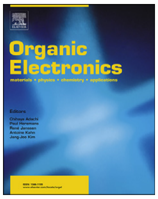
Organic Electronics 37 (2016) 305–311

Contents lists available at ScienceDirect

Organic Electronics

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



# Enhancing efficiency for additive–free blade–coated small–molecule solar cells by thermal annealing

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ARTICLE INFO

*Article history:*
Received 9 January 2016
Received in revised form
18 May 2016
Accepted 25 June 2016
Available online 18 July 2016

*Keywords:*
Additive–free
Small–molecule
Thermal annealing
Organic solar cells
Blade coating

ABSTRACT

Blade coating was successfully applied to realise high-efficiency small-molecule organic solar cells (OSCs) with a solution-processed active layer comprising a small organic molecule DR3TBDTT with a benzo[1,2–b:4,5–b′]dithiophene (BDT) unit as the central building block as the donor and [6,6]–phenyl–C71–butyric acid methyl ester ($PC_{71}BM$) as the acceptor. Using chloroform as the solvent, a DR3TBDTT/$PC_{71}BM$ blend active layer without an additive was effectively formed through blade coating. The power conversion efficiency (PCE) of small organic molecule solar cells was enhanced by 3.7 times through thermal annealing at 100 °C. This method produces OSCs with a high PCE of up to 6.69%, with an open circuit voltage ($V_{oc}$) of 0.97 V, a short-circuit current density ($J_{sc}$) of 12.60 mA/cm$^2$, and a fill factor (FF) of 0.55.

## 1. Introduction

Bulk heterojunction organic solar cells (OSCs) have attracted attention as a clean and renewable energy resource because of features such as low production cost, solution processability at high throughput, light weight, and flexibility [1–3]. Moreover, OSCs utilising small-molecule solar cells as donors and acceptors have gained considerable attention because of advantages over their polymer counterparts such as a well-defined molecular structure, a definite molecular weight, and high purity without batch to batch variations [4]. The highest power conversion efficiency (PCE) of OSCs based on small molecular donor/fullerene acceptors is greater than 7%–9% [4–12].

Amongst various methods for the optimisation of processing techniques, the most commonly used methods include thermal annealing [13–21] and the use of solvent additives [4–12,28–30]. Heat treatment causes the movement of molecules, resulting in the redistribution and eradication of the dislocations in bulk heterojunctions. The enhanced device performance obtained under optimized annealing conditions is thought to be due partly to the improved light harvest and the interfacial contact between the metal electrode and the active layer and mainly to better donor/acceptor morphology in the active layer [22–25]. Many studies have been conducted to enhance efficiency through thermal annealing of P3HT and low-bandgap-material cells. However, the performance has not been enhanced appreciably. Most low band gap systems the efficiency becomes worse with annealing, but the opposite of P3HT. It may be that side chains have noteworthy influence on a polymer's properties, mainly its crystallinity and stability. In general, donor groups with side chain are the most susceptible to degradation while the most stable are those without side chains [26,27]. However, P3HT is a simple polymer which has high thermal stability. Therefore, low band gap systems the efficiency becomes worse with annealing and the opposite of what happens to P3HT may be attributed to their molecular structure. Moreover, high-efficiency OSCs are usually obtained using low percentages of solvent additives during the active layer film-forming process [4–12,28–30]. The additives cause nanoscale phase separation and a bicontinuous interpenetrating network in the active layer, which are critical for achieving appropriate phase-separated domains with highly efficient exciton dissociation and

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http://dx.doi.org/10.1016/j.orgel.2016.06.029
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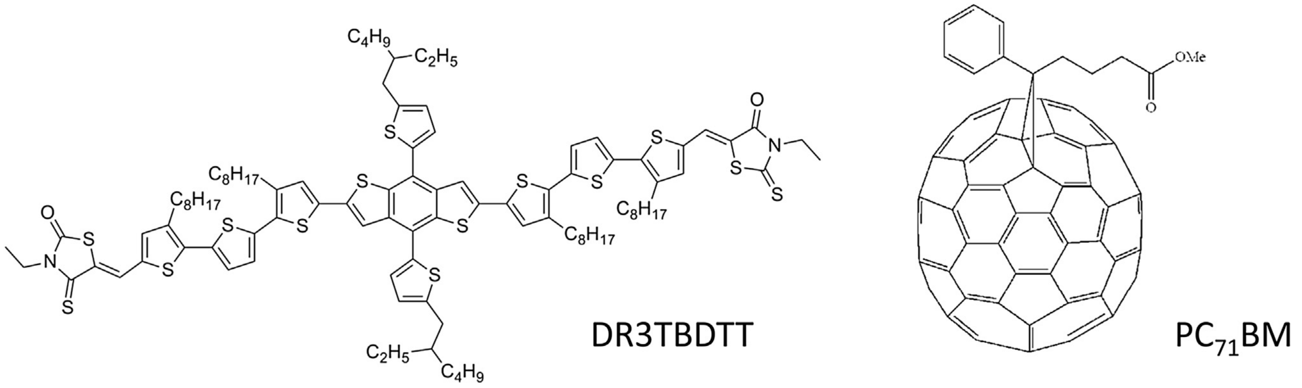

