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Applications of conducting polymers in solar cells

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Abstract

In this article, we provide an oversight of current achievements regarding the application of CPs in various classes of solar cells, which are here presented and analyzed considering different examples of active materials. The advantages of CPs and the challenges associated with their use in this regard are also introduced in this chapter. Additionally, we also discuss the basic fundamental concepts and techniques for CP synthesis as well as the basic working principle, device architecture, characterization, photovoltaic key parameters, and strategy for enhancing the performance of organic solar cells.

Keywords: Conducting polymers (CPs), Solar Cells, Dye-Sensitized Solar Cells (DSSCs), Organic Solar Cells (OSCs), Perovskite Solar Cells (PeSCs)

Introduction

CPs have been identified as promising alternatives in dye-sensitized solar cells (DSSCs), organic solar cells (OSCs), organic polymer tandem solar cells (TSCs), and more recently in perovskite solar cells (PeSCs) due to their unique optoelectronic properties. Commonly, polythiophene (PT), poly (3, 4-ethylene dioxythiophene), poly (3-hexylthiophene), PANi, poly (phenylvinylene) (PPV), and PPy are the most used CPs to fabricate the distinct layers in solar cells.

Dye-Sensitized Solar Cells (DSSCs)

A solar cell is a photovoltaic device that generates electrical energy from light. Particularly, a DSSC consists of a wide band gap semiconductor deposited onto a transparent conductive oxide (TCO) glass to form the electron transport material (ETM). Then, a dye molecule monolayer is anchored to the surface of the semiconductor as the photoactive layer, which absorbs light in the visible region and transfers the photo excited charges to the electron- and hole-conducting materials. The hole transport material (HTM) is a redox-coupled electrolyte, typically iodide/triiodide ions (I^-/I_3^-), in contact with a cathode or counter electrode (CE) where the reduction of the oxidized donor takes place.

Nowadays, the development of CEs for DSSCs plays a crucial role in the final photovoltaic performance of the solar cells. Although Pt is still the most preferred material as CE because of its conductivity and outstanding catalytic properties^[1], it is necessary to find alternative low-cost and noble metal-free materials to replace Pt in DSSCs, and conducting polymers seem to have interesting potential^[2, 4].

One suitable candidate for CE is PANi, which presents high conductivity, good chemical and electrical stabilities, and catalytic activity for I_3^- . PANi-nanoparticle CEs with highly porous surface area have been explored in the literature^[5, 6]. CE films composed of compact and scattered layers of PANi Nanoparticles show an increment on the active reaction interface and a decrease in the interfacial charge transfer resistance. The potential peak separation of I_3^-/I^- (I_2/I^-) for a PANi CE was comparable to that for a Pt CE, indicating that the PANi film was electrochemically active for the triiodide redox reaction^[7]. In order to improve the electron transfer and porosity, different PANi nanostructured morphologies have been proposed^[8, 9]. An inexpensive porous PANi nanotube CE was prepared via simple polymerization of aniline with ammonium persulfate in the presence of orthophosphoric acid. DSSCs assembled with PANi nanotubes as the CE obtained a superior photovoltaic performance compared to DSSCs based on Pt, mainly due to the higher electrocatalytic function of the PANi nanotubes^[8]. PPy, PT, and PEDOT are feasible CP alternatives to fabricate efficient CEs for DSSCs^[10, 11].

Organic Solar Cells (OSCs)

OSCs are devices that employ organic molecules as absorbers, which in general can be CPs or small molecules. In an OSC, incident photon absorption by the donor molecule (D) leads to the creation of an exciton. Excitons diffuse to the donor/acceptor (D/A) interface, where they become separated into electrons and holes followed by free charge transport to different contact electrodes.

Among the CP requirements to achieve efficient OSC devices are high charge conductivity, good processability and stability, low band gap, and optimal HOMO/LUMO levels^[12]. Despite the good conductivity and solubility of CPs, typical limitations are their band gaps, hygroscopicity, and inappropriate HOMO/LUMO energy levels^[13]. Nevertheless, diverse strategies have been pursued to surmount these limitations and improve the photovoltaic performance of OSC based on CPs.

P3HT has been extensively investigated as an electron donor (i.e., D layer) in OSCs, due to its relatively low band gap (2 eV) when compared to other CPs^[14]. In particular, the BHJ system formed by P3HT blended with PCBM offers a highly reproducible conversion efficiency in the range of 4.7–6.8%^[15] and a certified efficiency of 3.6%^[14]. It has been demonstrated that the efficiency of BHJ OSCs fabricated with P3HT: PCBM is strongly influenced by the deposition technique, blend composition, and post-treatment parameters^[16]. Many studies have been performed to understand and control the undesired morphology and phase separation of the D and A domains, by incorporating additives to the BHJ blend precursor solution. Upon introduction of different processing additives to the cast P3HT: PCBM solution (i.e., trihydrazone-functionalized cyanopyridine (CPTH-D16)^[17], 1, 8-diiodooctane^[18], and 1, 2, 4-trichlorobenzene^[19], a significant enhancement in photovoltaic performance has been observed.

The development of third-generation donor-acceptor (D-A) polymers has broadened the design of new building blocks in organic solar cells^[20]. Electron-deficient fused aromatic units such as diketopyrrolopyrrole (DPP), naphthalene diimide (NDI), and benzobisthiadiazole (BBT) have been extensively used as acceptor molecules^[21]. Fused heterocycles can achieve either low band gaps or high carrier mobilities depending on the orientation of the fused ring to the polymer main chain^[22].

Regarding the use of CPs as HTM in OSC, PEDOT:PSS continues to be the preferred hole extraction layer in bilayer and BHJ devices, because it is highly transparent and conductive, has good film forming ability, and is perfectly aligned with the work function of the indium tin oxide substrate (ITO)^[23]. Despite these excellent properties, corrosion of ITO by PEDOT: PSS at elevated temperatures and upon exposure to air must be addressed^[24].

Perovskite Solar Cells

In perovskite solar cells (PeSCs) the incident light is absorbed by the perovskite semiconductor material, inducing the formation of electron-hole pairs. Electrons and holes are separated by the ETM and HTM, respectively, followed by their transport to the ohmic contact electrodes. Organic/inorganic halide perovskites, including the most widely used methylammonium lead triiodide (MAPbI₃), are characterized by the general formula ABX₃, where A is an organic molecule, B is a metal cation, and X is a halide anion. There are two types of device architectures: mesoporous (nearly identical to conventional DSSCs) and planar (thin film

solar cells)^[25]. CPs have been used in rigid and flexible PeSCs as HTMs^[26], as ETMs, and also as protection from moisture^[25]. Since the majority of perovskite materials are solution processable as CPs, both are perfect candidates to assemble a fully solution-processed PeSCs. In addition to the requirements for CPs discussed above, it is important to investigate alternative doping agents to improve the CP conductivity without inducing undesirable chemical damage. As known, the main factor affecting the performance and degradation of hybrid solar cell devices stem from the interface instability of doped CP.

Conclusion

Conducting polymers are an important type of functional materials that have some valuable properties of organic polymers as well as semiconductors that are useful for advanced energy applications. These conducting polymers can be used in different applications, such as in solar cells for the electron transport layer, the hole transport layer, and the active layer of devices. So, different devices structures with varying parameters are used for the fabrication and optimization of organic solar cells for an optimized device. The power conversion efficiency of organic solar cells has improved rapidly in the last few years by using different approaches such as plasmonic and photon management. Further research needs to explore the commercialization and large-area flexible organic devices to overcome inorganic photovoltaics technology in the future.

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