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1,3,5-tri(phenyl-2-benzimidazole)-benzene Cathode Buffer Layer Effects on Solution-Processable Organic Solar Cell Based on 1,4,8,11,15,18,22,25-Octahexylphthalocyanine

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Abstract

We report systematic comparison studies of the insertion effects of a cathode buffer layer bulk hetero-junction organic solar cell based on 1,4,8,11,15,18,22,25-octahexylphthalocyanine ($C6PcH_2$) and 1-(3-methoxy-carbonyl)-propyl-1-1-phenyl-(6,6)C61 (PCBM) by using 1,3,5-tri(phenyl-2-benzimidazole)-benzene (TPBi) as a cathode buffer layer material, the external quantum efficiency and the short-circuit current markedly increased, resulting in the enhancement of the power conversion efficiency. The solar cell performances are discussed from the atomic force microscopy, photoelectron yield spectroscopy and X-ray photoelectron spectroscopy measurements.

1. Introduction

A discotic liquid crystalline phthalocyanine derivative, 1,4,8,11,15,18,22,25-octahexylphthalocyanine ($C6PcH_2$) appears as a highly suitable material for the development of small molecule/fullerene bulk hetero-junction (BHJ) organic solar cell (OSC) [1,2]. The charge transport properties in OSC can be enhanced in low weight molecule systems by post-anealing treatment as polymer-fullerene systems [3]. However, due to the temperature sensitivity of $C6PcH_2$ crystallite [3], the transport and collection of charges carrier can be affected by defect states induced during aluminum (Al) cathode deposition. In OSC, the improvement of the device performance is highly dependent on the top contact electrode (cathode) material, and lots of studies have been reported on this subject [4]. Benefic electrical or optical effects and diffusion barrier against the deposited Al are suggested to justify the improved solar cell after the buffer insertion [5,6]. In particular, buffer layer with high mobility, high transparency, stability against thermal deposition damage of Al, and a wide band gap to avoid exciton decay are suitable to improve transport and collection of charge carrier at the interface of OSC [5-7].

In this study, we reported on systematic studies of the BHJ OSC based on $C6PcH_2$ and 1-(3-methoxy-carbonyl)-propyl-1-1-phenyl-(6,6)C61 (PCBM) with 1,3,5-tri(phenyl-2-benzimidazole)-benzene (TPBi) buffer layer. The buffer layer of TPBi was investigated by using atomic force microscopy (AFM), photoelectron yield spectroscopy (PYS) and X-ray photoelectron spectroscopy (XPS), and the reason for the improved photovoltaic properties was discussed.

2. Experimental

The configuration of solar cells is ITO/MoO_3/$C6PcH_2$:PCBM/TPBi/Al. The $C6PcH_2$:PCBM film was spin-coated using toluene as a solvent in a glove box filled with nitrogen gas. The $C6PcH_2$ was used as a donor material and PCBM as an acceptor material.

The films were placed in multi-source thermal evaporation vacuum chamber. The deposition rate of TPBi was 0.3 Å/s under a pressure of 10^{-4} Pa. To form a cathode, 80-nm-thick Al was evaporated under a pressure of 10^{-4} Pa at a rate of 5.0 Å/s. Then, the device performance of the photovoltaic cells was measured in vacuum.

The ionization potential of the TPBi layer on ITO glass substrate was measured by using a PYS (Sumitomo Heavy Industries) with a deuterium lamp for light excitation. The surface morphology of the TPBi layer was investigated using tapping-mode AFM (Keyence-VN-8000). The Al diffusion depth was examined by using a ESCA 850 (Shimadzu) XPS systems.

3. Results and Discussion

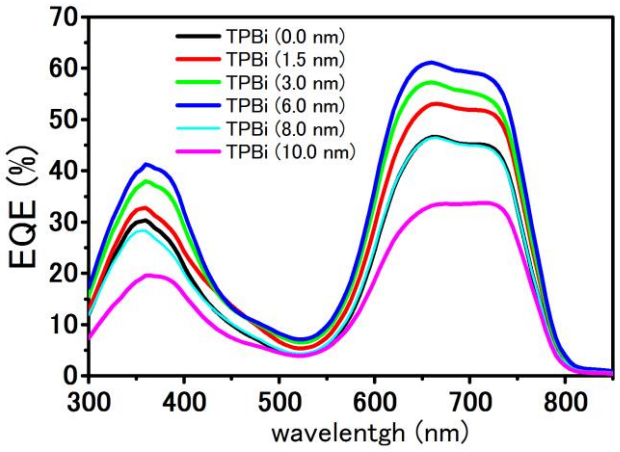

Fig. 1 EQE spectra of organic solar cells as a function of the TPBi thickness.

The insertion of TPBi buffer layer improved the cell performances as shown in Fig.1. Particularly, the external quantum efficiency (EQE) increased from 30% to 41% around 350 nm and from 48% to 62% around 650 nm,

which correspond to B-band and Q-band of $C6PcH_2$ respectively. In the case of TPBi layer with a thickness exceeding 6 nm, the EQE monotonically decreased.

Due to photocurrent enhancement and suppressed series resistance, the short-circuit current (Jsc) was improved from 6 to 8.4 mA/cm^2. As a consequence, the power conversion efficiency (PCE) increased from 2.1% to 3.4 % in OSC with 6-nm-thick TPBi layer, as shown in Fig.2.

