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Transfer Printing of Active Layers from controlled Swelling/De-Swelling of PDMS for realizing Bilayer Polymer Solar Cells

Anisha Mohapatra[1] and Chih Wei Chu [1]

[1]*Research Center for Applied Science, Academia Sinica,128 Academia Road, Section 2, Nangang Taipei 115-29 Taiwan (R.O.C.). Phone- +886-2-27873183, Email- gchu@gate.sinica.edu.tw*

Abstract

We demonstrate a simple method for controlling the surface energy of a PDMS stamp by exploiting its natural properties of swelling/de-swelling for use in transfer printing organic films. We prepared bilayer and graded bilayer structures after transferring indene-C60 Bis-adduct (ICBA) and ratio controlled poly(3-hexylthiophene) (P3HT:ICBA) blends, respectively, onto the P3HT layer. The optimal graded bilayer solar cell exhibited a power conversion efficiency of 5.13% an impressive value compared with that obtained for corresponding bilayer cell (3.67%). To the best of our knowledge, this report is the first to describe such a simple modification procedure for residue-free transfer of PDMS to target substrates without external factors. This approach is competitive with other transfer techniques, and that it is a better choice than spin-coating for the preparation of multi-stack structures for potential commercialization.

1. Introduction

The organic photovoltaics have progressed a lot in past few years because its numerous advantageous features like low cost, lightweight, and compatible with low temperatures [1,2]. Recently, some OSCs have displayed impressive power conversion efficiencies (PCE) greater than 14% for a single cell and 17.3% for a tandem cell that suggest great potential for further improvements and commercialization. [3] At present, the best solution-processed OSCs are based on bulk heterojunction (BHJ) structures, in which the active layer is a blend of a donor and acceptor in a bulk film. The efficiency of a BHJ is limited because of unbalanced charge transport for random phase separation. As an alternative to the BHJ structure, the sequential processing of the donor and acceptor into a bilayer structure has several advantages: greater morphological control, balanced charge transport, and direct pathways for charge collection from the interfaces to the electrodes.[4,5] Nevertheless, the fabrication of bilayer structures through solution-processing is susceptible to partial dissolution of the underlying layers, disrupting the formation of stacked layers.[6] Methods like vacuum deposition, spray deposition have certain drawbacks like reproducibility, complexity and increasing the manufacturing time.[7] Transfer printing would appear to overcome these drawbacks for transferring organic-organic, organic-inorganic layers without damaging the underlying layer. [8] In the transfer printing approach, the most commonly used transferring substrates have been polydimethylsiloxane (PDMS) stamps. Surface modification of the PDMS stamp is necessary prior to transfer-printing, because of its hydrophobic nature. Several groups modified the PDMS stamp by restricting the reusability of the PDMS stamps and complicating the transfer strategy. Furthermore, these approaches were developed to inhibit swelling of the PDMS stamps a constant problem when casting organic films. Nevertheless, because swelling modifies the surface energy of a PDMS stamp, controlling the swelling properties might possibly be an advantage, rather than a drawback, when casting films.

Herein, we demonstrate a simple method for controlling the surface energy of a PDMS stamp by swelling/de-swelling, using it to develop an effective technique for transfer printing organic films. To demonstrate this method's effectiveness. We transferred ratio controlled poly(3-hexylthiophene) (P3HT)/indene-C60 bis-adduct (ICBA) and ICBA layers to realize graded bilayer and bilayer solar cells.

2. Results and Discussion

We measured the contact angles of the PDMS stamps to investigate their surface energies after modification. The contact angles of the unmodified and the CB and CB/IPA-treated PDMS stamps were 99, 66, and 62°, respectively. Fig. 1 shows the schematic representation of the transfer printing process. We used the modified PDMS for transferring ratio controlled P3HT: ICBA (graded bilayer) and ICBA layer to form bilayer and graded bilayer solar cells. We used cross-sectional scanning electron microscopy (SEM) to examine the vertical profiles of P3HT and ICBA in the spin coated bilayer, stamped bilayer, and graded bilayer films. The cross-sectional SEM image of the spin coated bilayer film revealed no clear interface and a thickness of approximately 80 nm (Fig. 2a-c); for the bilayer and graded bilayer films, distinct interfaces were present having thicknesses of approximately
100 and 140 nm. Because S atoms were present only in P3HT, we used EDS element mapping to examine the dis-

