

Letter

Large-area organic solar cells by accelerated blade coating

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ABSTRACT

Large-area photovoltaic devices have been fabricated using the blade coating technique. In this study, the use of accelerated blade motion in this technique significantly improved the thickness uniformity of blade-coated layers of polymer solar cells on an A4 glass substrate. Two types of active layers, P3HT:PC₆₁BM and POD2T-DTBT:PC₇₁BM, were studied. For the P3HT:PC₆₁BM film, a thickness of 221 ± 14 nm was realised in a 12×15 cm² active region with a coating blade acceleration of 8 mm/s². For the POD2T-DTBT:PC₇₁BM film, a thickness of 98 ± 6 nm was realised with a coating blade acceleration of 10 mm/s². Ten cells, each measuring 0.9 cm \times 12 cm and monolithically fabricated, were connected in series, yielding a total active area of 108 cm². The power conversion efficiency of the resulting 10-cell module was 2.66% and 3.64% for P3HT:PC₆₁BM and POD2T-DTBT:PC₇₁BM, respectively. The blade coating technique involving the accelerated blade motion is therefore useful for fabricating low-cost large-area organic solar cells, and it may be a promising alternative for the commercialisation of organic solar cells.

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1. Introduction

Organic solar cells (OSCs) have received considerable attention because of their capability to convert power efficiently, cost-effectiveness, mechanical flexibility, light weight, and ability to be manufactured in a large area [1–4]. Considerable progress has been made in recent years in the development of OSCs, and a major increase in power conversion efficiency (PCE) has been reported for polymer bulk heterojunction solar cells fabricated from low band gap polymers and fullerene. Thus far, OSCs with PCE of over 10% have been reported [5].

Most of the highly efficient polymer solar cells reported are small-area devices fabricated using the spin coating technique. Although this technique helps achieve a high degree of control over the film thickness and homogeneity, it is unfavourable for the mass production of large-area devices because it inherently involves excessive use of materials and is incompatible with high-throughput continuous processing.

Alternative techniques, such as slot die coating, ink jet coating, and blade coating, have been applied for producing large-area OSCs. In slot die coating, the flow volume is adjusted using a metering pump, and thus, the wet film thickness for a given coating width and line speed can be controlled [6–8]. The minimal

achievable wet film thickness is limited by the stability of the liquid bridge between the die lip and the moving substrate. Because of its requirement of high-precision control over various coating parameters, slot die coating is expensive. Additionally, this technique has a low coating speed, and thus prevents the rapid drying of multilayer structures in high-throughput continuous processing. Ink jet coating is based on the generation of ink droplets under pressure [9,10,2,11]. However, the use of narrow nozzles in ink jet coating results in repeated clogging. Moreover, this technique is expensive, has a low coating speed, and can only be used with certain coating materials.

The development of large-area OPV has been intensively studied. Krebs et al. developed compact roll-to-roll processed polymer solar cell modules with an active area of 35.5 cm² and PCE of 2.75% [12]. Galagan et al. fabricated ITO-free OSCs on stainless steel substrates with an active area of 50 cm² and PCE of 1.3% [13]. Using the spin coating technique, Jin et al. developed a monolithic sub-module with an active area of 25 cm² and PCE of 3.17% [14]. In a survey of the current technological status of organic photovoltaics, Carlé and Krebs noted that studies on large-area devices (active area >100 cm²) are crucial for the successful commercialisation of OSCs [15,16].

Blade coating has been used for the processing of organic semiconductors. The advantages of this technique include low material waste, roll-to-roll compatibility, rapid drying of multilayer structures and high-throughput continuous processing [17–23]. In blade coating, a coating blade drags a deposited

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solution to obtain a wet polymer film. The solution is delivered to the blade gap with a pipette. Subsequently, the blade moves only after the solution spreads uniformly across the blade gap because of capillary action. Because no further solution is added during the blade motion, the volume of the solution beneath the blade gap inevitably decreases during coating, thereby resulting in a decreased and nonuniform wet film thickness in the coating direction. The present study addresses this problem. This study revealed that with a constant amount of solution beneath the blade gap, the wet film thickness increases substantially with an increasing blade speed. Therefore, a decrease in the wet film thickness because of the depletion of the solution can be compensated for by an acceleration of the blade motion.

In this study, large-area polymer solar cell modules were produced using this approach. Two types of photoactive layers were used: (1) poly(3-hexylthiophene-2,5-diyl) (P3HT) and a low band gap polymer poly{(benzo-2,1,3-thiadiazol-4,7-diyl)-alt-(3',4'-di(2-octyldodecyl)-2,2';5',2'';5'',2'''-quaterthiophen-5,5'''-diyl)}(POD2T-DTBT) as the electron donor and (2) [6,6]-phenyl-C₆₁-butyric acid methyl ester (PC₆₁BM) and [6,6]-phenyl-C₇₁-butyric acid methyl ester (PC₇₁BM) as the electron acceptor [24–29]. The large-area solar cell modules, with each module comprising 10 cells connected in series, having a total active area of 108 cm², and having PCE of 2.66% and 3.64% for P3HT:PC₆₁BM and POD2T-DTBT:PC₇₁BM, respectively, were demonstrated. The study results suggested that the accelerated blade coating technique may be a promising alternative for the commercialisation of large-area OSCs.

