Improved Efficiency of Polymer Solar Cells by means of Coating Hole Transporting Layer as Double Layer Deposition

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Abstract. Polymer solar cells is one of the promising technologies that gain tremendous attentions in the field of renewable energy. Optimization of thickness for each layer is an important factor determining the efficiency of the solar cells. In this work, the optimum thickness of Poly(3,4-ethylenedioxythione): poly(styrenesulfonate) (PEDOT:PSS), a famous polymer widely used as hole transporting layer in polymer solar cells, is determined through the analyzing of device's photovoltaic parameters, e.g. short circuit current density (J_{sc}), open circuit voltage (V_{oc}), fill factor (FF) as well as power conversion efficiency (PCE). The solar cells were prepared with multilayer of ITO/PEDOT:PSS/PCDTBT:$PC_{70}BM/TiO_x$/Al by rapid convective deposition. In such preparation technique, the thickness of the thin film is controlled by the deposition speed. The faster deposition speed is used, the thicker film is obtained. Furthermore, double layer deposition of PEDOT:PSS was introduced as an approach to improve solar cell efficiency. The results obviously reveal that, with the increase of PEDOT:PSS thickness, the increments of J_{sc} and FF play the important role to improve PCE from 3.21% to 4.03%. Interestingly, using double layer deposition of PEDOT:PSS shows the ability to enhance the performance of the solar cells to 6.12% under simulated AM 1.5G illumination of 100 mW/cm^2.

1. Introduction

Solar energy harvesting is a promising solution for solving energy crisis problems. Due to high photon-electron conversion efficiency, low manufacturing cost as well as lower electricity price per unit power comparing to other renewable energy, researches topic related to solar cells become the attractive issues. The solar cells fabricated from semiconducting polymers as bulk heterojunction is a well-known device that provides many advantages i.e. simple preparation and available for large area fabrication, suitable for flexible devices as well as less environmental effects.[1] However, the power conversion efficiency of polymer solar cells is significantly lower than those prepared from inorganic semiconducting materials. Therefore, the efficiency improvement of polymer solar cells become one of the challenging research topics. Several approached have been proposed in order to enhance the polymer solar cell efficiency, e.g., chemical structure modification of electron donor/acceptor material, architectural modification of photon-electron conversion devices as well as optimization of device's fabricating parameters. Among the fabricating parameters, the thickness of hole transporting layer is one of the factors evidently effecting on device efficiency. The thick layer provides better layer formation but the device would suffer from high internal resistance. On the other hand, the thin layer gives a benefit on charge transportation but the device possibly encounters with leakage current owing to short contacts between electrodes. Therefore, the optimization of thickness of hole transport layer is a key to achieve highly efficient solar cell device.[2] In this work, the optimum thickness of PEDOT:PSS, a famous material used as hole transport layer in polymer solar cells, that provides the highest power conversion efficiency (PCE) of PCDTBT:$PC_{70}BM$ bulk heterostructure device is determined. In addition, the double layer deposition of PEDOT:PSS is introduced as a strategy to further improve PCE of the polymer solar cells prepared by the optimum thickness of hole transport layer.

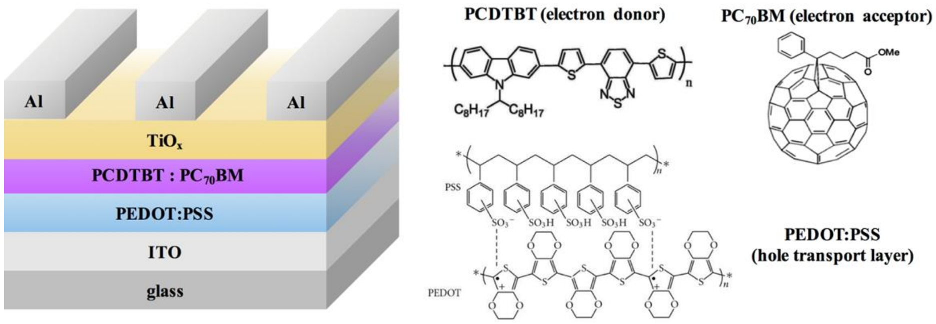

Figure 1. Chemical structure of semiconducting polymers and device structure of polymer solar cells used in this research.

