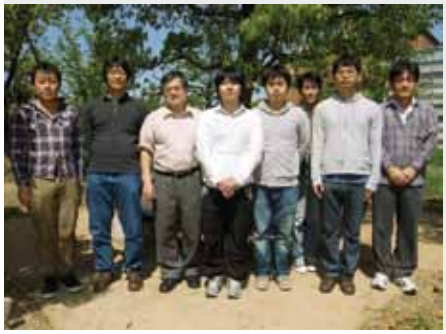
Organic Solar Cells

Research Center for Molecular Scale Nanoscience
Division of Molecular Nanoscience



HIRAMOTO, Masahiro	Professor
KAJI, Toshihiko	Assistant Professor
NAKAO, Satoru	Post-Doctoral Fellow
SHINMURA, Yusuke	Research Fellow
KUBO, Masayuki	Research Fellow
YOKOYAMA, Kazuya	Research Fellow
YOSHIOKA, Tadashi	Research Fellow
ISHIYAMA, Norihiro	Graduate Student
SUGIHARA, Hidemi	Secretary

Organic solar cell is recognized as a next generation solar cell. In 2009, 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.

Recently, we have established *pn*-control technique for organic semiconductors (Topic 1) and applied to the fabrication of the ohmic organic/metal contacts (Topic 2) and of the tandem cell formed in the codeposited film only by doping (Topic 3).

1. *pn*-Control and *pn*-Homojunction Formation in Single C_{60} and H_2Pc Films[1–3)]

Fullerene (C_{60}) and phthalocyanines are typical components in small-molecular-type organic photovoltaic cells. Based on experience with inorganic solar cells, to create a built-in potential, *pn*-control of highly purified organic semiconductors by doping is required.

In this study, complete *pn*-control and *pn*-homojunction formation were demonstrated for single C_{60} films[1,2)] and for single metal-free phthalocyanine (H_2Pc) films.[3)] Cesium carbonate (Cs_2CO_3) and molybdenum oxide (MoO_3) were used as donor and acceptor dopants, respectively. Doping was performed by the coevaporation. Here, results on H_2Pc films are summarized.

The Fermi level (E_F) of H_2Pc, located at the center of the bandgap (4.4 eV), is shifted to 3.8 eV, close to the conduction band (3.5 eV), by Cs_2CO_3 doping (5,000 ppm) and shifted to 4.9 eV, close to the valence band (5.1 eV), by MoO_3 doping (5,000 ppm) under oxygen free conditions (Figure 1). Formation of *n*- and *p*-type Schottky junctions and *pn*-homojunctions in single H_2Pc films, confirmed by their photovoltaic properties, clearly demonstrates the formation of *n*- and *p*-type H_2Pc.

Moreover, the band bending can be also mapped in real scale based on the Kelvin probe measurements and the widths of depletion regions for *n*-type (Figure 2(a)), *p*-type (Figure 2(b)) Schottky junctions and *pn*-homojunction (Figure 2(c)) were determined to 23, 30, and 35 nm, respectively.

Conventionally, H_2Pc and C_{60} have been regarded as inherent *p*- and *n*-type semiconductors, respectively. However, *n*-H_2Pc and *p*-C_{60} can be formed by doping. So, it is reasonable that single organic semiconductors can, in general, be controlled to be *n*- or *p*-type, similar to inorganic semiconductors.

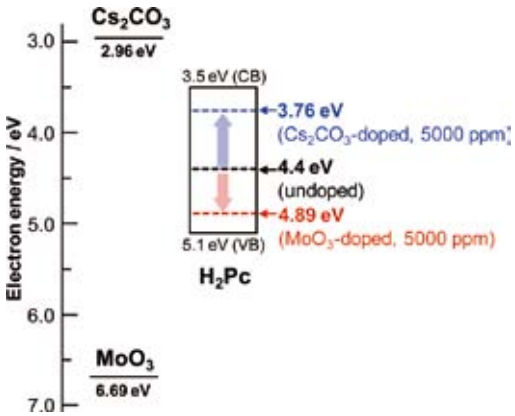


Figure 1. Energy diagram of a H_2Pc film. The broken lines show the energy levels of E_F for undoped (black), MoO_3-doped (red) and Cs_2CO_3-doped (blue) H_2Pc films.

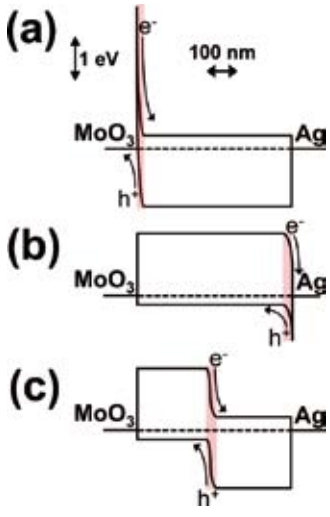


Figure 2. Energy structures for Cs_2CO_3-doped (a), MoO_3-doped (b), and Cs_2CO_3-/MoO_3-doped (c) cells in real scale based on the Kelvin probe measurements. Photocarrier generation occurs in the depletion regions (shaded).

