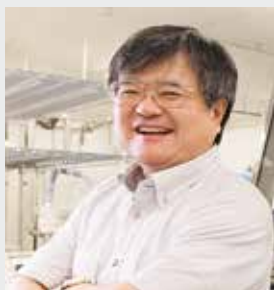


Organic Solar Cells

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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 establishment of “bandgap science for organic solar cells.” We believe that the following features are indispensable. (a) Organic semiconductors purified to sub-ppm level, at least seven nines (7N; 0.1 ppm), should be used. (b) A ppm-level doping technique should be developed. (c) Every individual organic semiconductor should be capable of displaying both *n*- and *p*-type characteristics by impurity doping alone, i.e., complete *pn*-control should be developed. (d) Unintentional and uncontrollable doping by oxygen and water from air should be completely eliminated. (e) The doping technique should be applicable not only to single organic semiconductor films, but also to codeposited films consisting of two kinds of organic semiconductors since a key element for exciton dissociation in organic solar cells is having a co-deposited films.

Recently, we have showed that in principle, almost all single organic semiconductors can be controlled to both *n*-type and *p*-type by doping alone, similar to the case of inorganic semiconductors (Figure 1). This can be regarded as a foundation for the construction of high efficient organic solar cells.

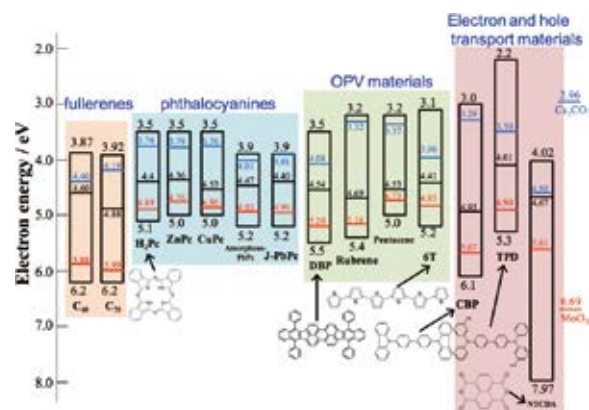


Figure 1. Energy diagrams of various organic semiconductor films. The black, red, and blue lines show the energetic position of E_F for non-doped, acceptor dopant (MoO_3)-doped, and donor dopant (Cs_2CO_3)-doped films. The doping concentration is 3,000 ppm. E_F values for MoO_3 and Cs_2CO_3 films (100 nm) are also shown.

Selected Publications

- C. Ohashi, Y. Shinmura, M. Kubo and M. Hiramoto, “ppm-Doping Effects in the Simplest n^+p -Homojunction Organic Photovoltaic Cells,” *Org. Electron.* **27**, 151–154 (2015).
- M. Hiramoto, M. Kubo, Y. Shinmura, N. Ishiyama, T. Kaji, K. Sakai, T. Ohno, M. Izaki and M. Hiramoto, “Bandgap Science for Organic Solar Cells,” *Electronics* **3**, 351–380 (2014).
- M. Kubo, K. Iketaki, T. Kaji and M. Hiramoto, “Conduction Type Control of Fullerene Films from *n*- to *p*-Type by Molybdenum Oxide Doping,” *Appl. Phys. Lett.* **98**, 023302 (3 pages) (2011).

1. Effects of Doping at the ppm Level in Simple n^+p -Homojunction Organic Photovoltaic Cells

We believe that a doping technique for very low concentrations of the order of parts per million should be developed. In this study, we adopted the simplest n^+p -homojunction cell that has a one-sided abrupt junction (Figure 2). The acceptor (FeCl_3) doping concentration in the p -layer was varied from the extremely low concentration of 1 ppm up to 1,000 ppm.

Figure 3(a) shows the dependences of short-circuit photocurrent (J_{sc}) and the fill factor (FF) on doping concentration. The doping effect of extremely low concentrations of the order of 1 ppm was confirmed. The doping effects can be divided into three regions. From 0 to 10 ppm, both FF and J_{sc} increase rapidly. From 10 to 100 ppm, J_{sc} still increases while FF maintains a constant value. From 100 to 1,000 ppm, both J_{sc} and FF decrease.

Figure 3(b) shows the dependences of the fill factor (FF) and the cell resistance (R_s) on doping concentration from 0 to 100 ppm. Clearly, R_s decreases and FF increases from 0 to 10 ppm. Once acceptor doping is performed, holes and electrons inevitably act as majority and minority carriers, respectively. Thus, we conclude that the increase in FF at 10 ppm doping is due to the appearance of majority carriers in the p -layer.

Figure 3(c) shows the dependences of J_{sc} and the built-in potential (V_{bi}) on doping concentration from 0 to 1,000 ppm. Clearly, there is a close relationship between J_{sc} and V_{bi} . In particular, there are simultaneous increases in J_{sc} and V_{bi} at the relatively low doping concentrations of 10 and 100 ppm. Based on these considerations, we conclude that the increase in J_{sc} is due to the increase in V_{bi} , that is, the formation of an n^+p -homojunction.

The decreases in FF and J_{sc} from 100 to 1,000 ppm doping (Figure 3(a)) are caused by the decrease in mobility of the majority carriers as a result of the disturbance of hopping transport by dopant molecules and by the decrease in the width of depletion layer, respectively.

The most important technical significance of the doping is the intentional design of built-in potentials in the cells. We believe that a new design concept that includes the doping technology needs to be developed in order to realize a high-performance cell.

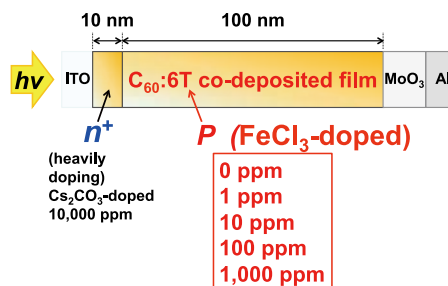


Figure 2. Structure of n^+p -homojunction cell with a one-sided abrupt junction.

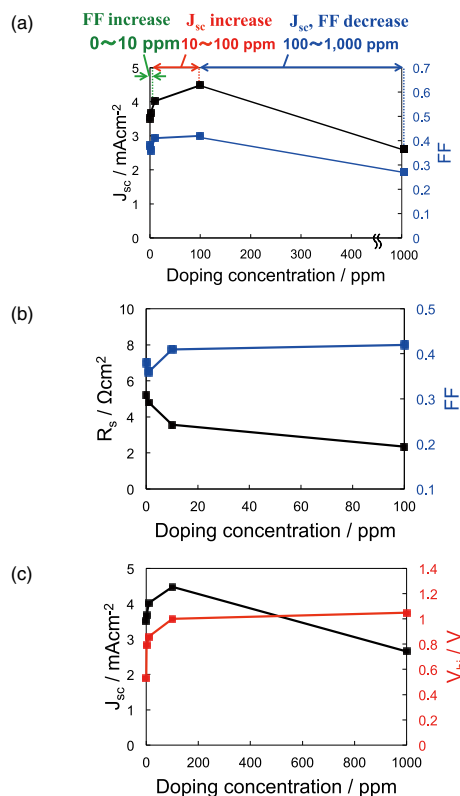


Figure 3. (a) Dependences of short-circuit photocurrent (J_{sc}) and the fill factor (FF) on doping concentration. (b) Dependences of FF and the cell resistance (R_s) on doping concentration. (c) Dependences of J_{sc} and the built-in potential (V_{bi}) on doping concentration.