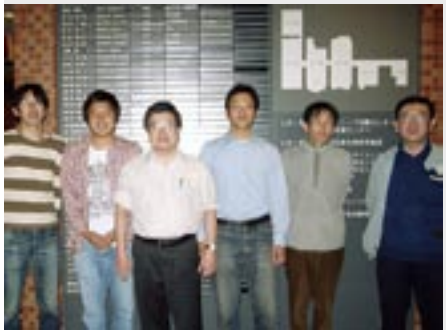
Organic Solar Cells

Research Center for Molecular Scale Nanoscience
Division of Molecular Nanoscience



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Organic solar cell is recognized as a future 3rd generation solar cell. Our group accomplished the world record conversion efficiency of 5.3% by ultra-high purification and nanostructure design.[1,2] Moreover, a new organic solar cell having the sensitivity of near-infrared (NIR) region to 1050 nm like Si cell is successfully fabricated.

1. Efficient Organic *p-i-n* Solar Cells Having NIR Sensitivity by Using J-Aggregate of Pb Phthalocyanine

In 1991, we proposed *p-i-n* organic solar cells in which the *i*-interlayer is a codeposited film composed of *p*- and *n*-type organic semiconductors.[3,4] *i*-interlayer acts as an efficient photocarrier generation layer.

Unfortunately, organic solar cells did not have sensitivity to near infrared (NIR) so far. Since there is a lot of NIR photon in the solar spectrum, they should be utilized in order to obtain photocurrent density reaching 30 mA/cm^2 like Si solar cells.

In order to solve this problem, we incorporated Pb phthalocyanine (PbPc) having shuttle-cock type molecular structure in *p-i-n* cell (Figure 1). *p*-type layer of ZnPc, codeposited *i*-interlayer composed of C_{60} and PbPc, and *n*-type layer of C_{60} were successively deposited by vacuum evaporation on ITO glass substrate.

Figure 2(a) shows the spectral dependence external quantum efficiency (EQE) of short-circuit photocurrent. The present cell showed the NIR sensitivity to 1050 nm. Maximum EQE reached 43%, which is the largest value of NIR sensitivity observed so far. Conversion efficiency by NIR light irradiation reached 2.3% (Figure 2(b)).

Codeposited *i*-interlayer was revealed to have nanostructure composed of 3 phases, *i.e.*, amorphous C_{60}, H-aggregate of PbPc, and J-aggregate of PbPc (Figure 3). This nanostructure has the efficient carrier generation ability due to 3-separated functions, *i.e.*, electron transport, hole transport, and photocarrier generation by NIR, respectively.

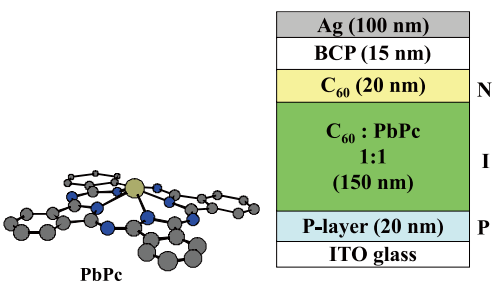

Figure 1. Structure of organic *p-i-n* cell incorporating PbPc:C_{60} *i*-interlayer.

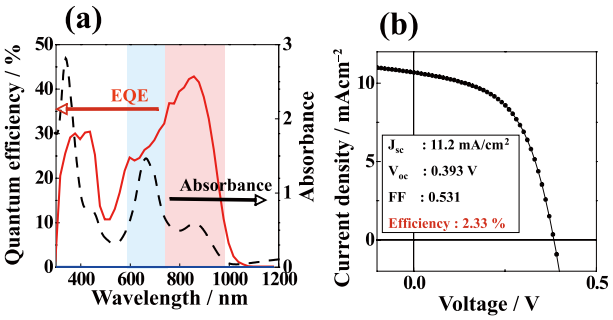

Figure 2. (a) Spectral dependence external quantum efficiency of short-circuit photocurrent. Absorption spectrum of PbPc:C_{60} *i*-interlayer is also shown. Absorption peaks at 650 nm and 860 nm are attributed to H- and J-aggregates of PbPc. (b) Photourrent-voltage characteristic for *p-i-n* cell.

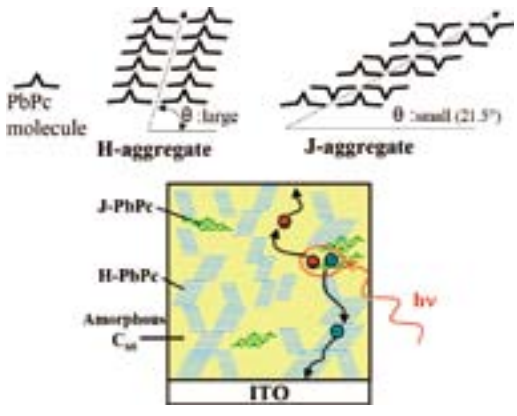

Figure 3. 3-function separated nanostructure consists of amorphous C_{60}, H-PbPc, and J-PbPc, which act as electron transport, hole transport, and photocarrier generation by NIR, respectively. Molecular stackings of H- and J-aggregates are also shown.

