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Full paper

Ternary small molecule solar cells exhibiting power conversion efficiency of 10.3%

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ABSTRACT

The elaborately prepared BTR:$PC_{71}BM$ based small molecule solar cells (SMSCs) exhibit a champion power conversion efficiency (PCE) of 9.37%, which should be among the highest values for previous reports on BTR:$PC_{71}BM$ based SMSCs. Based on the optimized binary SMSCs, small molecule DIB-SQ was selected as the third component to fabricate ternary SMSCs. The champion PCE of 10.3% was achieved for ternary SMSCs with 6 wt% DIB-SQ in donors. An approximate 10% PCE improvement was obtained due to obviously increased short current density (J_{SC}) of 15.44 mA/cm^2 and fill factor (FF) of 73.8%. The main contribution of DIB-SQ can be summarized as the enhanced photon harvesting in long wavelength range and the optimized phase separation for better exciton dissociation and charge transport in ternary active layer. The results further demonstrate that ternary strategy should be an efficient and versatile method to improve the performance of SMSCs.

1. Introduction

Small molecule materials have attracted intense attention owning to the advantages of well-defined molecular structure, easy purification and less batch-to-batch variation, which have great potentials for fabricating highly efficient solution-processed organic solar cells [1,2]. Recently, small molecule solar cells (SMSCs) have made a breakthrough on power conversion efficiency (PCE) through the efforts from material synthesis, morphology optimization, interfacial engineering and device structure [3,4]. Wei's group and Chen's group individually reported a rather high PCE of 11.3% for single-junction SMSCs and 12.7% for double-junction tandem SMSCs, which are mainly attributed to the broad absorption range and excellent morphology of small molecule active layer [5,6]. However, most of SMSCs also exhibit PCE values less than 10% due to the poorly regulated film morphology and insufficient light absorption of the active layer [7–11]. Meanwhile, the performance of SMSCs is very sensitive to the morphology of active layer, the PCE of SMSCs can be markedly improved for active layer undergoing extra treatments, such as thermal annealing (TA), solvent vapour annealing (SVA), solvent additive processing (SAP) or the combination of different treatments [12–17]. Here, some representative investigations on the performance of SMSCs are listed in Table 1. Obviously, the short circuit current density (J_{SC}) and fill factor (FF) of SMSCs can be distinctly improved by employing post-treatments on active layer, leading to more than 24% PCE improvement. Though the film morphology can be optimized by employing active layer post-treatments, narrow absorption range of active layers is still an issue to further improve the PCE of SMSCs, which inspires us to investigate ternary SMSCs.

Ternary strategy with two donors or two acceptors has been demonstrated as an effective method to improve photovoltaic performance of cells by enhancing photon harvesting, meanwhile maintaining the simple fabrication technology [25–30]. The first principle of the third component selection is to have complementary absorption spectra compared with the host system. The optimized content of third component strongly depends on the miscibility of third component with the host materials. The ideal selection of the third component is to have complementary absorption spectra and good miscibility with host materials [31–35]. In fact, the morphology optimization of active layer is still a great challenge for obtaining highly efficient ternary solar cells, especially for ternary SMSCs. Up to now, most of ternary solar cells

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Table 1
Investigations on SMSCs without and with different treatments on active layer.

Donor	J_{SC} [mA/cm^2]	V_{OC} [V]	FF [%]	PCE [%]	without/with treatments	Ref.
DR3TSBDT	12.19/14.62	0.97/0.92	56/74	6.62/9.95	~ /TA + SVA	[18]
BTR	11.64/13.90	0.96/0.90	47/74	5.2/9.3	~ /SVA	[19]
Se6FTh	11.33/14.55	0.90/0.88	55/72	5.64/9.26	~ /SVA + TA	[20]
OPD2FBT2–2	7.82/13.6	0.89/0.92	56/71	3.90/8.91	~ /SAP + SVA	[21]
BIT6F	11.68/13.47	0.92/0.90	62/75	6.66/9.09	~ /TA + SVA	[22]
BIT4FTh	12.02/13.06	0.94/0.89	62/75	7.00/8.70	~ /SVA	[23]
O-BDTdFBT	10.48/11.60	0.99/0.97	58/72	6.02/8.10	~ /SAP	[24]

