

# Interfacial layers for thick vacuum-deposited crystalline organic photovoltaic cells

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## Abstract

Upper and lower interfaces of the active layers are optimized for the organic photovoltaic cells (OPVs) with thick (400–1000 nm) crystalline donor:acceptor blends of zinc phthalocyanine (ZnPc) and fullerene (C<sub>60</sub>), which are typical OPV materials for vapor deposition. Especially, additional rubrene:C<sub>60</sub> blend as the upper interfacial layer for the active layer shows increase of short circuit current ( $J_{sc}$ ) and power conversion efficiency (PCE) at any film thickness from 400 to 1000 nm. Similarly, other interfacial layers are also examined to improve the photovoltaic properties. By combination of these interfacial layers, ZnPc:C<sub>60</sub> OPVs of  $J_{sc}$  around 20 mAcm<sup>-2</sup> and PCE around 5% are achieved with fine reproducibility.

## 1. Introductions

In recent decades, researches and developments of OPV, one of candidates for low-cost next-generation solar cells, have been promoted worldwide. In OPVs, the photocurrent is generated by the separation of excitons reached at the interface of two different organic semiconductors, the p-type (donor) and the n-type (acceptor). Currently, mainstream of OPV is the blend layer, called as bulk heterojunction structure, which has large interface area of blended donor and acceptor.

The film formation methods of the blend layers are roughly classified into two: solution method and vacuum deposition method. Most of the recently reported high efficiency OPVs, especially, almost all of single cell OPVs with around 10% of PCEs are fabricated by the solution method using polymer organic semiconductor as the donor materials. In contrast, for the vacuum deposition method using small molecular organic semiconductors as the donor and acceptor materials, reports of 10% efficiency are limited for the tandem cell; improvement of the single cell performance has been delayed by the typical problem of decreased  $J_{sc}$  and fill factor (FF) when the active layer thickness is greater than 100 nm.

To solve this problem of vacuum deposition, we have been developed a method to maximize  $J_{sc}$  of single vacuum deposited cells [1, 2], "co-evaporant induced crystallization method", which enables crystallization and growth control of molecular films with great excess compared to the conventional vacuum deposition by colliding liquid molecules

that does not remain on the device substrate with organic semiconductor molecules during the vacuum deposition. The phase separation and crystallization of blend films by this method enables improvement of  $J_{sc}$  of 100 nm or greater thickness of vacuum deposited OPVs.

Resultant improved current densities (including saturation current density) and efficiencies by this method are, however, limited because of un-optimized upper and lower layers of blend films. Therefore, in this study, we pursue the improvement of  $J_{sc}$  and efficiency by the optimization of the upper and lower interfacial layers.

## 2. Experiments and results

We added and optimized interfacial layers upper and lower to the active layers successively by vacuum deposition. The totally added composition of the ZnPc:C<sub>60</sub> cells is [ITO/F<sub>4</sub>TCNQ (0.6 nm)/CuI (3 nm)/ ZnPc (2 nm)/ C<sub>60</sub> (2.5 nm) /ZnPc (1 nm)/ZnPc:C<sub>60</sub> (400–1000 nm)/rubrene:C<sub>60</sub> (40 nm)/C<sub>60</sub> (5 nm)/Alq<sub>3</sub>:C<sub>60</sub> (25 nm)/LiF (2 nm)/Ag (100 nm)]. ZnPc, C<sub>60</sub>, ZnPc:C<sub>60</sub>, and rubrene:C<sub>60</sub> layers were crystallized by introducing co-evaporant molecules (polydimethylsiloxane (PDMS)) onto the heated substrate during film growth. Moreover, we examined how the photovoltaic properties changed by varying the upper and lower interfacial layers for ZnPc:C<sub>60</sub> active layer.

The current-voltage (J-V) characteristics under simulated solar illumination (AM1.5G) and the spectral sensitivity characteristics for monochromatic light of OPV samples were measured in glove-box filled by N<sub>2</sub> gas.