2. Hole-Transport Highway in Phthalocyanine:C_{60} *i*-interlayer Showing Conversion Efficiency of 5.3%

Our group accomplished the world record conversion efficiency of 5.3% by *p*-*i*-*n* cell having *i*-interlayer composed of metal-free phthalocyanine (H_2Pc) and seven-nine (7N, 99.99999%) purified C_{60} (Figure 4).[1,2] Utilization of entire visible light of solar spectrum without decreasing fill factor by incorporating 1 μm-thick C_{60}:H_2Pc *i*-interlayer is essential to obtain large J_{sc} value of 20 mAcm^{-2} and efficiency of 5.3%.

Figure 5 shows the TEM image of 1 μm-thick H_2Pc:C_{60} codeposited *i*-interlayer. H_2Pc whisker structures having diameter of around 20 nm were clearly observed. Carrier is photogenerated at H_2Pc whisker/C_{60} interface and photogenerated holes are efficiently transported *via* this H_2Pc whisker to electrode. This observation suggests that H_2Pc hole-transport highway is formed in H_2Pc:C_{60} *i*-interlayer.

We also investigated the nanostructure of 1 μm-thick ZnPc:C_{60} *i*-interlayer which showed essentially the same results to H_2Pc:C_{60} system. Figure 6 shows the schematic illustration of a ZnPc nanocrystal (a) and nanocrystals-connected nanostructure clarified by cross sectional SEM and XRD observations. (i) ZnPc nanocrystals having diameter of around 20 nm surrounded by amorphous C_{60} (Figure 6(a)). (ii) ZnPc:C_{60} thickness < 300 nm; π-stacking direction is parallel to the substrate electrode (Figure 6(a)(b)). (iii) 300 nm < ZnPc:C_{60} thickness < 1 μm; π-stacking direction is changed to be vertical to the electrodes (Figure 6(b)). Since photogenerated holes are transported *via* π-stacking, the present observation suggests the formation of hole-transport highway between two metal electrodes. Note that the H_2Pc whisker structure in Figure 5 resembles to this hole-transport highway. Formation of such hole-transport highway is one of the reasons of 5.3% high efficiency of *p*-*i*-*n* cells.

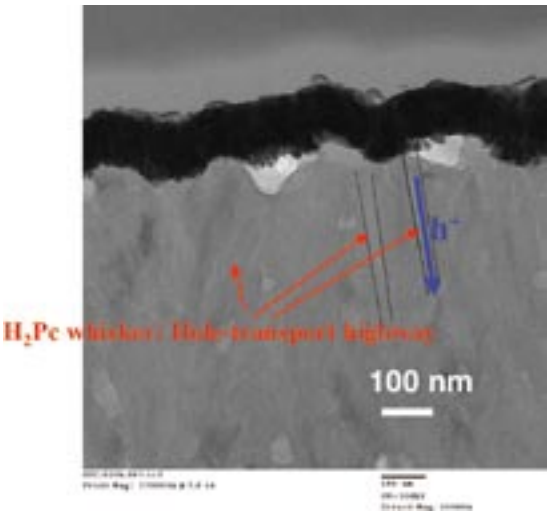

Figure 5. TEM image of 1 μm-thick H_2Pc:C_{60} codeposited *i*-interlayer.

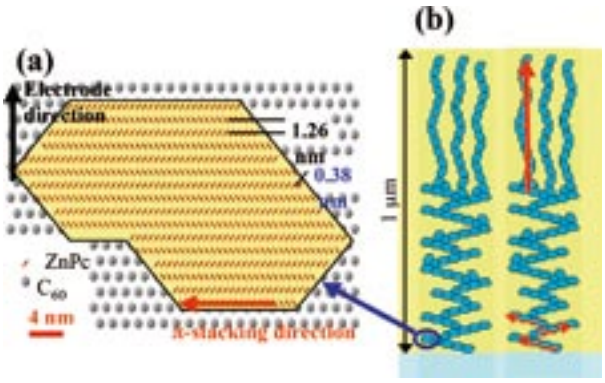

Figure 6. (a) Schematic illustration of a ZnPc nanocrystal surrounded by C_{60}. (b) Schematic illustration of 1 μm-thick ZnPc:C_{60} *i*-interlayer. Red arrows represent the direction of π-stacking, *i.e.*, hole transport direction. Hole-transport highway between electrodes is formed.

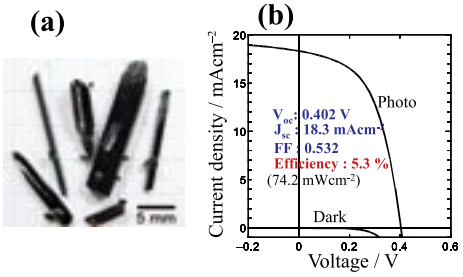

Figure 4. (a) Photograph of 7N(99.99999%)-C_{60} single crystals. (b) Current-voltage characteristics for *p*-*i*-*n* cell having 1 μm-thick H_2Pc:C_{60} *i*-interlayer.

References

1) M. Hiramoto, *Proc. SPIE Vol. 7052, Organic photovoltaics IX* pp. 70520H-1–6, San Diego, CA, 12-14 Aug. (2008).
2) K. Sakai and M. Hiramoto, *Mol. Cryst. Liq. Cryst.* **491**, 284–289 (2008).
3) M. Hiramoto, H. Fujiwara and M. Yokoyama, *J. Appl. Phys.* **72**, 3781 (1992).
4) M. Hiramoto, H. Fujiwara and M. Yokoyama, *Appl. Phys. Lett.* **58**, 1062 (1991).
5) M. Hiramoto, T. Yamaga, M. Danno, K. Suemori, Y. Matsumura and M. Yokoyama, *Appl. Phys. Lett.* **88**, 213105 (2006).

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