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Property Enhancement of Hole Transport Layer and Transparent Electrode by the Addition of Polar Solvents for Organic Solar Cells

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Abstract

For high performance organic solar cells, a hole transport layer based on PEDOT:PSS layer was fabricated by adding polar solvents, dimethyl sulfoxide (DMSO) and ethylene glycol (EG). The addition of polar solvent resulted in the increase of roughness at the surface and decrease of PSS composition ratio which could improve the solar cell performance. We also discussed the effect of polar solvents on the electrical conductivity of organic transparent electrode.

1. Introduction

Organic solar cells(OSCs) have received significant attention due to the great potential advantages compare to inorganic solar cells [1]. In OSC structure, the conducting polymer of poly(3,4-ethylene-dioxithiophene) (PEDOT) has been considered as a role of hole transport layer (HTL) or electrode [1-3]. Because high conductivity PEDOT shows a high hydrophobic characteristic to be dissolved in any solvent, it need to blend with poly-styrenesulfonate (PSS) which makes possible to be dissolved in water and deposited stably on substrate. But higher ratio of PSS could create film too insulative, resulting in the bad effect on the charge collection [4]. There are several efforts to get both solubility and conductivity of 1:2.5 PEDOT:PSS film for the transparent electrode by adding various polar solvents [1]. However the optimized fabrication process of the 1:6 PEDOT:PSS film as HTL has not studied yet in the thieno[3,4-b]thiophene/benzodithiophene:[6,6]-phenyl C_{71}-butyric acid methyl ester (PTB7:PCBM)-based bulk heterojunction solar cells.

In this study, we used two polar solvents, dimethyl sulfoxide (DMSO) and ethylene glycol (EG) to fabricate high performance 1:6 PEDOT:PSS films as HTL in the PTB7:PCBM-based device. And the effects of additive polar solvents are systemically analyzed by the observation of surface morphology, chemical composition, and conductivity. In addition, the modified 1:2.5 PEDOT:PSS films which generally used as a transparent electrode were also fabricated as a function of additive ratio of polar solvent. Finally, we discussed the optimum fabrication process of PEDOT:PSS film for both HTL and electrode.

2. Experimental procedure

A commercial solution of PEDOT:PSS was used with two different weight ratio of 1:6 for HTL and 1:2.5 for transparent electrode. Various concentration of the DMSO and EG were added to PEDOT:PSS(1:6) solution with volume ratio of 10% DMSO, 17% DMSO, 7% EG, and 17% EG and co-solvent (10% DMSO and 7% EG). A blend of PTB7:PCBM solution was dissolved in dichlorobenzene with 3% DIO and then spin-coated as a photoactive layer. The conductivity of PEDOT:PSS(1:2.5) films was measured using a four-point van der Pauw method. Atomic force microscopy (AFM) and X-ray photoelectron spectroscopy (XPS) were performed to analysis the morphological and compositional changes at surface.

3. Results and Discussions

In general, both DMSO and EG are widely known as a kind of catalysts for separating the PEDOT and PSS [5]. Because well-separated domains could help the charge transport performance of conductive polymer [6], we observed the surface morphology change according to the concentration of additive polar solvents. As shown in Fig. 1(a-c), the surface morphology of PEDOT:PSS was significantly changed with the increased root mean square (rms) roughness from 0.476 to 1.347 as a function of DMSO ratio. This morphological change is helpful for the charge carrier collection, because the rough interface resulted in the increased area for the electrical contact. EG and co-solvent (DMSO:EG) also influenced the surface morphology, but relatively less change was observed as shown in Fig (d-f).

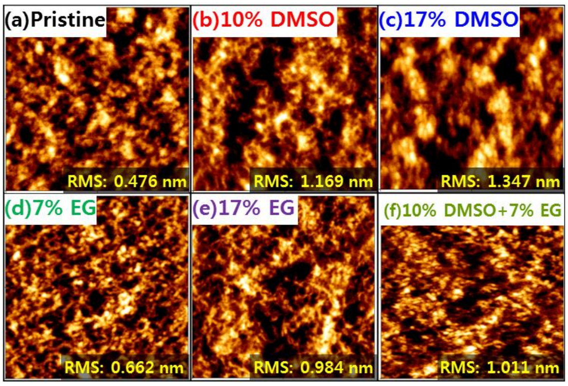

Fig.1. AFM height image of PEDOT:PSS films as (a) pristine, and modified with (b)10% DMSO, (c) 17% DMSO, (d)7% EG, (e)17% EG, and (f)10% DMSO and 7% EG

On the other hand, PSS composition ratio at the interface between PEDOT:PSS and PTB7:PCBM is also known as one of important factors for the efficient hole collection, because PSS shows strong electrical insulation which could interrupt the hole transportation from PTB7 to PEDOT domains. The PSS/PEDOT composition ratio for the pristine and modified films was measured by XPS analysis. As shown in Fig. 2, the pristine film shows the PSS ratio of almost 8, even though the weight ratio is only 1:6. In cases of 10% DMSO, 17% DMSO and co-solvent, the PSS ratio slightly decreases to 6.75, 7.0, and 7.55 respectively. Especially, in the case of 7% EG the PSS ratio was reduced to 5.5. From these results, we believe that DMSO and EG are helpful to enhance efficient hole collection with different mechanisms, such as the fact that DMSO results in larger domains and rough interface while EG plays a role to decrease PSS composition ratio at the surface.

