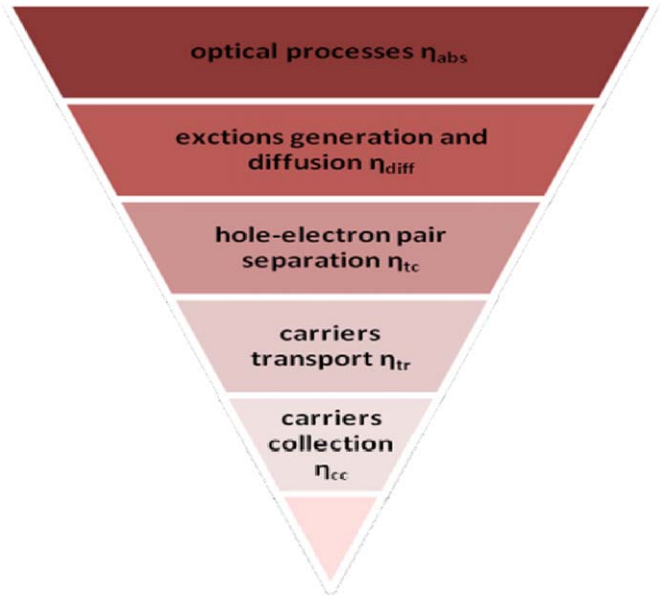

Fig. 3. Schematic illustration of energy transfer efficiencies in polymer solar cells.

the electron acceptor, that is, charge separation occurs and charge transport within the polymer blend to the respective electrodes.

The *PCE* of solar cell is defined as

$$PCE = \frac{J_{sc} V_{oc} FF}{P_{in}} \tag{1}$$

where J_{SC} is the short circuit current, V_{OC} is the open circuit voltage, *FF* is the fill factor and P_{in} is the incident light power which is standardized as 100 mW/cm^2.

J_{SC} can be obtained by

$$J_{sc} = \frac{q}{\hbar c} \int_{\lambda_{min}}^{\lambda_{max}} EQE P_{in}(\lambda) \lambda \, d\lambda \tag{2}$$

where q is the elementary charge, $\hbar$ is Planck constant, C is the speed of light and *EQE* is the external quantum efficiency, which is the ratio of output electrons to the incident photons. *EQE* is equal to the multiplication of all the efficiencies in the energy transfer processes.

$$EQE = \eta_{abs} \eta_{diff} \eta_{tc} \eta_{tr} \eta_{cc} \tag{3}$$

where η_{abs} is the photon absorption efficiency. The last four parameters, namely η_{diff}, η_{tc}, η_{tr} and η_{cc}, are the internal quantum efficiency (IQE), which represents the efficiencies of the exciton diffusion process, the hole–electron separation process, the carrier transport process and the charge collection process, respectively. The energy transfer process efficiencies in the solar cells can be described in Fig. 3.

The most effective way to improve the J_{SC} is to enlarge η_{abs}. In the standard solar spectrum (AM 1.5 G), the maximum irradiance energy is at ~500 nm, the maximum photon flux is at ~670 nm. Therefore, polymer solar cells materials need not only to absorb the photons at the maximum irradiance but also to have a broad absorption spectrum and high absorption coefficient.

Semiconducting polymers have lower dielectric constant than that of inorganic semiconductors. The electrostatic attractive force between the holes and the electrons, coulomb attraction, is proportional to $1/\varepsilon$, $\varepsilon \approx 3$ [9] (typical values for semiconducting polymers). The coulomb attraction in inorganic semiconductors with a larger dielectric constant can be neglected. In contrary, semiconducting polymers require a force more than 0.4 eV [10] to separate the exciton. The split area is at the interface between