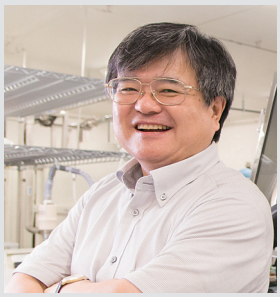
Organic Solar Cells

Department of Materials Molecular Science
Division of Molecular Functions



HIRAMOTO, Masahiro
Professor
[hiramoto@ims.ac.jp]

Education
1984 B.E. Osaka University
1986 Ph.D (Engineering) Osaka University

Professional Employment
1984 Technical Associate, Institute for Molecular Science
1988 Research Associate, Osaka University
1997 Associate Professor, Osaka University
2008 Professor, Institute for Molecular Science
Professor, The Graduate University for Advanced Studies

Awards
2017 Fellow Award of Japan Society of Applied Physics
2006 Paper award, Molecular Electronics & Bioelectronics division, Japan Society of Applied Physics
2006 Research and Education Award, Osaka University
2004 Editor Award, Japanese Journal of Applied Physics

Member
Assistant Professor
IZAWA, Seiichiro
Research Fellow
YABARA, Yusuke
Graduate Student
LEE, Jihyun
PALASSERY ITHIKKAL, Jaseela
Secretary
SUGIHARA, Hidemi
NAKAMURA, Yuka

Keywords Organic Semiconductors, ppm-Doping, Lateral Junction

Organic solar cells have been intensively studied due to many advantages like flexible, printable, light, low-cost, fashionable, etc. Last year, we proposed a novel concept of the structure of organic solar cell, namely, a lateral multilayered junction (Figure 1). An essential point is that the photo-generated holes and electrons are laterally transported and extracted to the respective electrodes. We also investigated the reduction of open-circuit voltage loss in organic solar cells by using high-mobility organic semiconductors (Figure 2). On the other hand, we have been focused on the research on the ppm-level doping effects in organic semiconductor films and organic single crystals for organic solar cells. So far, we have reported complete *pn*-control, doping sensitization, ppm-level doping effects using an extremely low-speed deposition technique reaching 10^{-9} nm s^{-1}, in organic single crystals measured by the Hall effect, which shows a doping efficiency of 24%, and enhancement of open-circuit voltage of organic solar cells by doping. These results can be regarded as a foundation for the construction of high efficient organic solar cells.

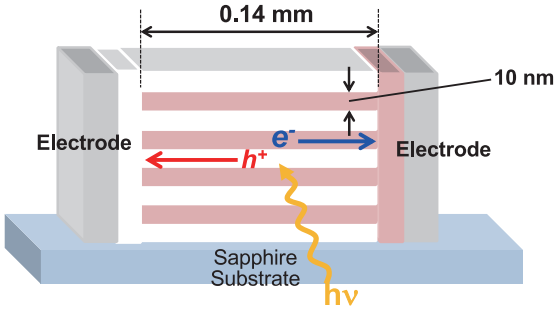


Figure 1. Lateral multilayered junction which can replace the blended junction.

Selected Publications

- M. Hiramoto, M. Kikuchi and S. Izawa, "Parts-per-Million-Level Doping Effects in Organic Semiconductor Films and Organic Single Crystals," *Adv. Mater.* **30**, 1801236 (15 pages) (2018). [Invited Progress Report]
- M. Kikuchi, M. Hirota, T. Kunawong, Y. Shinmura, M. Abe, Y.Sadamitsu, A. M. Moh, S. Izawa, M. Izaki, H. Naito and M. Hiramoto, "Lateral Alternating Donor/Acceptor Multilayered Junction for Organic Solar Cells," *ACS Appl. Energy Mater.* **2**, 2087–2093 (2019).
- S. Izawa, N. Shintaku, M. Kikuchi and M. Hiramoto, "Importance of Interfacial Crystallinity to Reduce Open-Circuit Voltage Loss in Organic Solar Cells," *Appl. Phys Lett.* **115**, 153301 (2019).

1. Reduction of Open-Circuit Voltage Loss in Organic Solar Cells[1)]

Reducing the energy loss in output voltage is critically important for further enhancing the efficiency of organic solar cells. In this work, we showed that the organic solar cells with high mobility and highly crystalline donor and acceptor materials can reduce an open-circuit voltage (V_{oc}) loss.

Two-layer cells consisting of C8-BTBT and C_n-PTCDI (Figure 2(a)), which acts as the donor and acceptor were fabricated. V_{oc} increases in the order of C3 < C6 < C8 of C_n-PTCDI (Figure 2(a)) and reached to thermodynamic (Shockley–Queisser) limit (Figure 2(b), red dots). Simultaneously, electron mobility increases by the suppression of molecular vibration of π-stacking due to the increase of crystallinity by fastener effect by increasing the chain length (C3 < C6 < C8). V_{oc} increase can be reasonably explained by the suppression of non-radiative (vibrational) recombination from CT (charge transfer) exciton (D^+/A^-) to ground state (D/A) (Figure 2(c)).