2. Experimental

Polymer solar cells were fabricated on prepatterned indium-tin-oxide (ITO) glass with device structures of ITO/PEDOT:PSS/P3HT:PC₆₁BM/LiF (0.8 nm)/Al (100 nm) and ITO/PEDOT:PSS/POD2T-DTBT:PC₇₁BM/Al (100 nm). Fig. 1 shows the device and chemical structures of the active layer materials used. P3HT and POD2T-DTBT have low band gaps of 1.9 eV and 1.59 eV, respectively. P3HT was purchased from Rieke Metals, Inc. and POD2T-DTBT was synthesised and provided by Chen [29]. Fig. 2a and b shows the design of large-area OSCs, each comprising 10 cells connected in series. Each cell measured 0.9 cm in width and 12 cm in length and they were spaced at 0.2 cm intervals. The total active area of a large-area OSC was 108 cm² and the aperture ratio, the ratio of illuminated active region to total area, was 0.82. We can design the amount of cells in series to achieve the output voltage. The cathode of the cell in the left is connected

to the ITO of the cell in the right to form series connection. However, the current in a series circuit goes through every component in the circuit, the disadvantage is opening or breaking a series circuit at any point causes the entire circuit to “open” or stop operating. In a series circuit, every device must function well for the circuit to be complete. Therefore, how to control the uniformity of film is important. Fig. 2c and d shows the metal mask used to define the active layer by mechanical scratch for the series connection amongst the cells. PEDOT:PSS [poly-(3,4-ethylenedioxythiophene):poly-(styrenesulfonate), CLEVIOS™ PVP AI4083] was purchased from HC Starck. PC₆₁BM and PC₇₁BM were purchased from Nano-C, Inc. and Solenne, respectively. The patterned ITO-coated glass substrates were treated in an ultrasonic bath for 60 min in acetone, rinsed three times with deionised water and cleaned using a UV Ozone cleaner for 20 min. PEDOT:PSS and isopropyl alcohol (IPA) were mixed at a volume ratio of 1:2. To prepare P3HT and PC₆₁BM solutions, P3HT and PC₆₁BM powders were mixed and dissolved using chlorobenzene, respectively. The weight ratio of P3HT, PC₆₁BM and chlorobenzene was fixed at 25 mg:25 mg:950 mg. POD2T-DTBT and PC₇₁BM powders were also mixed and dissolved using chlorobenzene. The weight ratio of POD2T-DTBT, PC₇₁BM and chlorobenzene was fixed at 20 mg:20 mg:960 mg.

Fig. 3 shows the domestic A4 autoblade coating machine with an acceleration control system for film coating. This machine comprises an automatic feeding device, blade coater, substrate heating device, hot air blowing device, and linear motor to drive the tappet at a constant or accelerating speed. The substrate heating device, which employs vacuum sucking grooves for better thermal contact between the substrate and the heater and thus improved temperature uniformity, is 20 cm in width and 30 cm in length, and a substrate's temperature ranging from 30 to 150 °C can be stably maintained by means of a resistant heater. The hot air produced by a blower containing a diffusing shower head was applied to enhance the drying speed and uniformity. The PEDOT:PSS layer was blade coated twice, both at 60 °C, in opposite directions for more satisfactory uniformity. In both directions, the coating blade moved at a constant speed of 10 mm/s, and a solution of 400 μL was delivered to the blade gap in each coating direction. The film was baked at 150 °C in air for 20 min. The combined thickness of the double-coated PEDOT:PSS layer was 36 ± 3 nm.

The blade coatings of the P3HT:PC₆₁BM and POD2T-DTBT/PC₇₁BM active layers were performed with rapid-drying air blowing on a hot plate at 80 °C. The P3HT:PC₆₁BM active layer was blade coated at an optimal acceleration of 8 mm/s². A solution of 500 μL

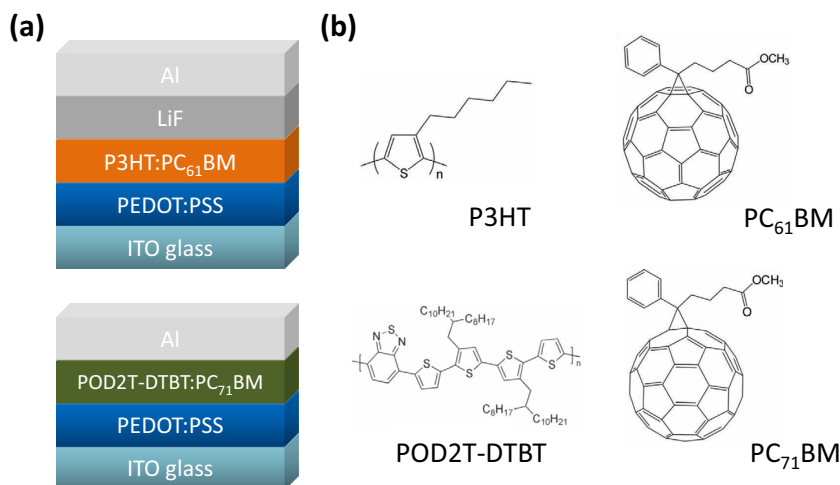


Fig. 1. (a) The device structures and (b) the chemical structures of active materials used in this work.

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