Solar Energy 157 (2017) 71–80

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

Review

The effect of processing conditions on performance of small-molecule organic solar cells

Hui Zhang [a], Congxu Wang [b], Xiao Li [a], Jianli Jing [b], Youyi Sun [b,*], Yaqing liu [b]

[a] School of Computer Science and Control Engineering, North University of China, Taiyuan, Shanxi Province 030051, China
[b] Shanxi Province Key Laboratory of Functional Nanocomposites, North University of China, Taiyuan 030051, China

ARTICLE INFO

Article history:
Received 11 March 2017
Received in revised form 11 July 2017
Accepted 14 July 2017

Keywords:
Organic solar cells
Small molecular
Power conversion efficiency
Processing conditions

ABSTRACT

Recent decade, small molecule organic solar cells have attracted lots of interests. Especially, the synthesis of novel p-conjugated small donor-acceptor molecules and optimization of small molecule organic solar cells processing conditions have been investigated in detail. Although some important progress have been reached, it was still a challenge for further improving their power conversion efficiency, durability and cost effectiveness. This review provided the scientific community with both general and in depth information on the relationships between structure and property depended on processing conditions, for example, donor/acceptor (D/A) weight ratios, solvent and treatment. These drew some rules for process of small molecule organic solar cells, which were very important for further improving the performance of small-molecule organic solar cells.

Contents

1. Introduction

Small molecule-based organic solar cell (SM-OSC) was a promising technology developed for renewable energy sources due to be low overall cost, flexibility and environmental friendliness (Fan et al., 2015; Do et al., 2015). It was well-known that the performance of SM-OSC was mainly determined by the structure and properties of active layer, which was further affected by the chemical structure of donor and acceptor materials (Chen et al., 2014a; Dutta et al., 2012a; Patra et al., 2013; Ni et al., 2014; Kumar et al., 2015a, 2015b; Kim et al., 2014; Sung et al., 2017). The power conversion efficiency (PCE) of SM-OSC has reached over 10% by optimizing the chemical structure of donor and acceptor materials (Kan et al., 2014). However, the PCE was difficult to be further improved by optimizing the chemical structure of donor and acceptor material. In fact, the performance of SM-OSC was also strongly influenced by the processing techniques, in which the PCE of SM-OSC could be easily controlled by the processing conditions. So, there were lots of works to report the effect of the processing conditions on PCE of SM-OSC (Fan et al., 2015; Do et al., 2015; Chen et al., 2014a, 2014b, 2014c, 2014d; Dutta et al.,

* Corresponding author.
E-mail address: syyi@pku.edu.cn (Y. Sun).

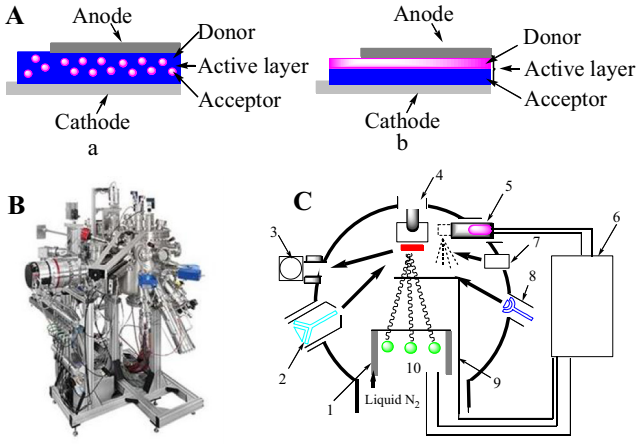
http://dx.doi.org/10.1016/j.solener.2017.07.043
0038-092X/

2012a,b,c,d; Patra et al., 2013; Ni et al., 2014, 2015; Kumar et al., 2015a, 2015b; Kim et al., 2014, 2015, 2013; Kan et al., 2014; Bagde et al., 2016, 2015; Du et al., 2015; Jadhav et al., 2015; Mercier et al., 2014; Bai et al., 2014a, 2014b; Sharma et al., 2014; Liang et al., 2016; Arrechea et al., 2015; Gautam et al., 2015a, 2015b; Li et al., 2013; Liu et al., 2012; Narayanaswamy et al., 2016; Zhang et al., 2015a, 2015b, 2016; Xia et al., 2015; Feng et al., 2016; Lim et al., 2016; Yang et al., 2014, 2016, 2015a, 2015b; Cui et al., 2015; Zhu et al., 2016; Lee et al., 2015; Guo et al., 2013; Zhen et al., 2015; Jiang et al., 2015; Wang et al., 2015; Lim et al., 2014; Jia et al., 2015a, 2015b; Zhou et al., 2015; Pan et al., 2013; Somasundaram et al., 2016; Ouhib et al., 2015; Yang et al., 2013; Areephong et al., 2015; Tomassetti et al., 2015; Wang et al., 2013; Chen et al., 2015; Williams and Aziz, 2014; Williams and Aziz, 2015; Kong et al., 2010; Lin et al., 2011; Shim et al., 2016; Chen et al., 2012; Che et al., 2014; Oseni and Mola, 2017; Ciro et al., 2017). However, it was quite usual that most of the work done so far was devoted to the development and optimization of the effect than to a deeper understanding of the mechanism of the process. In addition to this, the effect of processing conditions on performance of SM-OSC has been few reviewed and discussed.