2. Invertible Organic Photovoltaic Cells with Heavily Doped Organic/Metal Ohmic Contacts[4)]

In this study, we applied *pn*-control to make the two organic/metal contacts in a photovoltaic cell ohmic. Figure 3 shows the energetic structure for ITO/n^+-C_{60} contact depicted based on the Kelvin probe measurements. 10,000 ppm Cs_2CO_3 was heavily doped in the vicinity of ITO electrode and made C_{60} n^+-type. Though there is a distinct barrier to electrons with a height of 0.34 eV from the conduction band of C_{60} to the ITO, since the band bends down steeply within 5 nm of the interface, photogenerated electrons can tunnel through this barrier. Thus, an ohmic contact is formed.

Heavily doped 10-nm-thick p^+- and n^+-type regions of H_2Pc and C_{60} were formed to facilitate the formation of ohmic contacts at the organic/metal interfaces of two-layered organic photovoltaic cells [ITO/H_2Pc/C_{60}/Ag]. Formation of the ohmic contacts allowed the cells to be invertible [ITO/C_{60}/H_2Pc/Ag] and independent of the type of electrode material used.

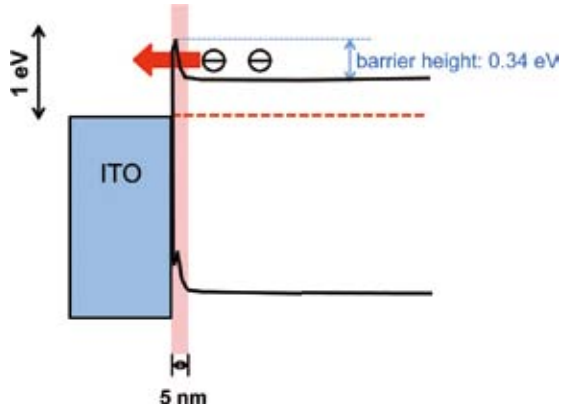


Figure 3. Energy structure for ITO/n^+-C_{60} contact in real scale. A tunneling ohmic junction for photogenerated electrons is formed.

3. Tandem Organic Photovoltaic Cells Formed in Codeposited Films by Doping[5)]

pn-control technique should be extended to co-deposited films since organic solar cells should use co-deposited films to generate significant photocurrent densities based on the dissociation of excitons by the photoinduced electron transfer process.

In this study, tandem organic solar cells connecting two single homojunctions were formed in C_{60}:6T (α-sexithiophene) co-deposited films only by doping with MoO_3 and Cs_2CO_3 (Figure 4). Doping were performed by "three component co-evaporation."[6)] The single and tandem cells showed the open-circuit voltage of 0.85 and 1.69 V and conversion efficiency of 1.6 and 2.4%, respectively.

Figure 5 shows the energetic structure of tandem cell. Photocurrent is generated in the intrinsic (i) layers in front and back cells. Two single cells are connected by heavily doped n^+p^+-homojunction. Since the depletion region width of the n^+p^+-homojunction is extremely thin, *i.e.*, 20 nm, it can act as ohmic interlayer due to the carrier tunneling. Thus, the photovoltage of tandem cell (1.69 V) is doubled compared to that of single cell (0.85 V).

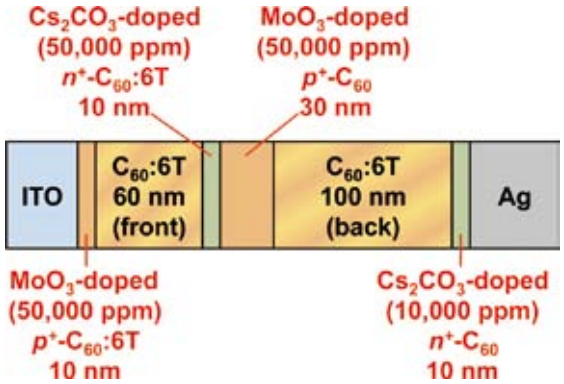


Figure 4. Structure of a tandem cell connecting two homojunction cells, which is made only by doping to C_{60}:6T codeposited film.

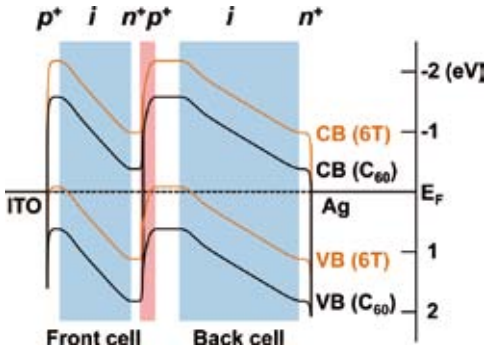


Figure 5. Energy structure of a tandem cell in real scale. n^+p^+-heavily doped homojunction acts as an ohmic interlayer connecting two single cells.

References

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6) N. Ishiyama, M. Kubo, T. Kaji and M. Hiramoto, *Appl. Phys. Lett.* **99**, 133301 (2011).

Award

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