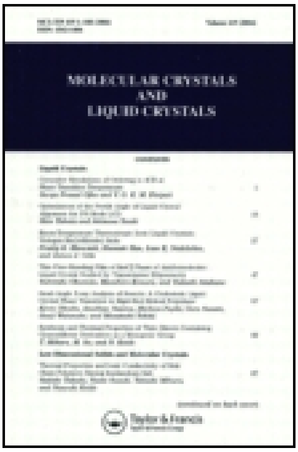

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Performance Characteristics of Organic Photovoltaic Cells using Pentacene as a Hole Conducting Layer Material

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The performance characteristics of organic photovoltaic cells using pentacene as a hole conducting material have been investigated. Pentacene has been extensively studied as a p-type semiconductor in organic field-effect transistors. In this study, pentacene was incorporated into PEDOT:PSS Film to improve mobility in the hole conducting layer. Organic photovoltaic cells have been fabricated with the structure of ITO/poly(3,4-ethylenedioxythiophene)-poly(styrenesulfonate)(PEDOT:PSS)-pentacene/CuPc/CuPc:C_{60}/C_{60}/BCP(bathocuproine)/Al. The power conversion efficiency was strongly dependent on the doping amount of pentacene in the PEDOT:PSS-pentacene films. Fabrication parameters also affected on the performance of pentacene-based photovoltaic cells.

Keywords pentacene; organic photovoltaic cell; hole conducting layer; doping; hole transport layer; deposition distance

Introduction

Organic photovoltaic cells which have attractive properties such as low cost of fabrication, light weight and easy processing have been extensively studied as a next generation renewable energy [1–3]. In the last decade, the performance of organic photovoltaic cells has been steadily enhanced but the power conversion efficiency of organic photovoltaic cells is still limitation due to the relatively short exciton diffusion lengths of a hole transport layer and low charge carrier mobility between active layer and electrode in the device [4–6].

Pentacene is an identified material as a p-type semiconductor in organic field-effect transistors because of the advantages offered by pentacene such as a high mobility and good semiconducting behavior [7–9]. Various researchers reported on organic photovoltaic applications of pentacene as a dopant into a hole transport layer [10], an interlayer for polymer bulk-heterojunction photovoltaic cells [11], and a donor material for p-n junction photovoltaic cells [12–17] because of a high mobility, long exciton diffusion length and well suited absorption spectrum in the solar spectrum [18–21]. Moreover, it was

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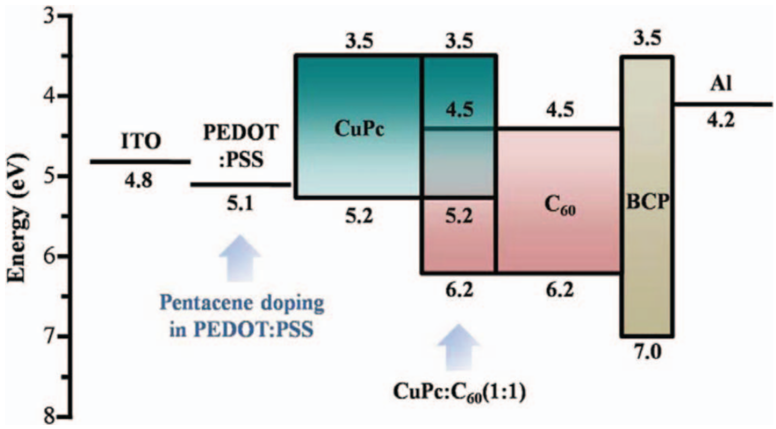


Figure 1. Energy level diagrams of the devices with a PEDOT:PSS-pentacene.

