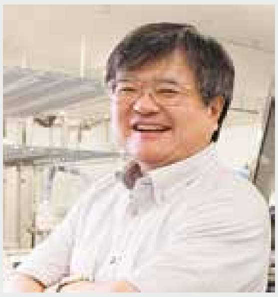
Organic Solar Cells

Department of Materials Molecular Science
Division of Molecular Functions



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Keywords Organic Semiconductors, Organic Solar Cells, ppm-Doping

Organic solar cells have been intensively studied due to many advantages like flexible, printable, light, low-cost, fashionable, etc. We have been focused on the research on the ppm-Level doping effects in organic semiconductor (OSC) films and organic single crystals for organic solar cells. We believe that the following features are indispensable. (i) A ppm-doping strategy should be performed on sub-ppm purified OSCs together with the total removal of oxygen from the air, which acts as an external dopant. (ii) Perfect *pn*-control, namely, any single or blended OSCs should exhibit either *n* or *p*-type behavior only by impurity doping. (iii) To precisely clarify the nature of the doping effects, ppm doping in the bulk of OSC single crystals with few grain boundaries should be performed.

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} (Figure 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.

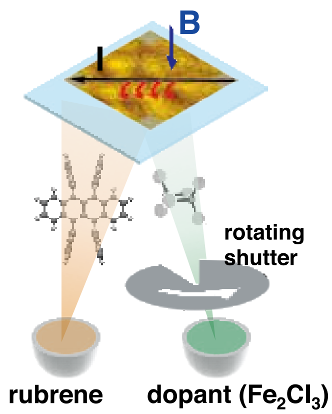

Figure 1. Ultra-slow co-deposition technique to produce the doped rubrene single crystal for Hall effect measurements.

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]
- S. Izawa, N. Shintaku and M. Hiramoto, "Effect of Band Bending and Energy Level Alignment at the Donor/Acceptor Interface on Open-Circuit Voltage in Organic Solar Cells," *J. Phys. Chem. Lett.* **9**, 2914–2918 (2018).
- 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).

1. Lateral Multilayered Junction for Organic Solar Cells[1)]

Bulkheterojunctions (blended junctions) are indispensable for organic solar cells. However, the fabrication of electron and hole transport routes in blended junction remains quite challenging. We proposed a novel concept of the structure of organic solar cell, namely, a lateral alternating multilayered junction (Figure 2). An essential point is that the photogenerated holes and electrons are laterally transported and extracted to the respective electrodes.

Minimum units of proposed junction are hole highway and electron highway. At first, we demonstrated that lateral extraction of photogenerated holes and electrons of the order of 1 mm in the hole and electron highways using ultra-high mobility organic films. Observed macroscopic value of milli-meter order is surprising long compared to the conventional value below 1 μm. Next, we demonstrated the successful operation of organic solar cell having a lateral alternating multilayered junction by combining the hole highway and electron highway. A total of 93% of the photogenerated electrons and holes are laterally collected over a surprising long distance (0.14 mm). The exciton-collection efficiency reaches 75% in a lateral alternating multilayered junction with a layer thickness of 10 nm. Therefore, the lateral junction is proved to have an ability to collect both excitons and carriers almost completely.

A lateral alternating multilayered junction can be regarded to be an alternative blended junction for organic solar cells. Advantage of a lateral cell is its unlimited thickness in the vertical direction. Therefore, tandem solar cells that can utilize the full solar spectrum can be freely designed. The present new concept paves the way to exceed the conversion efficiency of organic solar cells above 20%.

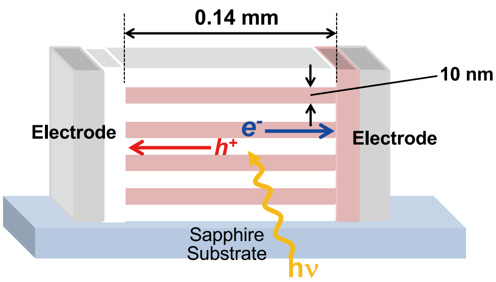

Figure 2. Lateral alternating multilayered junction. Present junction has layer thickness of 10 nm and lateral distance of 0.14 mm, *i.e.*, aspect ratio reaches 1.4×10^4.

2. Organic *pn*-Homojunction Solar Cell[2)]

Formation of *pn*-homojunction in a single semiconductor material through doping is key for photocurrent generation in inorganic solar cells. In contrast, a donor/acceptor heterojunction is generally utilized in organic solar cells to split coulombically bound exciton forming in organic semiconductors. We reported an organic *pn*-homojunction solar cell showing high internal quantum efficiency of about 30%. *pn*-homojunction was created by co-deposition of *p* or *n* type dopants and an organic semiconductor. An increase of the photocurrent density by more than 8 times, from the undoped device to *pn*-homojunction device with 5% doping, was observed. The increase of photocurrent due to charge separation assisted by the built-in potential near the *pn*-homojunction interface that was controlled by doping concentration (Figure 3). The result demonstrated that the *pn*-homojunction interface in a single organic semiconductor layer formed by doping can achieve efficient charge separation and provide a suitable alternative to the donor/acceptor interface that has been considered necessary for photoconversion in organic solar cells.

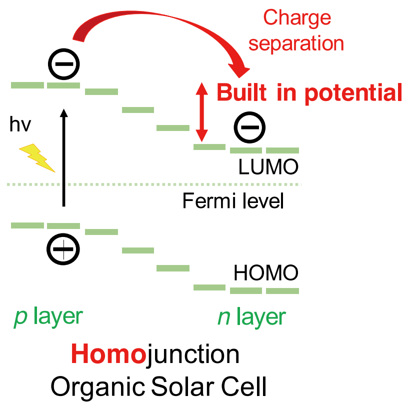

Figure 3. Schematic diagram of the working mechanism of organic *pn*-homojunction solar cells.

References

1) M. Kikuchi, M. Hirota, T. Kunawong, Y. Shinmura, M. Abe, Y.Sadamitsu, A. M. Moh, S. Izawa, M. Izaki, H. Naito and M. Hiramoto, *ACS Appl. Energy Mater.* **2**, 2087–2093 (2019).

2) S. Izawa, A. Perrot, J. Lee and M. Hiramoto, *Org. Electron.* **71**, 45–49 (2019).

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