By using the high mobility (band conductive) organic semiconductors, high efficient organic solar cells would be realized by reducing V_{oc} loss.

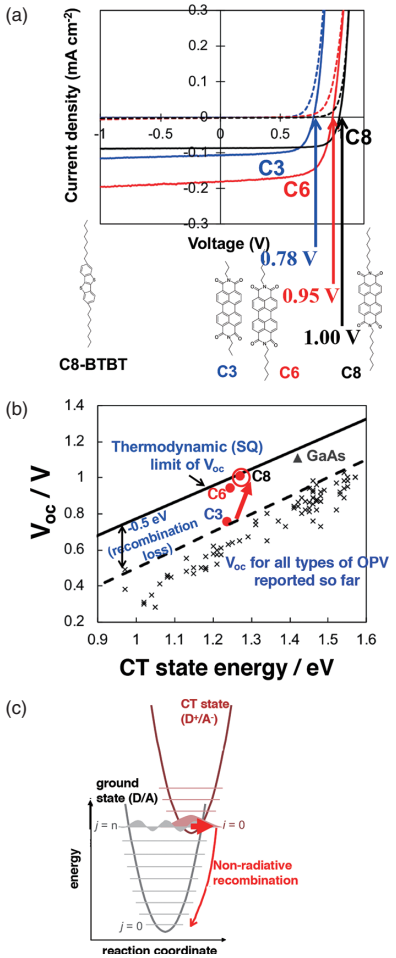


Figure 2. (a) J–V characteristics of C8-BTBT/C_n-PTCDI cells. (b) V_{oc} vs. CT state energy. (c) Non-radiative recombination from CT state to ground state.

2. Ultra-Thick Blended Layer up to 10 μm in Organic Solar Cells[2)]

Blended layer thickness of organic solar cells made with small molecules has limitation up to the order of a few hundred nm which is still not enough to absorb whole solar light. In this work, we succeeded to operate the organic solar cells having 10-μm-thick photoactive blended layer, consisting of zinc phthalocyanine (ZnPc), and fullerene (C_{60}).

A method of co-evaporant induced crystallization[3)] was used for the deposition of ZnPc:C_{60} codeposited films. Co-evaporant molecule (polydimethylsiloxane; PDMS) acts as a liquid in the vacuum, which induces the crystallization and phase separation of the codeposited film. The cross-sectional image of co-deposited films with a co-evaporant show the columnar structures of ZnPc and C_{60} which offer the vertical transport routes for holes and electrons (Figure 3, inset).

With co-evaporant, short-circuit photocurrent (J_{sc}) and fill factor (FF) showed almost constant value up to the surprising blended layer thickness of 10 μm (Figure 3, blue diamonds). However, without co-evaporant, they steeply decreased within several hundred nm (Figure 3, green crosses). Photocurrent density of 20 $mAcm^{-2}$ and the conversion efficiency (PCE) of 4.3% were observed. Whole solar light absorption by ultra-thick blended layer fabricated by co-evaporant will open the way to realize the high efficient small-molecular type organic solar cells.

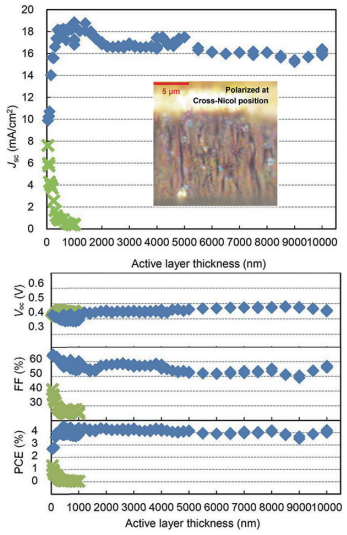


Figure 3. Dependence of cell performance on blended layer thickness. Inset: Phase separated columnar structure made by co-evaporant induced crystallization.

References

1) S. Izawa, N. Shintaku, M. Kikuchi and M. Hiramoto, *Appl. Phys. Lett.* **115**, 153301 (2019).
2) M. Katayama, T. Kaji, S. Nakao and M. Hiramoto, *Front. Energy Res., Section Solar Energy* **8:4**, 1–12 (2019).
3) T. Kaji, M. Zhang, S. Nakao, K. Iketaki, K. Yokoyama, C. W. Tang and M. Hiramoto, *Adv. Mater.* **23**, 3320–3325 (2011).