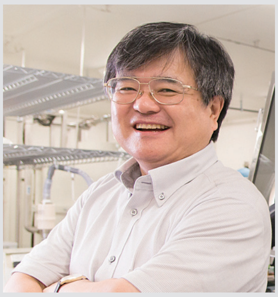
Organic Solar Cells

Department of Materials Molecular Science
Division of Molecular Functions



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Education
1984 B.E. Osaka University
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Professional Employment
1984 Technical Associate, Institute for Molecular Science
1988 Research Associate, Osaka University
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Awards
2021 Outstanding Achievement Award, Molecular Electronics & Bioelectronics Division, Japan Society of Applied Physics
2017 Fellow Award of Japan Society of Applied Physics
2006 Paper award, Molecular Electronics & Bioelectronics division, Japan Society of Applied Physics
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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 (V_{oc}) loss due to non-radiative recombination in organic solar cells by using high-mobility organic semiconductors. We observed the V_{oc} reaching to thermodynamic (Shockley-Queisser) limit (Figure 2, double red dot). 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.

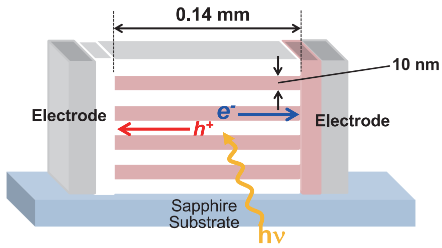

Figure 1. Lateral multilayered junction.

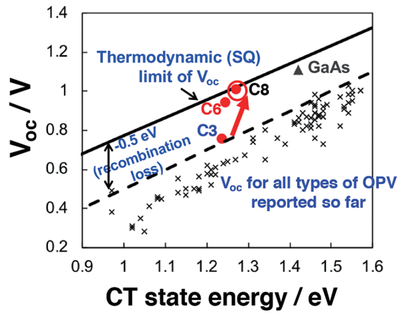

Figure 2. V_{oc} vs. Charge Transfer (CT) state energy of donor/acceptor type organic solar cells. By using high carrier mobility organic semiconductors, V_{oc} reaching SQ-limit was observed (double red dot).

Selected Publications

- 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).
- 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]

1. Efficient Solid-State Photon Upconversion Enabled by Spin Inversion at Organic Semiconductor Interface[1)]

Energy of photons, *i.e.* the wavelength of light, can be upgraded through interactions with materials—a process called photon upconversion (UC). Although UC in organic solids is important for various applications, such as in photovoltaics and bioimaging, conventional UC systems, based on intersystem crossing (ISC), suffer from low efficiency.

In this study, we report a novel UC mechanism at heterojunctions of organic semiconductors in bilayer structures. The UC occurs through spin inversion during the charge separation and recombination at the interface (Figure 3(a)). This spin inversion can efficiently convert the incident photons to triplets without relying on the ISC, whose rate is typically accelerated by the heavy-atom effect. As a result, a solid-state UC system is achieved with an external efficiency of two orders of magnitude higher than those of the conventional systems. Using this result, efficient UC, from near-infrared to visible light, can be realized on flexible organic thin films under a weak light-emitting diode-induced excitation, observable by naked eyes (Figure 3(b)).

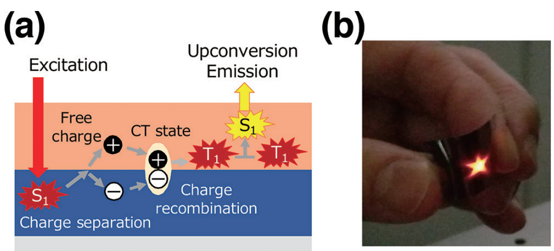

Figure 3. (a) Up-conversion (UC) emission by star-shape patterned NIR LED irradiation. (b) Photographs of UC emission by a star-patterned NIR LED irradiation (750 nm, 71.7 mW/cm^2) on a flexible thin film.

2. Photovoltaic Behavior of Centimeter-Long Lateral Organic Junctions[2)]

Recently, we reported a lateral alternating multilayered junction using a high mobility organic semiconductor.[1)] In this study, we fabricated lateral junction cells having lateral distance (L) reaching cm order (Figure 4(a)). A donor [C8-BTBT (hole mobility: 43 cm^{2}V^{-1}s^{-1})]–acceptor [PTCDI-C8 (electron mobility: 1.7 cm^{2}V^{-1}s^{-1})] combination was used. Buffer layers of BCP and MoO_3 were used for the selective carrier collection of electrons and holes, respectively. Surprisingly, even lateral cells with L = 1.8 cm (Figure 4(b)) showed clear photovoltaic behavior (Figure 4(c), red curve). Figure 4(d) shows the L dependence of observed J_{sc} (red curve) and calculated J_{sc} (blue curve) obtained from diffusion lengths of electrons (4.7 mm) and holes (5.5 mm), which are dominated by traps. These diffusion lengths were obtained by the experiments using the moving photomask covering the irradiated surface from respective electrodes. Thus, considerable decrease in photocurrent is attributed to the trap-assisted recombination indicated by the blue curve. A further difference between the observed and calculated curves is due to bimolecular recombination and its effect is small. Thus, we concluded that trap-assisted recombination can be the main reason for photocurrent loss of the long lateral cells. Hence, identifying and removing the defects acting as traps can be done to improve cell performance.

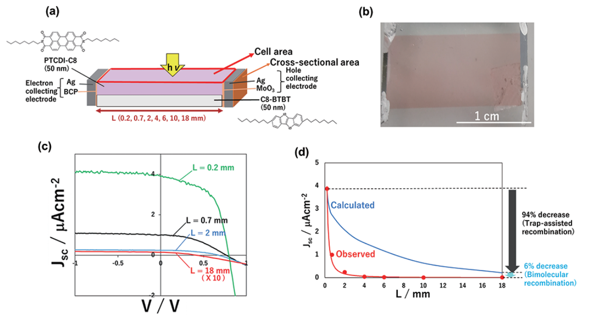

Figure 4. a) Structure of a lateral junction cell. (b) Photograph of a cell with L = 18 mm. (c) J-V curves of cells with L = 0.2, 0.7 and 18 mm. (d) Dependence of short-circuit photocurrent (J_{sc}) on L.

References

1) S. Izawa and M. Hiramoto, *Nat. Photonics*, in press (2021).
2) J. P. Ithikkal, A. Girault, M. Kikuchi, Y. Yabara, S. Izawa and M. Hiramoto, *Appl. Phys Express* **14**, 094001 (2021).

Awards

HIRAMOTO, Masahiro; Outstanding Achievement Award, Molecular Electronics and Bioelectronics Division, Japan Society of Applied Physics (2021).
IZAWA, Seiichiro; The Young Scientist Award, Molecular Electronics and Bio Electronics Division in the Japan Society of Applied Physics (2021).
IZAWA, Seiichiro; Konica Minolta Imaging Science Encouragement Award (2021).
IZAWA, Seiichiro; The Outstanding Presentation Award of the 31st Japan OLED Forum (2021).