

## Study of Electron Extraction Layers in Inverted Organic Photovoltaic Cells Using Small Molecules

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### Abstract

Electron extraction layers are used in inverted organic photovoltaic cells to obtain high efficiency, where C60 as an electron acceptor is directly deposited on electron extraction layers. Here we report on the effect of film quality of electron extraction layers for the performance of inverted cells based on small molecules. We obtained an improved power conversion efficiency using smooth ZnO as the electron extraction layer compared with rough TiOx.

### 1. Introduction

There are two kinds of the organic photovoltaic (OPV) cell structures, which are called conventional structure and inverted structure. In conventional structure, p-type organic semiconducting layer such as zinc phthalocyanine (ZnPc) is deposited on indium tin oxide (ITO) substrate. However, n-type organic semiconducting layer such as fullerene (C60) is deposited on ITO substrate in inverted structure. On the other hand, inverted OPV cells have air-stable properties [1]. Unfortunately, the power conversion efficiency (PCE) of inverted OPV cells using small molecules is lower than that of conventional cells [2]. In particular, suitable electron extraction layers for inverted organic solar cells based on small molecules were not fully understood. In this paper, we study to obtain high PCE of inverted OPV cells.

### 2. Experiment

Bare ITO was treated with oxygen plasma for 20min before use. TiOx and ZnO as electron extraction layers were prepared by chemical bath deposition [3] and sol-gel method [4] in air, respectively. Thickness of TiOx and ZnO was 30 and 25 nm, respectively. ZnPc layer was grown in an ultra-high-vacuum evaporation system under a deposition pressure of about  $1 \times 10^{-6}$  Pa. Then, C60, MoO<sub>3</sub> (thickness; 8nm) and Au (100nm) were deposited in conventional vacuum deposition system. Device structure is ITO / electron extraction layer / C60 / ZnPc / MoO<sub>3</sub> / Au as shown in Fig. 1. The cell area was 0.04 cm<sup>2</sup>. The current-density versus voltage (J-V) curve of the cells was measured under dark and simulated AM 1.5G solar illumina-

tion with a Keithley 2401 Digital Source Meter. Incident photon-to-electron conversion efficiency (IPCE) spectra were collected by using a Xe lamp, which was integrated with a computer controlled monochromator. Surface morphology was investigated with an atomic force microscope (AFM, SII) using dynamic mode.

### 3. Results

J-V curves of OPV cells using TiOx or ZnO are shown in Fig. 2. PCE of OPV cell using ZnO was improved up to 0.45 % compared with 0.1 % of OPV cell using TiOx. Especially, fill factor (FF) of the TiOx cell was very small value of 0.23, and large leakage current was observed. However, the defects were somewhat improved for the ZnO cell. We investigated the morphology of both film surfaces of TiOx and ZnO by AFM (see Fig. 3). On the TiOx sur-

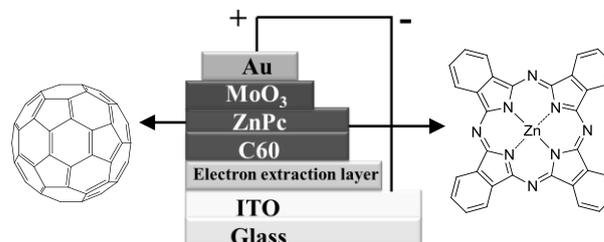


Fig. 1 Diagram of the cell structure and chemical structures of C60 and ZnPc.

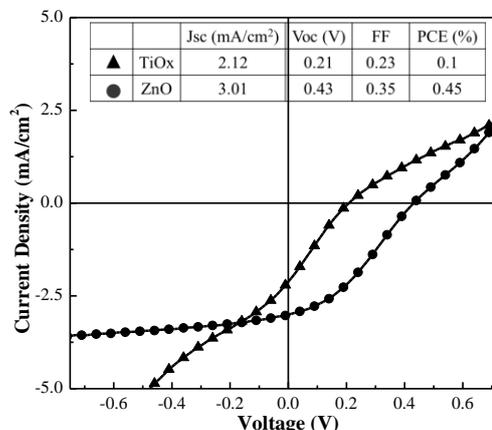


Fig. 2 J-V curves and performance of C60 (thickness; 40 nm) / ZnPc (50 nm) OPV cells.

face, several islands of 200 nm in diameter are observed. On the other hand, we could not observe such islands on ZnO. We deposited the ZnPc/C60 on the TiOx or ZnO surface by evaporation method, directly. Therefore, the surface of the organic layer on the TiOx may be rough as same as the TiOx surface, resulting in low PCE and large leak current.

In order to decrease the leak current of the ZnO cell, we changed the ZnPc thickness from 30 to 70 nm and C60 thickness from 40 to 60 nm, respectively. The J-V curves and the performance are shown in Fig. 4 and Table. 1. When increased the film thickness, the short circuit current ( $J_{sc}$ ) and the series resistance ( $R_s$ ) decreased from 3.41 to 2.95 mA/cm<sup>2</sup> and increased from 10 to 3000  $\Omega$ cm<sup>2</sup>, respectively. On the other hand, the shunt resistance ( $R_{sh}$ ) was gained with increasing the film thickness.