tributions of the concentrations of S atoms in the active layers for the spin coated and stamped bilayer films (Fig. 2d–f). In the B-Spin films (Fig. 2d), the S atoms were distributed throughout the bilayer cross-section, suggesting that an inferior interface had formed as compared to the stamped films. For the ICBA transferred films, however, the higher concentration of S atoms toward the bottom side of the bilayer cross-section suggested that a distinct interface formed between the P3HT and ICBA layers (Fig. 2e). In contrast, the distribution of S atom in the ratio controlled P3HT:ICBA transferred film revealed a higher concentration of S atoms in the top layer than in the bottom layer (Fig. 2f). The enrichment of S atoms at the bottom of the bilayer cross-section suggests that it is possible to control the donor and acceptor ratio through transfer printing. Thus, transfer printing appears to be a more efficient method for forming stacked layers when compared with spin-coating. After assessing the potential of the swelling/de-swelling modified PDMS transfer printing process for the preparation of organic thin films for bilayer solar cells, we used it to fabricate OSC devices. The performances of the stamped devices were enhanced significantly relative to that of the B-Spin device. Fig. 3 displays the enhanced current density–voltage (J–V) characteristics of the OSCs incorporating the ICBA and P3HT:ICBA stamped bilayer devices. The spin coated bilayer OSC prepared with exhibited a power conversion efficiency (η) of 2.42%.The transferred devices performed significantly better: for the ICBA transferred, we got an PCE of 3.67%, while 5.13% for the ratio controlled P3HT:ICBA transferred(graded bilayer) respectively.

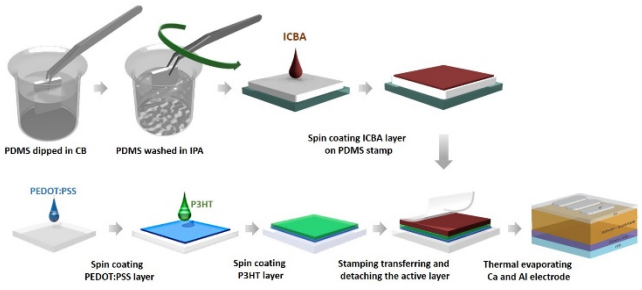

Fig. 1 Schematic representation of the fabrication of P3HT/ICBA-based solar cells through transfer printing

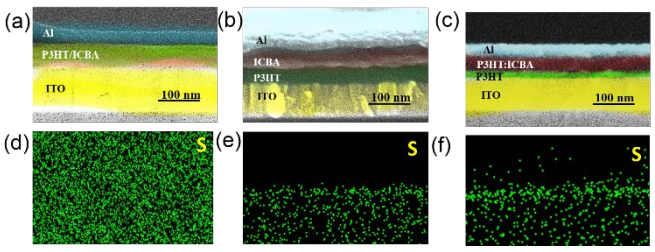

Fig. 2 (a–c) Cross-sectional SEM images, (d–f) EDX sulfur mapping of spin coated bilayer, ICBA stamped bilayer and (P3HT:ICBA) stamped graded bilayer.

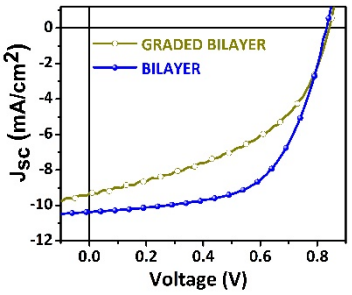

Fig. 3 J–V characteristics of spin coated bilayer and stamped bilayer devices.

3.Conclusion

We have developed a novel transfer printing process in which control over the surface properties of a PDMS stamp allows the fabrication of multi-stack organic films. This strategy for modification of PDMS stamps results in residue-free transfer printing as a means of forming stacked structures. With these advances, we obtained a PCE of 5.13% for a ratio-controlled P3HT/ICBA graded bilayer solar cell and 3.67% for bilayer solar cells.This PCE suggests that this approach is competitive with other transfer techniques, and that it is a better choice than spin-coating for the preparation of multi-stacked structures.

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