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Efficiency Improvement of Organic Solar Cells by Hot-Pressing

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1. Introduction

Poly(3-hexylthiophene) (P3HT) and 1-(3-methoxycarbonyl)-propyl-1-phenyl-(6,6)C61 (PCBM)-based bulk heterostructure has been one of the most studied organic photovoltaics (OPVs). Various methods have been proposed to improve the cell efficiency. Efficiencies up to ~4-5% have been demonstrated [1-4]. Among these successful approaches, post-annealing of such a bulk heterosturcture plays an important role that increases the crystallinity of the polymer and reduces the interface area, promoting the dissociation of the excitons and enhancing carrier transport behavior. Besides, nanoimprinting has been proven to improve the PCE and incident photon-to-electron efficiency (IPCE) of organic-based photovoltaic devices. [5-6] Previously, we reported that the imprinting pressure under room temperature contributes to the charge mobility and the PCE. [7] In this paper, an attempt was made to combine the advantages of both the heat-treatment and imprinting to improve the OPVs. The process was called hot-pressing. By systematically tuning the pressure of the hot-pressing, the power conversion efficiency (PCE) significantly increased by ~10% when a 0.3 MPa pressure was used. The mechanism related to the PCE enhancement was attributed to the enhanced organic/metal contact properties.

2. Experimental details

Solar cell devices were fabricated on indium-tin oxide (ITO) glass each with an area of $1\times2\ \mathrm{cm}^2$. Each piece of glass has six cells. The size of a cell ($0.4\times0.3\ \mathrm{cm}^2$) was defined by the area of overlap between the strip cathode (Al) and the anode (ITO). The purified poly(3,4-ethylenedioxythiophene): poly(styrenesulfonate) (PEDOT:PSS) (Baytron P, HC Stark) was spin-coated (5000 rpm) on the patterned ITO, with a thickness of 30 nm, from aqueous solution. The 1:0.8 P3HT:PCBM (w/w) solution was prepared in chlorobenzene, and subsequently spin-coated at 2000 rpm on the top of the PEDOT:PSS layer. After the Al cathode was coated, the sample was hot-impressed at 160 $^{\circ}$C. The pressing pressures applied to the samples were kept at 0.1, 0.2, 0.3, 0.4 and 0.5 MPa for 1 min.

3. Discussions

Figure 1 shows the schematic of the hot-pressing process, in which a plain Si wafer was used as a stamp. Figures 2(a)-(d) show the open-circuit voltage (V_{oc}),

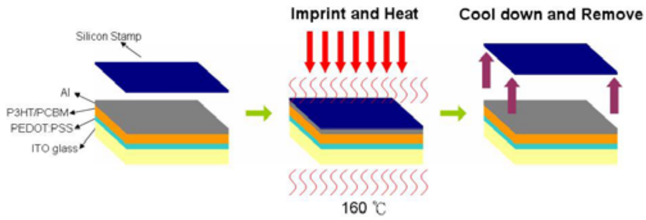
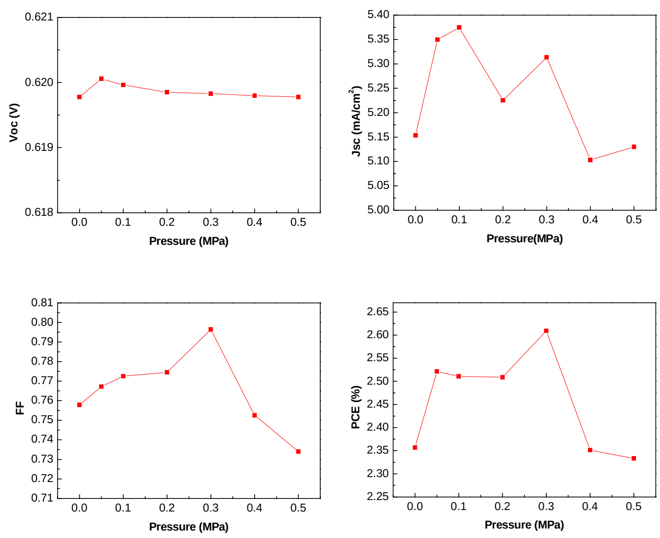


Fig. 1 Schematic of the hot-pressing process of the organic solar cells

short-circuit current density (Jsc), fill factor (FF) and PCE as functions of hot-pressing pressure. The device performance was optimized at an imprinting pressure of 0.3 MPa. Hot-impressing significantly increased the short-circuit current density (Jsc) and the fill factor (FF), increasing the power conversion efficiency (PCE) by ~10% when a 0.3 MPa impressing pressure was used. The FF contributed most to the cell efficiency.



