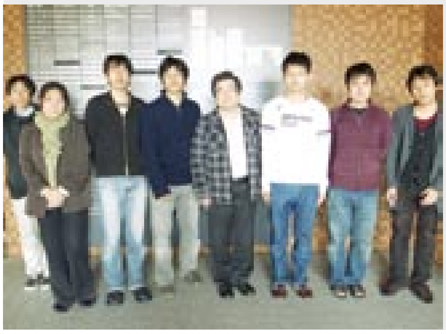
Organic Solar Cells

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. Last year, we started CREST Project; "Bandgap Science for Organic Solar Cells." Target of this project is 15% efficiency of organic solar cells by establishing bandgap science for organic semiconductors, which is equivalent to that for silicon semiconductor.

1. Carrier Concentration Determination for Organic Semiconductors by AC Hall Effect

We accomplished the world record conversion efficiency of 5.3% by using seven-nines (7N, 0.1 ppm, 99.99999%) purified fullerene.[1,2] Taking this result into consideration, determination technique of ppm-level concentrations of impurities in organic semiconductors is very important.

Hall effect measurement is well established for inorganic semiconductors. However, for high resistant organic semiconductors, reproducible results of Hall voltage of the order of μV has not been reported. In this study, we applied the AC Hall effect technique to metal-free phthalocyanine (H_2Pc) film and succeeded to obtain the first reproducible results.

H_2Pc was purified by single-crystal formed sublimation 3 times (Figure 1). The van der Pauw type Au electrodes were formed on the 1 μm-thick H_2Pc film (Figure 2). AC Hall measurement system (Toyo Technica, Resitest 8300) was used. AC magnetic field (0.1 Hz, 0.3 T at max.) was applied perpendicular to the film surface and Hall voltage of about 10^{-6} V was precisely detected by the lock-in technique.

Carrier type was determined to p-type. Values of carrier concentration and hole mobility were determined to 3.5×10^{14} /cm^3 and 0.03 cm^2/Vs, respectively. Very small value of carrier concentration of 10^{14} /cm^3 suggests that the purity of H_2Pc film is seven nines (7N) at least.

Purification and doping technique are crucially important to realize 15% efficient organic solar cells. The present AC Hall measurement is revealed to be a powerful tool to evaluate the purity and doping concentration in organic semiconductor films.

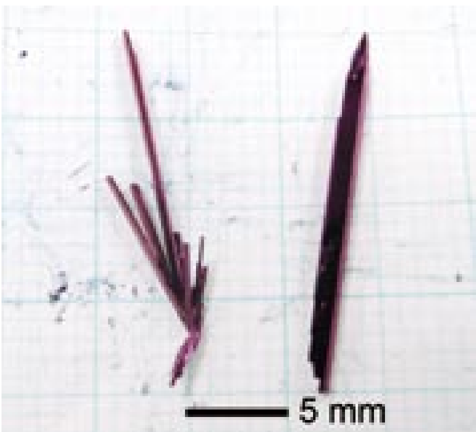

Figure 1. Photograph of single crystals of H_2Pc.

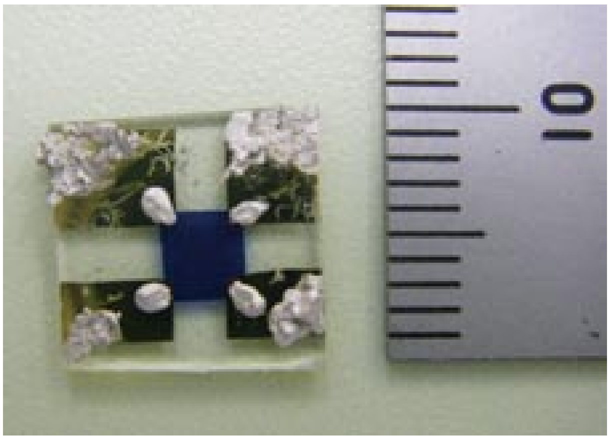

Figure 2. Photograph of H_2Pc cell for AC Hall effect measurements. Blue square part is H_2Pc film (1 μm).