2. Methods

PCDTBT (as electron donor), $PC_{70}BM$ (as electron acceptor), PEDOT:PSS (as hole transport layer) were purchased from Ossila Ltd and used in the experiments without any purification. The solar cells were fabricated by rapid convective deposition with the structure ITO/PEDOT:PSS/PCDTBT :$PC_{70}BM/TiO_x$/Al as presented in figure 1. For rapid convective deposition, the thickness of the layer can be controlled through deposition speed. The faster translational speed moves, the thicker layer is obtained. To fabricate solar cells, ITO substrates (sheet resistance > 5 Ω.cm) were cleaned via alcohol processes followed by oxygen plasma treatment at the power of 100 Watt for 2 minutes. The PEDOT:PSS layer were deposited on the ITO substrate by using 40 μL and varying deposition speed from 0.5 to 3.0 mm/s. Then, the sample annealing at 120 °C for 30 minutes was applied. The active layer of the solar cells was prepared from the mixture of PCDTBT:$PC_{70}BM$ in o-dichlorobenzene with the ratio of 1:4 by weight. 10 μL mixture of PCDTBT:$PC_{70}BM$ were fabricated on the PEDOT:PSS layer by using the deposition speed of 1.25 mm/s. Next, 20 μL TiOx solution was coated on top of the active layer with the deposition speed of 1.25 mm/s as optical spacer. All the fabricated solar cells were annealed at 80 °C for 20 minutes before transferring to the evaporating chamber. Finally, 300 nm of aluminium was deposited as metal electrode by thermal evaporation. The optimum thickness of PEDOT:PSS was determined by the condition that provides the highest PCE. To obtain the photovoltaic parameters, the J-V characteristics of the solar cells with the effective active area of 0.1 cm^2 were measured under AM 1.5 G at intensity of 100 mW/cm^2 generated by solar simulator (ABET Technology Co. Ltd.). Moreover, after obtaining the optimum PEDOT:PSS thickness, double layer deposition was introduced to further enhance the PCE of the optimum solar cell. In this work, preparation of double layer deposition of PEDOT:PSS was done by coating two times of PEDOT:PSS layer with the optimum deposition speed but using only half amount of solution comparing to that used for preparation of single PEDOT:PSS layer.

3. Results and Discussion

Figure 2(a) presents the current density-voltage characteristics measured from bulk heterostructure polymer solar cells prepared as a function of PEDOT:PSS thickness. All devices evidently show the photovoltaic characteristic suggesting that the minimum thickness obtained in this experiment is thick enough to avoid the short contact between two electrodes. In order to acquire more information, the photovoltaic parameters, e.g. short circuit current density (J_{sc}), open circuit voltage (V_{oc}), fill factor (FF) as well as calculated power conversion efficiency (PCE) were extracted from the J-V characteristic and separately presented in figure 2(b) and table 1. The results indicate that the solar cells prepared as the thicker PEDOT:PSS layer (higher translational speed) tend to provide higher PCE. All the factors that related to the PCE are increased with the increasing PEDOT:PSS thickness. Since, the electron donor/acceptor were similar in all the preparation conditions, V_{oc} of the devices exhibit the insignificantly change from 0.84 to 0.88 V. In addition, the increments of J_{sc} from 11.05 to 11.98 mA/cm^2 and FF from 34.48 to 38.25 observed in the higher deposition speed of PEDOT:PSS layer are attributed to the better in both film formation and charge transportation taken place in the thicker PEDOT:PSS film.[3] Therefore, it can be concluded that the increase of PEDOT:PSS thickness is a key to improve the solar cell efficiency. Although deposition speed of rapid convective deposition can control film thickness, this technique still has limitation of maximum thickness that can be obtained. To overcome this limitation, double layer deposition was applied to prepare thicker layer of PEDOT:PSS leading to the enhancement solar cell performance.