**Fig. 1.** The chemical structures.

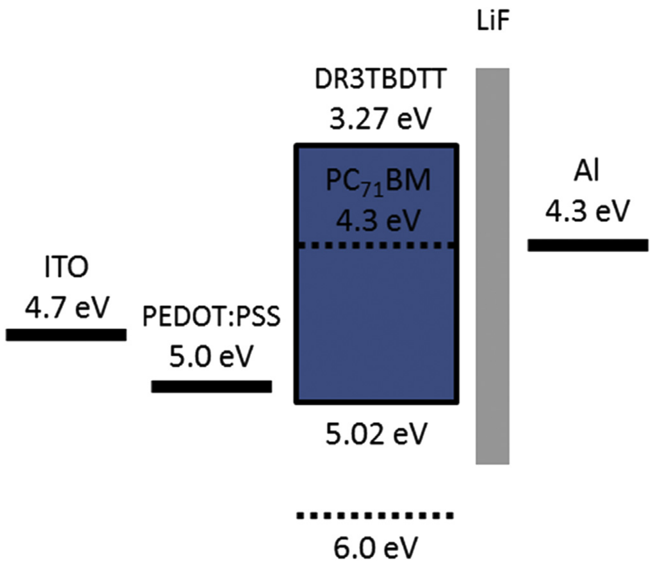

**Fig. 2.** Energy band diagram.

carrier transport [30]. Nevertheless, the drying process of the residual high boiling point additives induces undesirable morphological variation as well as unfavourable interfacial contact [31]. In this study, the PCE of OSCs based on DR3TBDTT without additives was up to 6.69% after thermal annealing.

Practical application of organic photovoltaics relies on high-throughput processing. However, almost all device demonstration and fundamental research to date has utilised spin coating for thin film deposition. Spin-coated processing wastes a considerable amount of solution and is incompatible with large-scale processing and roll-to-roll fabrication. Blade coating has the advantages of large-area uniformity, a low amount of material waste, prevention of interlayer dissolution, and compatibility with the roll-to-roll process. Blade coating involves a rapid drying process that prevents the fabrication throughput from being slowed by conventional solvent annealing [32–42]. This study focused on the small-molecule donor DR3TBDTT [6]. Devices in which this donor was deposited through blade coating exhibited a high efficiency of 6.69% without additives after thermal annealing at 100 °C for 5 min, with an open circuit voltage ($V_{oc}$) of 0.97 V, a short-circuit current density ($J_{sc}$) of 12.60 mA/cm$^2$, and a fill factor (FF) of 0.55. The PCE of

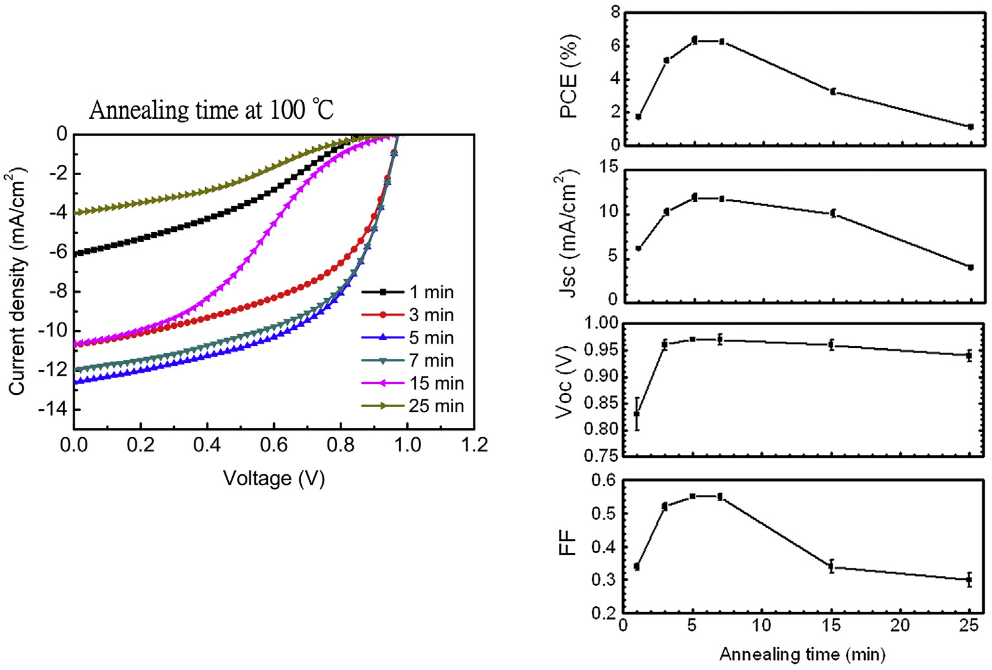

**Fig. 3.** J–V curves of DR3TBDTT/PC$_{71}$BM solar cells after thermal annealing at 100 °C for different time under illumination of AM 1.5 G, 100 mW/cm$^2$.