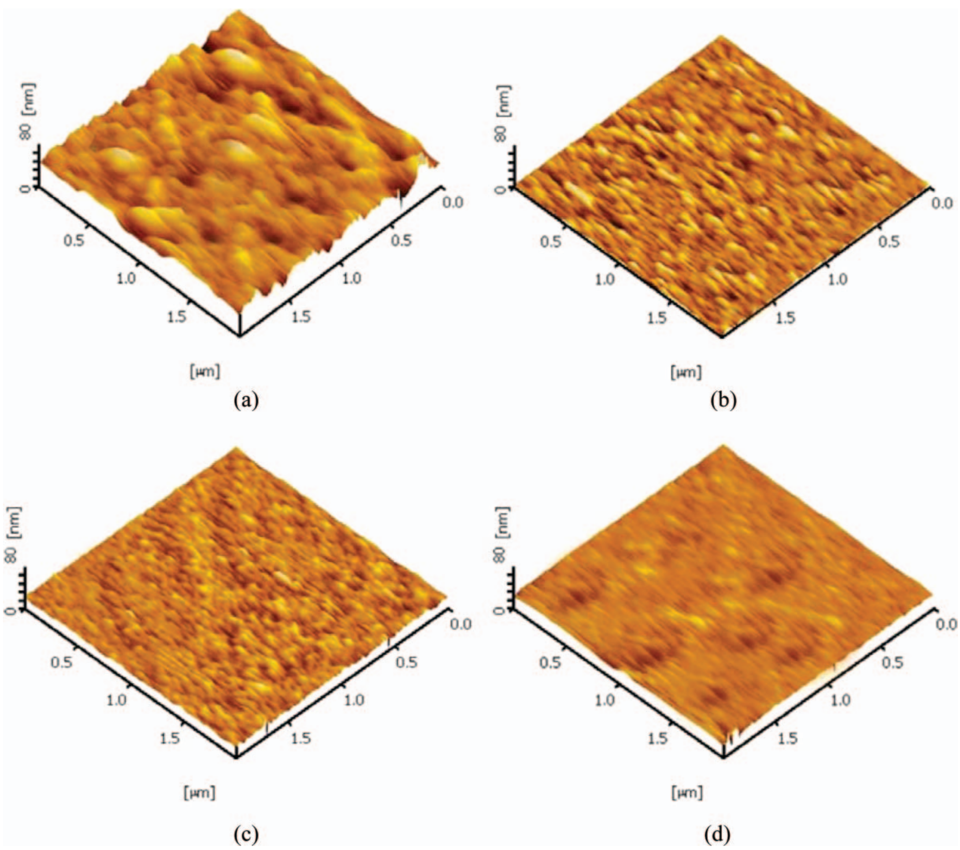


Figure 2. AFM images (2 μm × 2 μm) of CuPc:C_{60} thin films deposited at the distance of (a) 15 cm, (b) 17 cm, (c) 19 cm, and (d) 21 cm.