Incident photon-to-current efficiency (IPCE) spectra were measured for samples with and without hot-pressing and were shown in Fig. 3. Device with hot-pressing showed higher quantum efficiency than that without hot-pressing in the vicinity of 400-500 nm, revealing that the hot-pressing could enhance the carrier transport beneath the metal contact rather than enhance the ordering of the bulk heterostructure.

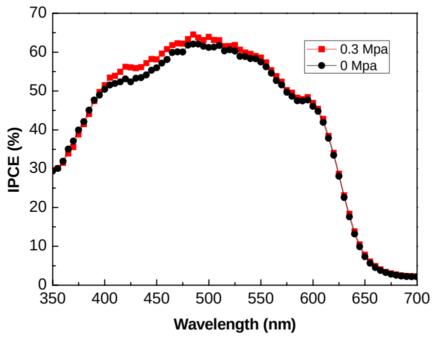


Fig. 3 Incident photon-to-electron efficiency spectra of cells with and without imprinting.

Figure 4 shows the current density-voltage relation for samples with and without hot-pressing. The improvement of PCE came from the J_{sc} mostly, indicating a modified carrier transport behaviors. This result consisted with the IPCE observation.

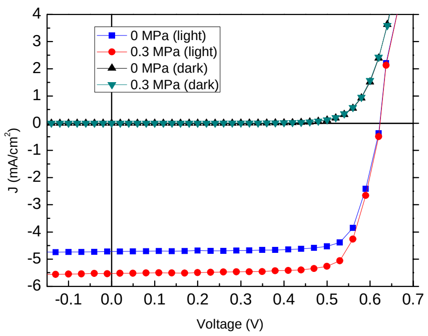


Fig. 4 Dark and light current density-voltage relation for samples with and without hot-impressing.

In order to clarify the mechanism that leads to the efficiency improvement, the electron-only devices were made by replacing the PEDOT:PSS layer with a thin Cs_2CO_3 layer. [9-10] The electron mobility of the active layer were calculated according to the space-charge limited current model (SCLC) by fitting the dark J-C curves, as shown in Fig. 5. From the SCLC model, the current is given by $J = 9\varepsilon_0\varepsilon_r\mu V^2/8L^3$ where $\varepsilon_0\varepsilon_r$ is the permittivity, μ is the mobility, and L is the thickness, the electron mobility of the reference and hot-pressed samples were 7.52×10^{-5} cm^2/ V-s and 18.9×10^{-5} cm^2/ V-s, respectively. An increase of 2.5 times in electron mobility by hot-pressing gives reason to the increase in J_{sc} and conversion efficiency.

4. Conclusion

This work demonstrates the effects of hot-pressing on poly (3-hexylthiophene) and 1- (3-methoxycarbonyl)-propyl-1-phenyl-(6,6)C61 (P3HT:PCBM)-blended organic solar cells. Hot-pressing significantly increased the short-circuit current density (J_{sc}) and the fill factor (FF), increasing the power conversion efficiency (PCE) by ~10% when a 0.3 MPa pressure was used. The FF contributed most to the cell efficiency. The mechanism related to the PCE enhancement was attributed to the enhanced organic/metal contact properties.

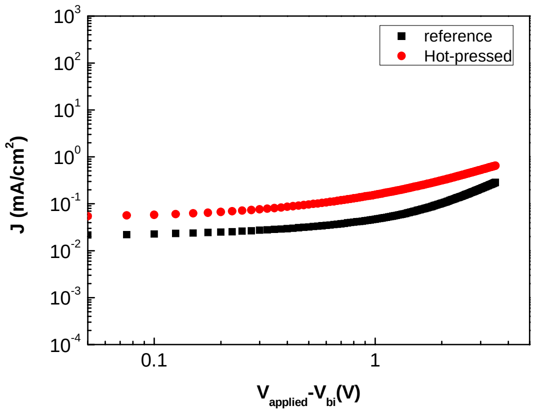


Fig. 5 Dark current of the electron-only devices.

Acknowledgements

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