Here we considered the reason of the decrease in  $J_{sc}$  with increase in the film thickness. The IPCE decreased with increasing the film thickness as shown in Fig. 5. The photo-produced excitons in thick organic layer may deactivate easier than those in thin layer. When the film thickness of C60 and ZnPc was 60 nm and 30 nm, respectively, we obtained highest PCE of 0.63 % for the ZnO cell. Therefore, the thickness of n-type and p-type organic semiconducting layers is important to obtain high PCE of OPV cells.

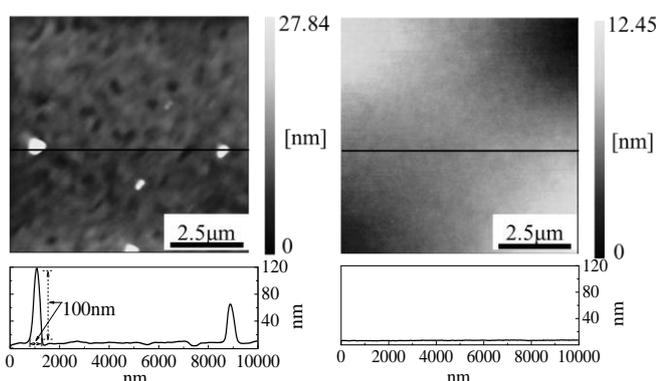


Fig. 3 AFM images of (a)TiOx and (b)ZnO electron extraction layers on ITO.

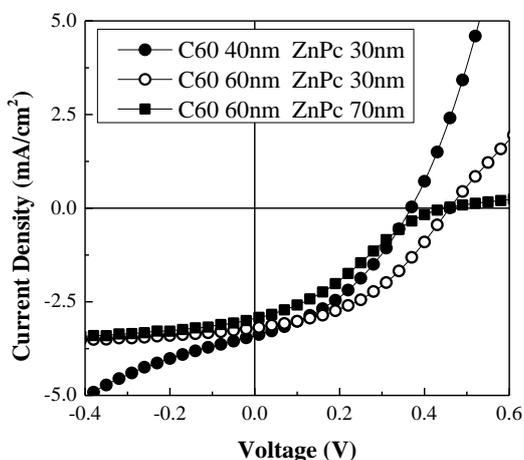


Fig. 4 J-V curves of C60 / ZnPc OPV cells using ZnO.

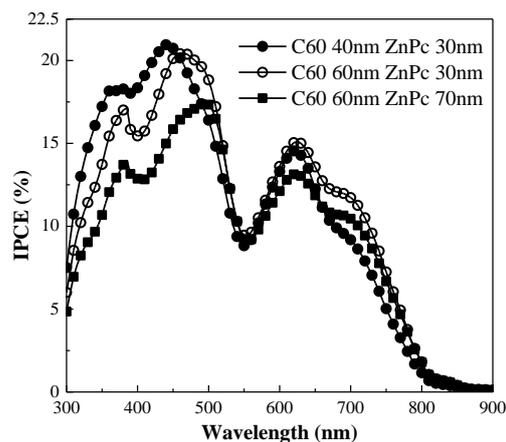


Fig. 5 IPCE spectra of C60 / ZnPc cells using ZnO.

Table. 1 Performance of C60 / ZnPc OPV cells using ZnO.

Mark in Fig. 4 and 5	●	○	■
C60 (nm)	40	60	60
ZnPc (nm)	30	30	70
$J_{sc}$ (mA/cm <sup>2</sup> )	3.41	3.20	2.95
$J_{sc}$ calculated IPCE (mA/cm <sup>2</sup> )	3.23	3.49	3.08
Voc (V)	0.37	0.46	0.45
FF	0.38	0.43	0.29
PCE (%)	0.48	0.63	0.39
$R_s$ (dark) $\Omega$ cm <sup>2</sup>	10	279	3000
$R_{sh}$ (dark) $\Omega$ cm <sup>2</sup>	$2.1 \times 10^3$	$3.6 \times 10^4$	$9.7 \times 10^6$

### 3. Conclusions

We investigated the effect of film quality of electron extraction layers for the performance of the inverted cells based on small molecules. The TiOx surface was very rough, large islands of about 200 nm in diameter being observed here and there. On the other hand, the ZnO surface was smooth. As the result, PCE of OPV cells using ZnO was about 4.5 times higher than that using TiOx. The rough surface of TiOx as an electron extraction layer resulted in large leak current and low PCE.

In order to optimize the performance of OPV cells using ZnO, we changed the film thickness of ZnPc and C60. The leak current of the ZnO cell decreased with increasing the film thickness, as the result, we obtained highest PCE of 0.63 % for the C60 (60 nm)/ZnPc (30 nm) OPV cells using ZnO in this work.

### References

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