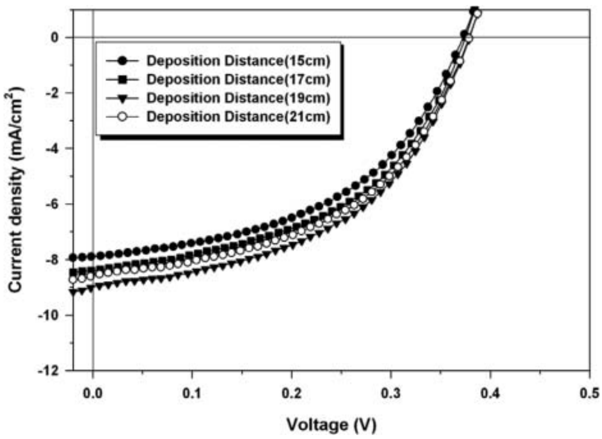
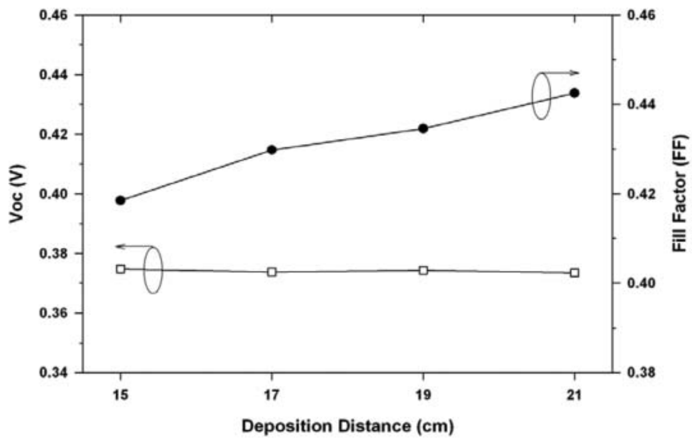
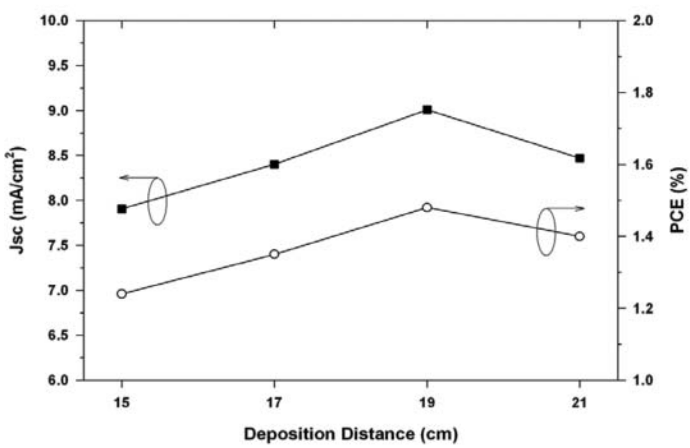


Figure 3. J-V characteristics of pentacene-based photovoltaic cells fabricated by adjusting deposition distance.



(a)



(b)

Figure 4. Photovoltaic response of pentacene-based photovoltaic cells fabricated by adjsting deposition distance.

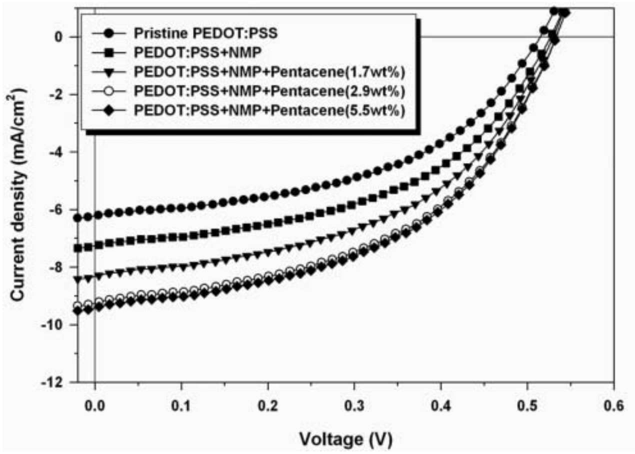


Figure 5. J-V characteristics of organic photovoltaic cells with aPEDOT:PSS-pentacene layer.

reported that the performance of polymer schottky diode was improved by poly(3,4-ethylenedioxythiophene):poly(styrene sulfonate)(PEDOT:PSS)-pentacenelayer [22,23].

In this work, the performance characteristics of organic photovoltaic cells using pentacene as a hole conducting layer have been investigated. We have focused on the dependency of the power conversion efficiency on the concentrations of pentacene in the PEDOT:PSS-pentacene for a hole conducting with the structure of ITO/PEDOT:PSS-pentacene/CuPc/CuPc:C_{60}/C_{60}/BCP/Al.

Experimental

Twice sublimed pentacene (formula: $C_{22}H_{14}$, molecular weight: 278.35 g/mol, melting point: 372–374°, purity 99.99%) was purchased from Sigma-Aldrich. It was used as received, without further purification. Pentacene was used as a dopant in PEDOT:PSS solution (Baytron P from H. C. StarckGmbH) with N-methylpyrrolidone(NMP) solvent to make a hole conducting layer and was incorporated as a hole transport layer into organic photovoltaic cells.