2. n-Type C_{60} Formation by H_2-Doping

Hydrogen (H_2) doping effect[3] for C_{60} was investigated. Highly purified 7N-C_{60} (seven nines; 99.99999%) sample was used. Doping was performed by introducing H_2 gas (1×10^{-4} Torr) into the evaporation chamber during the co-evaporation of C_{60} and H_2Pc (Figure 3). For ITO/H_2Pc:C_{60} codeposited layer/Al cell (Figure 3), open-circuit photovoltage (V_{oc}) and short-circuit photocurrent (J_{sc}) increased from 0.3 to 0.5 V and from 2 to 5 mA/cm^2, respectively, by H_2-doping (Figure 4). Internal quantum efficiency of J_{sc} increased 4 times from 5% to 20% in the absorption region of C_{60} (400–500 nm). Similar result was observed for ITO/C_{60} single layer/Al cell.

Above results can be reasonably explained by the increase of the built-in potential, which is caused by the negative shift of Fermi level (E_F) of C_{60} by H_2-doping (Figure 5). We think that the n-type C_{60} was formed by the intentional H_2-doping. This is a clear demonstration of pn-control by the doping technique for organic semiconductors. Quantitative evaluation of donor concentration by H_2-doping is now in progress by the AC Hall effect.

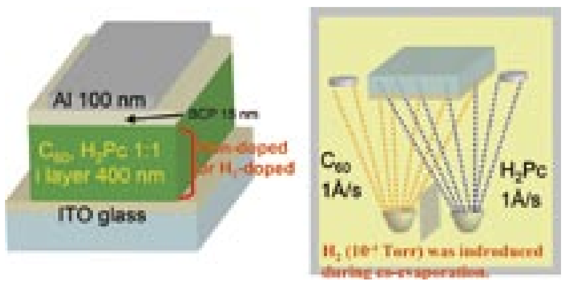

Figure 3. Sandwich-type cell of C_{60}:H_2Pc codeposited layer and H_2-doping during co-evaporation.

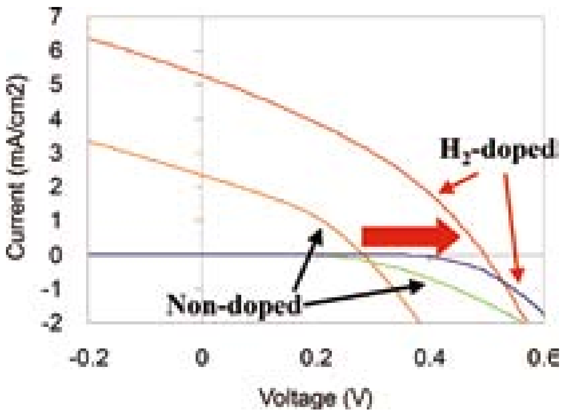

Figure 4. Current-voltage characteristics for undoped and H_2-doped cells.

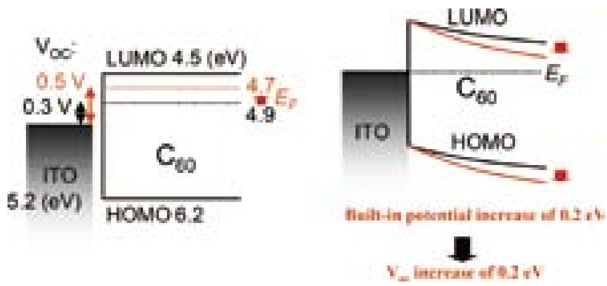

Figure 5. (a) Negative shift of Fermi level (E_F) of C_{60} by H_2-doping. (b) Increase of built-in potential caused by V_{oc} increase.

References

1) M. Hiramoto, *Proceedings of 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 *et al.*, *Chem. Lett.* 119 (1990).