The scope of this paper was to discuss some mechanistic aspects about the effect of processing conditions on PCE of SM-OSC, which was plausible and in line with earlier and new findings in recent years. The proposed discussion provided an explanation for the improving PCE of SM-OSC. Moreover, the effect of processing conditions on PCE of SM-OSC was firstly reviewed and discussed. Although some explanations were reported earlier, here the whole explanation was introduced to a broader community for the first time. It may be a help for further developing better SM-OSC.

2. The preparation of SM-OSC

SM-OSC was consisted of transparent cathode, active layer (donor/acceptor) and metal anode as shown in Scheme 1(A). The SM-OSC could be prepared by solution processing or vacuum deposited method. The solution processing method included three steps. Firstly, the organic small molecule donor was synthesized and the surface of fullerene acceptor was modified; Secondly, the donor and acceptor were dissolved and dispersed in organic solvent; Finally, the mixing solution was coated on surface of transparent cathode or metal anode by spin-coating or casting method. The vacuum deposited method included two steps. Firstly, the organic small molecule donor was synthesized and the surface of fullerene acceptor was modified, which was similar with solution processing method. Secondly, the small molecule donor and the fullerene acceptor powder was coated on surface of transparent cathode or metal anode by vacuum deposited method in a high-vacuum chamber with base pressure 1×10^{-6} Torr, in which the special experiment set-up of organic molecular vapor deposition system was used as shown in Scheme 1(B) and (C).



Scheme 1. (A) The schematic diagram of typical SM-OSCs with (a) doping and (b) layered structure, (B) optical image and (C) schematic diagram of organic molecular vapor deposition system: 1-Auger Electron Spectroscopy; 2-Auger Electron Spectroscopy; 3-electronic gun of reflection high-energy electron diffraction; 4-Substrate and heater; 5-Quadrupole mass spectrometer; 6-computer; 7-electronic gun; 8-Ion sputtering gun; 9-shutter; 10-Spray furnace.

3. Results and discussion

3.1. The effect of processing method

During the last decade, SM-OSC was mainly prepared by the solution processing method due to be the easy fabrication and low cost. However, the solubility of donor materials in organic solvent and film-forming property of donor materials was very important consideration for the design and synthesis of small molecule donor material. Contrarily, the solubility and film-forming property of donor materials was few consideration for the vacuum deposited method. So, there were more donor materials to prepare SM-OSC by the vacuum deposited method. For example, the active layer based on donor-(p-bridge)-acceptor (D-p-A) systems could be prepared by the vacuum deposited method, which showed high performance, such as (1) the absorption spectrum of the D-p-A molecules was extended toward longer wavelength by effective intramolecular charge-transfer (ICT) between donor and acceptor moieties; (2) the energy level was readily tuned by incorporating different electron-donating and/or -accepting groups and even the p-bridges; (3) the intermolecular p-p interaction was manipulated by the judicious selection of central p-bridges; (4) the thickness of active layer was easily controlled and the mutil-junction cell was easily prepared as shown in Scheme 2. So, the vacuum deposited method was an extremely interesting future candidate for fabrication of SM-OSC in the future. The performance of SM-OSC prepared by various processing method (solution processing method and vacuum deposited method) were summarized and compared as shown in Table 1. At the same structure, the PCE (ca. 6.6%) of SM-OSC prepared by the vacuum deposited method was lower than that of SM-OSC prepared by solution processing method. The result was due to that the structure of SM-OSC and vacuum-evaporation processing conditions were not optimized.

3.2. The effect of donor/acceptor weight ratio

It was found that the performance of SM-OSC also strong depended on donor/acceptor (D/A) weight ratios. So, there were lots of works to report the performance of SM-OSC as function of D/A weight ratios as shown in Table 2. For example, the best performance was obviously obtained at a D/A weight ratio of 1:1 for the TIBDT donor, in which the PCE of 3.94% with a Voc of 0.89 V, a Jsc of 7.36 mA cm^{-2} and a FF of 60.2% was observed for SM-OSC based on TIBDT:$PC_{71}BM$ (Fan et al., 2015). When decreasing D/A weight ratio to 1:2 and 1:3 or increasing to 2:1, the PCE was obviously reduced to be 2.43%, 1.32% and 3.25%, respectively. In a comparison, the SM-OSC containing TBDTCNR and $PC_{61}BM$ at a blend weight ratio of 1:0.25 exhibited a value of Voc of 0.90 V, a value of Jsc of 6.35 mA cm^{-2}, a FF of 65%, and a PCE of 3.69%. These values were further improved to 0.90 V, 9.08 mA cm^{-2}, 66%, and 5.42% at a D/A weight ratio of 1:0.4, respectively (Patra et al., 2013). Optimal fabrication conditions were achieved using a BDTSe-TTPD/$PC_{71}BM$ weight ratio of 1:2, in which the Voc, Jsc, FF