Various amounts of pentacene such as 0.7, 1.2, and 2.3 mg were dissolved in 3.2 g NMP solvent. The prepared pentacene solutions were mixed with 3.2 g of PEDOT:PSS solution(1.3 wt%) to become 1.7, 2.9, and 5.5 wt% and then PEDOT:PSS or PEDOT:PSS-pentacene solution were filtered using a 0.45 μm Millipore polytetrafluoroethylene (PTFE) syringe filter. The solution were spin-coated on pre-patterned ITO (15 Ω/sq) surface and dried for 6 h at 80°. PEDOT:PSS or PEDOT:PSS-pentacene thin films were controlled to be 40 nm.

The energy level diagrams of organic photovoltaic cells with pentacene as a dopant and a hole transport material are shown in Fig. 1. To produce the device injected PEDOT:PSS-pentacene thin film as a hole conducting layer, copper phthalocyanine (CuPc, formula: $C_{32}H_{16}CuN_8$, molecular weight: 576.78 g/mol, melting point: >360°, Tg: 240°, Tokyo Kasei Kogyo Co. Ltd.) and C_{60} (C_{60}, molecular weight: 720.64 g/mol, melting point: >280°, Tg: 174°, Sigma Aldrich, 99.5%) were used as a hole transport and an electron transport material, respectively. As hole/exciton blocking layer material, bathocuproine

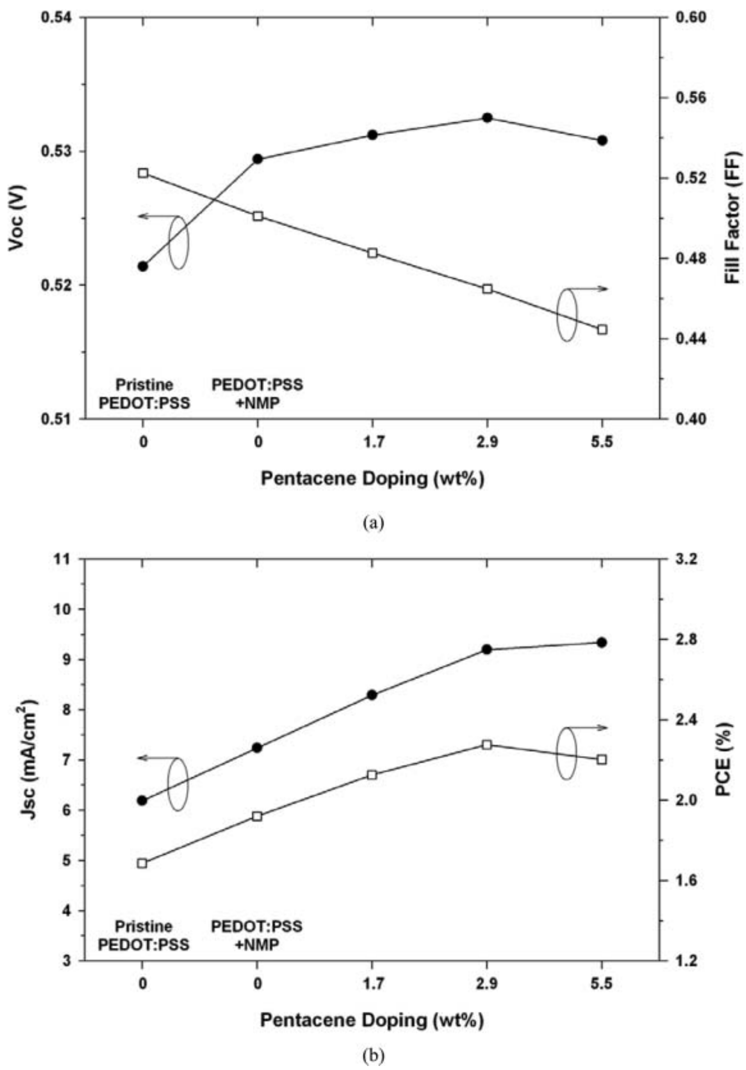


Figure 6. Photovoltaic response of the devices with a PEDOT:PSS-pentacene layer.