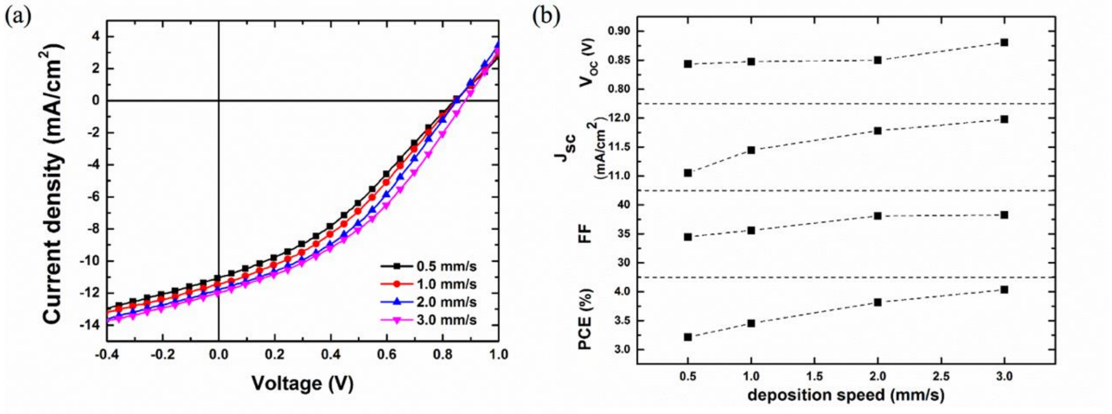

Figure 2. (a) Current density (J) – voltage (V) characteristics of polymer bulk heterostruture solar cells and (b) photovoltaic parameters extracted from the J-V curves prepared as different translational speed of PEDOT:PSS layer.

Table 1. Photovoltaic parameters extracted from solar cells prepared by different deposition speed of PEDOT:PSS layer.

deposition speed (mm/s)	J_{sc} (mA/cm^2)	V_{oc} (V)	FF	PCE (%)
0.5	11.05	0.84	34.48	3.21
1.0	11.45	0.85	35.60	3.45
2.0	11.78	0.85	38.11	3.82
3.0 (single layer)	11.98	0.88	38.25	4.03
3.0 (double layer)	14.54	0.91	46.37	6.12

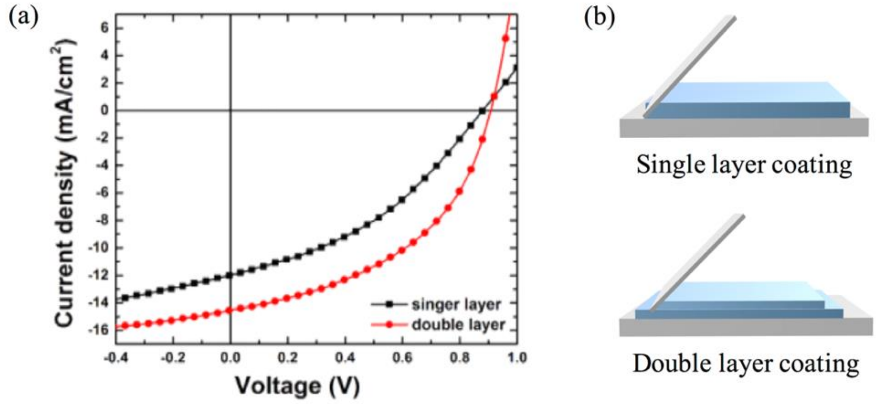

Figure 3. (a) Comparison of J-V characteristics of polymer solar cells obtained from single PEDOT:PSS layer coating (black square) and double PEDOT:PSS layer coating (red circle) and (b) the schematic representation of single layer and double layer coating.

Figure 3(a) shows the comparison of J-V characteristics between solar cells obtained from single layer coating and double layer coating of PEDOT:PSS layer (see figure 3(b)). The results show that, by applying double layer deposition, the PCE was dramatically enhanced from 4.03 to 6.12%. The improvement of PCE is a consequence of the increment of both J_{sc} and FF as clearly shown in table 1. It is possible to assume that the enhancements of J_{sc} and FF result from the improvement of charge transportation as well as the reduction of roughness at the interface of active layer/hole transporting layer that are obtained from the thick PEDOT:PSS layer.[4] These results suggest that double layer deposition is an alternative approach to enhance solar cell performance.

4. Conclusion

Polymer solar cells prepared as the multilayers of ITO/PEDOT:PSS/PCDTBT:$PC_{70}BM/TiO_x$/Al by rapid convective deposition were used to determine the optimum preparation condition for PEDOT:PSS layer. The preparation condition that tends to increase the PEDOT:PSS thickness provides the high PCE due to the better film formation and hole transportation generally observed in thick film. To improve the efficiency and overcome the thickness limitation of preparation method, Double layer coating technique was employed to fabricate the PEDOT:PSS layer. As consequence, the PCE of the polymer solar cells was further enhanced from 4.03 to 6.12%.

Acknowledgements

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