

ZnO Electron-Collecting Layers Deposited Using Atomic Layer Deposition to Fabricate High-Performing Organic Photovoltaics

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During the past decade, organic photovoltaics (OPVs) have attracted great attention because of their light weight and potential low cost thanks to low-temperature printing techniques on flexible substrates. In spite of their high power conversion efficiency, the traditional bulk-heterojunction (BHJ) architecture has limitations in terms of device stability due to the air-sensitive low-work-function metal cathode, such as Al. Diffusion of oxygen into the active layer through pinholes and grain boundaries in Al cathode causes the degradation of the active layer, leading to device instability in air. One approach to solve this issue is using an inverted structure, where the charge separation and collection nature of the electrode is reversed [1]. In inverted structures, the highly acidic PEDOT:PSS -commonly used as the anode interfacial layer- can be avoided and replaced by a low-work function and stable-in-air metal oxide layer, such as TiO₂ and ZnO, used as the cathode interfacial layer [1].

Herein we report on an efficient inverted bulk-heterojunction based on regioregular of poly(3-hexylthiophene):(6,6)-phenyl C₇₁ butyric acid methyl ester solar cell with a highly uniform ZnO film, deposited using an atomic layer deposition method (ALD), as electron collecting layer and MoO_x as the hole collecting layer. In particular, ZnO was deposited on the indium tin oxide (ITO) anode on glass substrates. Since atomic layer deposition is based on the self limiting nature of layer-by-layer growth, it can produce homogeneous films with thickness control in the sub-nanometer scale. Hence, this technique is suitable for producing films with uniform and precisely controlled thickness [2]. We have also fabricated devices incorporating a solution processed s-ZnO layer, formed with a sol-gel method to serve as references. The zinc oxide layers thickness was kept at ~10 nm in both cases. Both type of ZnO films were highly transparent in the visible spectrum (where they exhibit transmittance values higher than 80%), as shown by the transmittance spectra of these films (Fig 1), and thus, they are appropriate to be used at the cathode side of the inverted device, where the light insertion occurs. Their bulk electronic properties were characterized using x-ray and photoelectron spectroscopy and found nearly similar. Their influence in inverted OPV devices performance was then examined. The device structure and the corresponding energy diagram are shown in Figure 2. Both devices exhibited high efficiency and long-term air stability. The current-density-voltage (J-V) characteristics under AM 1.5G irradiation are shown in Figure 3 and reveal more efficient operation for the device bearing the uniform nanostructured layer (J_{sc}=-10.0 mA/cm², V_{oc}=0.60V, FF=0.50 versus J_{sc}=-6.5 mA/cm², V_{oc}=0.56V, FF=0.35) as it can be seen in Figure 3. Improved photovoltaic cell efficiency in the case of the ALD-ZnO layer seems to be due to more efficient electron collection as reveal from the incident photon-to-electron conversion efficiency, presented in Figure 4. Considering the 3D growth mechanism of both s-ZnO and ALD-ZnO layers, more boundaries between the s-ZnO grains could be formed. These grain boundaries could be detrimental to OPV performance. These grain boundaries have a high local density of oxygen vacancies that could possibly act as efficient recombination centers for electrons and holes in actual OPV devices. We have thus demonstrated the successful implementation of ALD deposited zinc oxides as a promising solution for highly-efficient electron-collection layers in inverted organic photovoltaic cells.

Acknowledgments

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References

- [1] M. Vasilopoulou, A. M. Douvas, D. G. Georgiadou, L. C. Palilis, S. Kennou, L. Sygellou, A. Soutati, I. Kostis, G. Papadimitropoulos, D. Davazoglou, and P. Argitis "The Influence of Hydrogenation and Oxygen Vacancies on Molybdenum Oxides Work Function and Gap States for Application in Organic Optoelectronics", *J. Am. Chem. Soc.*, 134 (39),16178–1618, August 2012.
- [2] S. Esmaili-Sardari, A. Berkovich, and A. A. Iliadis "Observation of conductivity type conversion in undoped ZnO films grown by pulsed laser deposition on silicon (100) substrates", *Appl. Phys. Lett.* 100, 053505, February 2012

Figures

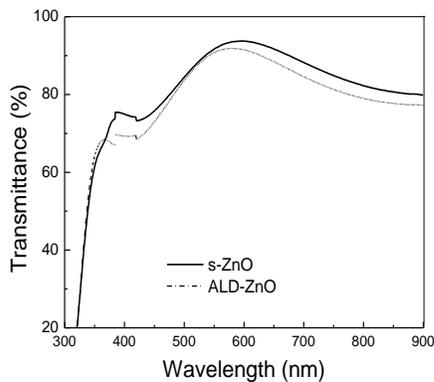


Figure 1: Transmittance spectra of the two different ZnO films.

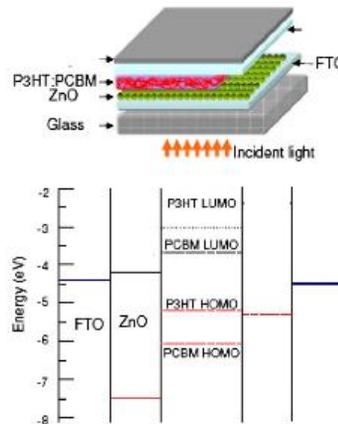


Figure 2: OPV device structure (top) and the corresponding energy diagram (down).

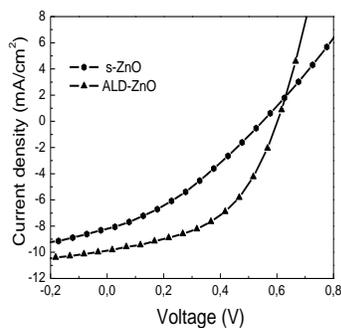


Figure 3: Current density versus voltage characteristics for P3HT:PC₇₁BM devices embedding ZnO electron collecting layers.

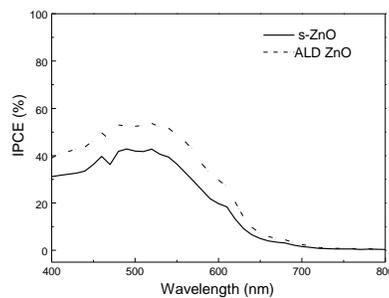


Figure 4: IPCE measurements for P3HT:PC₇₁BM devices embedding different ZnO electron collecting layers.