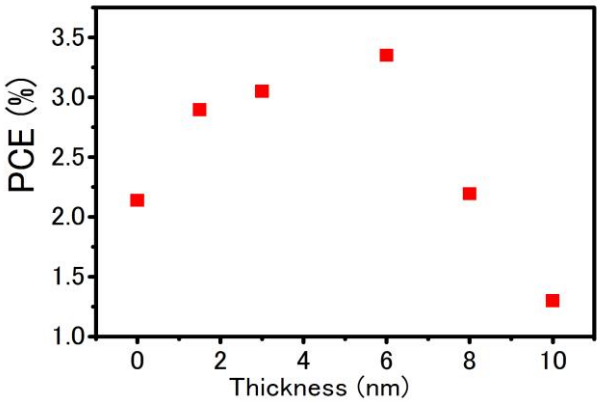

Fig. 2 TPBi buffer layer thickness dependences of PCE.

Hence, in order to clarify the effect of TPBi on the active layer, the highest occupied molecular orbital (HOMO) energy level and the surface morphology of TPBi layer were analyzed by PYS and AFM.

The TPBi HOMO level was estimated to be 6.7eV except for the TPBi film thinner than 3 nm, therefore we deduced that the exciton blocking effect appears around 3 nm of TPBi layer thickness. Furthermore, concerning the morphology, it is found that the roughness of the active layer surface significantly decreased as the TPBi thickness increased. It is considered, therefore, that the formation of an efficient blocking layer were strongly correlated to a reduce of the series resistance [8], as consequence a considerable enhancement of Jsc with an increase of the fill factor from 44% to 50% were achieved.

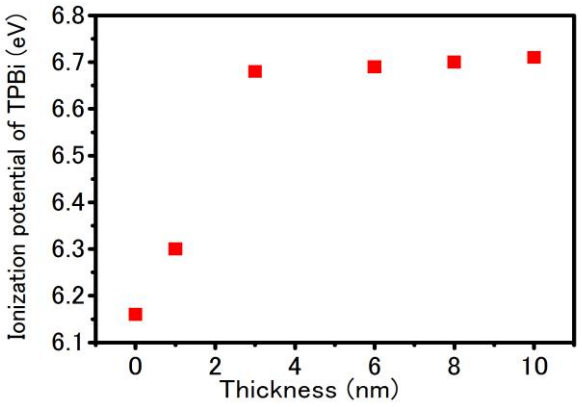

Fig. 3 Ionization potential of TPBi as a function of the TPBi thickness.

Whereas, in the case of the thicker layer than 6 nm of TPBi, the series resistance considerably increased, because of a higher bulk resistance, which ultimately leaded to the decrease of Jsc, FF and PCE [9].

Concerning the Al diffusion barrier, the composition depth profiles of the chemical states were investigated across TPBi/Al inter-layer structure by XPS measurement. The TPBi thickness varied from 3 to 10 nm and the Al layer was fixed to 10 nm. It is clarified that a 6 nm-thick TPBi layer was needed to avoid drastically the thermal damage of the Al particle depth penetration on the active layer top surface.

4. Conclusions

The effects of TPBi as a top cathode buffer layer on the BHJ $C6PcH_2$-PCBM was investigated. The external quantum efficiency has been improved to be 62% at Q-band, and the power conversion efficiency of 3.4% was achieved with 6-nm-thick TPBi layer. The photovoltaic parameters were also enhanced successfully due to the improved interface contact, which was discussed by taking the optical and morphological investigation into consideration.

Acknowledgements

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References

[1] Y. Miyake, Y. Shiraiwa, K. Okada, H. Monobe, T. Hori, N. Yamasaki, H. Yoshida, M.J. Cook, A. Fujii, M. Ozaki and Y. Shimizu, Appl. Phys. Express **4** (2011) 02160450.

[2] Q.D. Dao, T. Hori, K. Fukumura, T. Masuda, T. Kamikado, A. Fujii, Y. Shimizu, M. Ozaki, Organic Electronics **14** (2013) 2628-2634.

[3] M. Ohmori, H. Fukui, Q.D. Dao, T. Kumada, A. Fujii, Y. Shimizu and M. Ozaki, Jpn. J. Appl. Phys. **53** (2014) 05FZ02.

[4] P. Peumans, V. Bulović and S. R. Forres, Appl. Phys. Lett. **76**, (2000) 2650.

[5] H. Hänsel, H. Zettl, G. Krausch, R. Kisselev, M. Thelakkat and H.-W. Schmidt, Adv. Mater. **15** (2003) 2056.

[6] H. Gommans, B. Verreet, B.P. Rand, R. Muller, J. Poortmans, P. Heremans and J. Genoe, Adv. Mater. **18** (2008) 3686.

[7] T. Yanagidate, S. Fujii, M. Ohzeki, Y. Yanagi, Y. Arai, T. Okukawa, A. Yoshida, H. Kataura and Y. Nishioka, Jpn. J. Appl. Phys. **53** (2014) 02BE05P.

[8] J. Yu, N. Wang, Y. Zang, Y. Jiang, Sol. Energy Mater. Sol. Cells **95** (2011) 664-668.

[9] V. Tripathi, D. Datta, G.S. Samal, A. Awasthi, S. Kumar, J. Non-Cryst. Solids **19** (2008) 354.