(BCP, formula: $C_{26}H_{20}N_2$, molecular weight: 360.46 g/mol, melting point: 277–285°, Acros Organics) was used. 13 nm CuPc layer, 10 nm CuPc:C_{60} (1:1) layer, 35 nm C_{60}, and 8 nm BCP layer were sequentially deposited onto the PEDOT:PSS-pentacene thin film, followed by a 100 nm thick Al cathode, which was evaporated through a shadow mask.

The J-V characteristics and power conversion efficiencies were measured using Keithley 2400 multi-sourcemeter unit and a solar simulator(XES 301S, SAN-EL Electronics). The Xenon lamp (100 mW/cm^2) was used as a light source and light intensity has been measured by a silicon photo-diode calibrated for an AM 1.5 spectrum.

Result and Discussion

The J-V characteristics and photovoltaic responses of ITO/PEDOT:PSS-pentacene(40 nm)/CuPc(13 nm)/CuPc:C_{60}(10 nm)/C_{60}(35 nm)/BCP(8 nm)/Al(100 nm) photovoltaic cells have been measured. As the device employs PEDOT:PSS thin film processed with NMP solvent without pentacene, the performance characteristics of the device were improved. It has been reported that NMP solvent in PEDOT:PSS solution leads to enhancement of the power conversion efficiency in the device with increased an open-circuit voltage (V_{oc}) and a short-circuit current density (J_{sc}) [24]. By the effect of NMP solvent in PEDOT:PSS thin film, the performance characteristics of the device were achieved, showing that $J_{sc} = 7.24$ mA/cm^2, a fill factor (FF) $= 0.50$, $V_{oc} = 0.53$ V, and a PCE of 1.92%. In general, deposition parameters such as distance, rate, and substrate temperature crucially affected on the morphology, crystallinity of thin films, and performance characteristics of devices [25]. We could clearly observe the dependency of the morphology of CuPc:C_{60} thin films with various deposition distances in Fig. 2. As the deposition distance of CuPc:C_{60} increased, FF values increased by smooth morphology. Additionally, J_{sc} values increased due to improved FF values. Higher performance characteristics of the photovoltaic cells were obtained at 19 cm of deposition distance, showing that a $J_{sc} = 9.01$ mA/cm^2, FF $= 0.43$, $V_{oc} = 0.37$ V, and a PCE of 1.48%, as shown in Figs 3 and 4.

When the concentration of pentacene in PEDOT:PSS thin film increased, enhanced V_{oc} and J_{sc} values lead to improvement of the power conversion efficiency in the device. But FF value decreased because of poor morphologies induced by NMP solvent and pentacene [22,23]. Higher performance characteristics of the device were achieved at 2.9 wt% of pentacene doping, showing that $J_{sc} = 9.20$ mA/cm^2, FF $= 0.46$, $V_{oc} = 0.53$ V, and a PCE of 2.28%, as shown in Figs 5 and 6.

Conclusions

Organic photovoltaic cells using pentacene as a hole conducting layer have been demonstrated with the structure of ITO/PEDOT:PSS-pentacene/CuPc/CuPc:C_{60}/C_{60}/BCP/Al. For the photovoltaic cells with a PEDOT:PSS-pentacene layer, the power conversion efficiency was significantly affected by NMP solvent and the doping amount of pentacene. Since NMP solvent could be considered as a processing agent and pentacene as a mobility promotor. By incorporating NMP and pentacene into hole conducting layer during fabrication process, current density was increased due to enhanced hole mobility, leading to improved power conversion efficiency in this study.

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