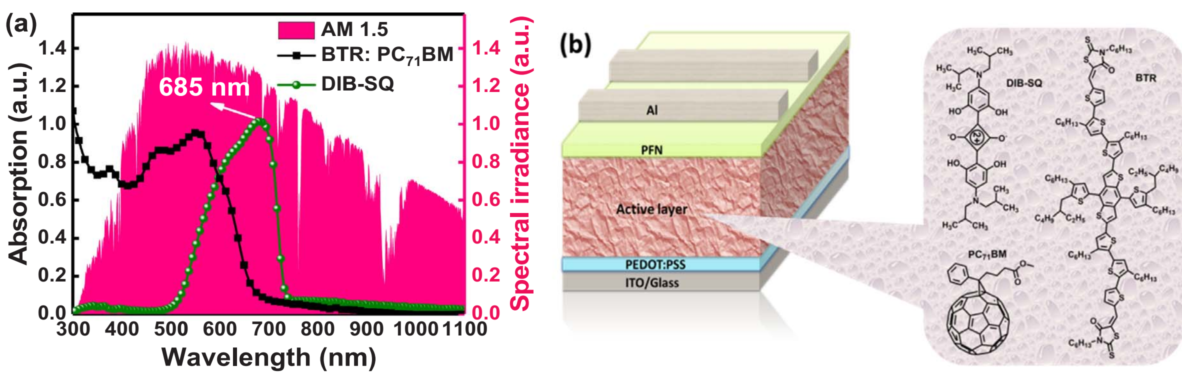

Fig. 1. (a) Reference solar light radiation spectrum, absorption spectra of neat DIB-SQ film and blend BTR:$PC_{71}BM$ film; (b) Schematic diagram of device architecture and molecular structure of used materials.

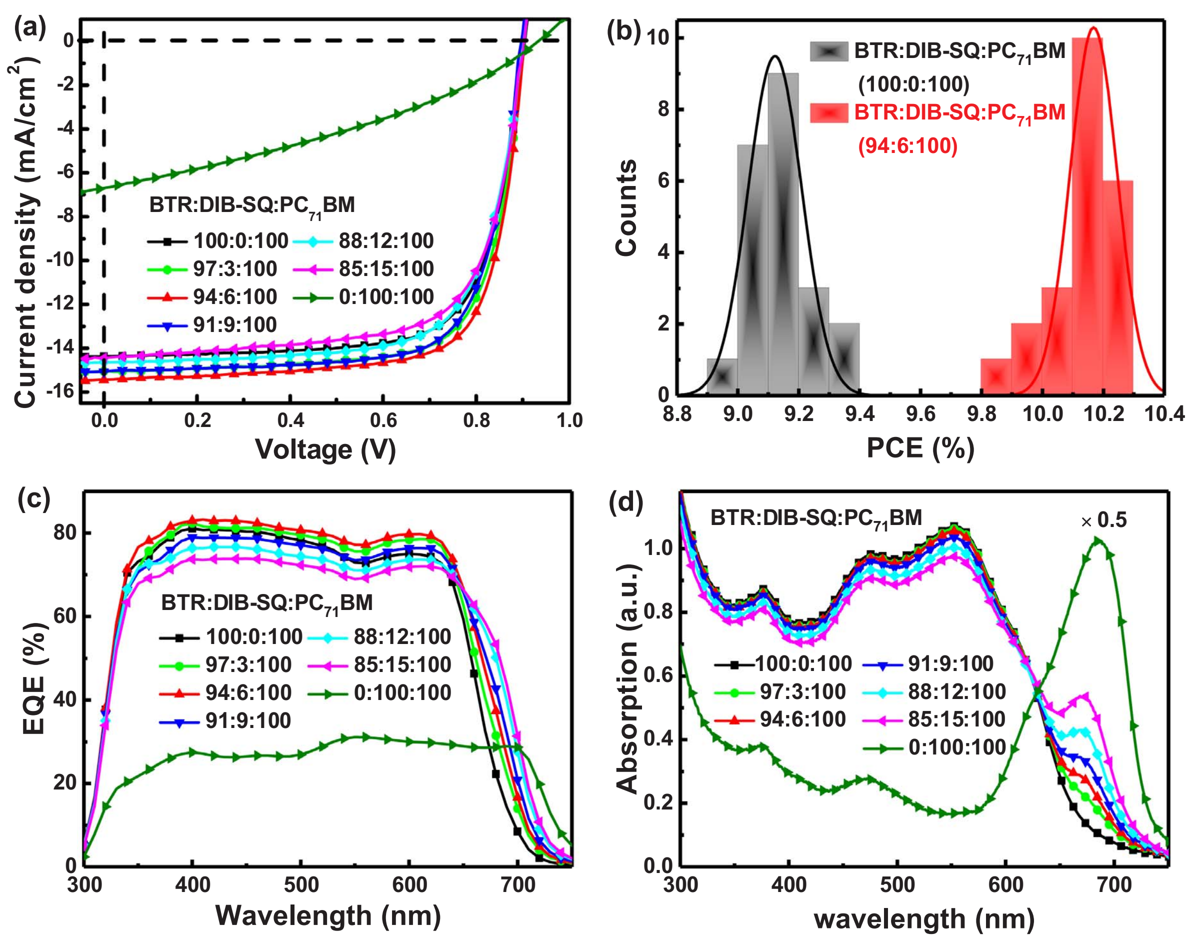

Fig. 2. (a) *J-V* characteristics of all SMSCs; (b) Statistical histogram of PCE counts for the reference SMSCs and the optimized ternary SMSCs, the fitted curves represent PCE normal distribution; (c) EQE spectra of all SMSCs; (d) Absorption spectra of blend films with different DIB-SQ contents.