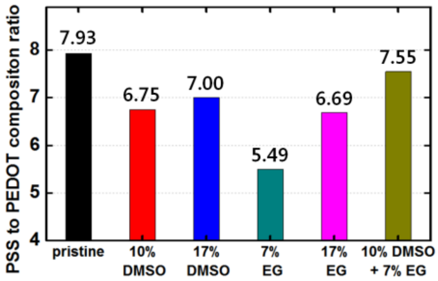

Fig. 2. The composition ratio of PSS to PEDOT for each modified film at the surface of layer.

J-V characteristics of OSCs were measured as shown in Fig. 3. As shown in the inserted Table, the short circuit current (Jsc) is a most affected factor in this solar cell performance. In cases of 10% DMSO and 17% DMSO, the Jsc increased from 11.92 mA/cm^2 to 14.04 mA/cm^2 and 14.95 mA/cm^2, respectively. However, in cases of 7% EG, 17% EG and co-solvent, the enhancement of Jsc is relatively small compared to the cases of DMSO addition. Because this trend of Jsc enhancement agreed well with the measurement results of rms roughness, we believe that the rough interface mainly improved the electrical contact for the better charge collection. On the other hand, the fill factor (FF) also slightly affected by the modified PEDOT:PSS films. Though the FF value increased from 52.89% to 54.32% by the addition of 7% EG, this change of FF makes comparatively less influence on the power conversion efficiency (PCE) compared to the Jsc change. Moreover, the case of 17% DMSO shows the decrease of FF to 48.8%. Thus we considered that the modified PEDOT:PSS film with 10% DMSO results in the most effective HTL with the highest PCE of 5.48%.

In addition, the 1:2.5 PEDOT:PSS film was modified by adding the DMSO and EG, and the electrical conductivity changes were measured as a key factor for high performance electrode. As shown in Fig. 4, the conductivity of the modified films showed the extremely increased values, especially the conductivity from 0.72 S/cm to 1100 S/cm and 341 S/cm for the 5% DMSO and 5% EG addition, respectively. Tough the solar cells fabricated with these modified transparent electrode have not fully analyzed yet, we can include the morphological changes and the solar cell performance in detail at the SSDM conference.

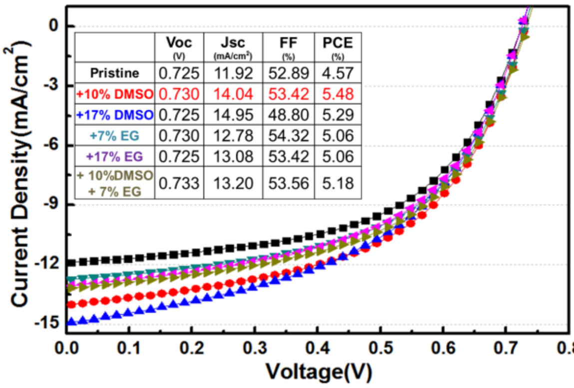

Fig. 3. The J-V characteristics of OSC devices made with PEDOT:PSS treated by various concentrations of solvent.

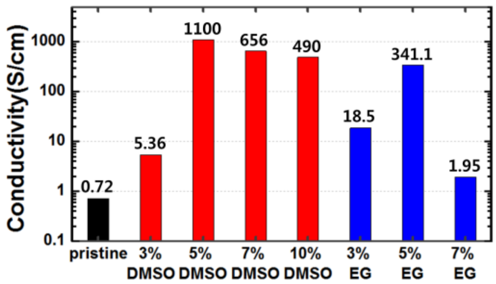

Fig. 4. The electrical conductivity of pristine and modified 1:2.5 PEDOT:PSS films as a function of additive solvent ratio.

4. Conclusions

The modification process for the high performance PEDOT:PSS was developed by adding two polar solvents, DMSO and EG. We observed that the roughness and PSS composition at the surface of PEDOT:PSS(1:6) films are strongly related to Jsc and FF, and a film modified by 10% DMSO resulted in the increased PCE from 4.57% to 5.48%. In addition, PEDOT:PSS(1:2.5) films as a transparent electrode were modified and characterized according to various additive ratio of polar solvent. From the results, we understood that DMSO is more effective than EG for increasing the conductivity, and confirmed that 5% DMSO could be the optimum concentration for high performance electrode.

Acknowledgements

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