Fig.1 shows change of current density with respect to the thickness of the active layer up to 1000 nm. The addition of upper rubrene:C<sub>60</sub> blend layer on the active layer increased current density at any film thickness.

Examples of improved J-V curves and photovoltaic properties are shown in Fig. 2 and Table I, respectively.  $J_{sc}$  around 20 mAcm<sup>-2</sup> and PCE around 5% were reproduced repeatedly, after the optimization of the upper and lower interfacial layers and addition of an antireflection film. Details of the upper and lower interfacial layers will be described in presentation.

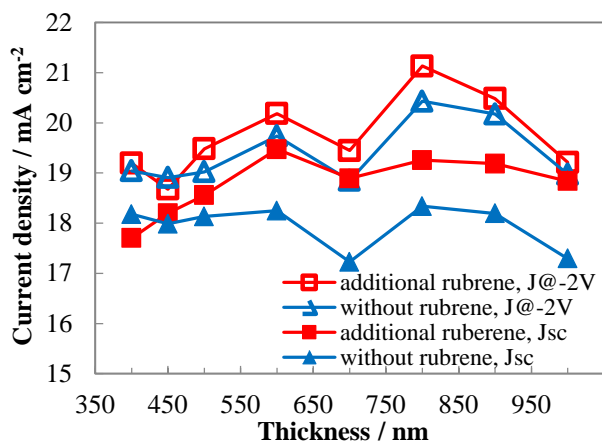


Fig. 1 Photocurrent density of ZnPc:C<sub>60</sub> OPVs with / without upper rubrene:C<sub>60</sub> interfacial layer at various ZnPc:C<sub>60</sub> thickness. J@-2V represents saturated photocurrent density.

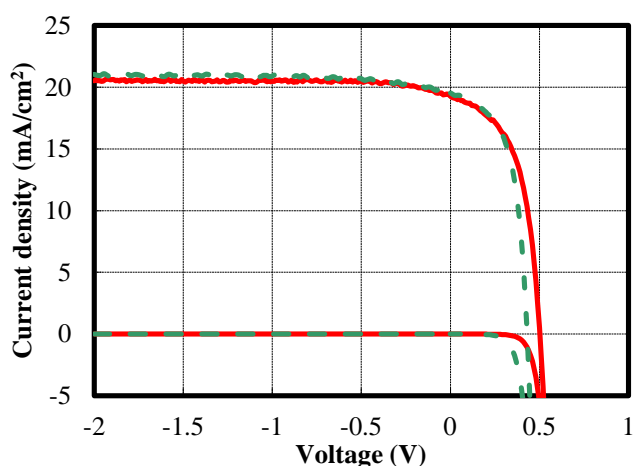


Fig. 2 Current density-voltage (J-V) curves of OPV cells with optimized upper and lower interfacial layers. Active layer thickness is (a) 700 nm (solid line), and (b) 600 nm (dashed line).

Table I photovoltaic properties

cell	$J_{sc}$ mA cm <sup>-2</sup>	$J_{sat}$ mA cm <sup>-2</sup>	$V_{oc}$ V	FF -	PCE %
a	19.39	20.51	0.50	0.54	5.19
b	19.73	21.03	0.44	0.59	4.94

### 3. Conclusions

We have demonstrated optimization of upper and lower interfacial layers for thick vacuum deposited active layers phase separated and crystallized by "co-evaporant induced crystallization method". ZnPc:C<sub>60</sub> active layer is used as an example of typical vacuum deposited OPV materials.

Optimization of the upper and lower interfacial layer improved  $J_{sc}$  and PCE; especially, addition of rubrene:C<sub>60</sub> blend layer to upper interface of the active layer realized  $J_{sc}$  around 20 mAcm<sup>-2</sup> and PCE around 5% with good reproducibility.

### Acknowledgements

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### References

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