

Effects of different materials use for internal floating electrode on the photovoltaic properties of tandem type organic solar cell

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1. Introduction

Due to the potential for very low cost solar energy conversion, organic solar cells based on organic thin films have attracted much attention. Organic heterojunction cells using 3,4,9,10-perilene-tetracarboxylic-bis-benzimidazole (PTCBI) and copper phthalocyanine (CuPc) as an acceptor and donor respectively, which gave high conversion efficiency exceeding 1.0 %, have been intensively studied [1-3]. Meanwhile, the improvement both of the Voc and the PCE has been achieved by multiple-heterojunction cells incorporating internal Ag clusters structure [4]. The use of internal floating electrodes in organic solar cells was proposed as early as 1991, although PCE was rather low[5].

The ITO/CuPc/PTCBI/Ag type cell produces negative voltage on the Ag electrode. On the other hand, the ITO/PTCBI/CuPc/Au type cell gave positive voltage on the Au electrode. Thus it is expected that the use of different metal for floating internal electrodes may provide new features in multiple-heterojunction solar cells. In this paper, we report our investigation on the triple-heterojunction structure based on PTCBI and CuPc. Two electrode materials, Ag and Au in addition to the ITO electrode were chosen both as an internal floating electrode and a top electrode. Ag and Au were chosen as representative of electrodes which have workfunction lower and higher than that of ITO, respectively. Effects of internal floating and top electrode material on photovoltaic characteristics, and effects of the deposition sequence of organic layers in the individual HJ cells on the polarity of device output voltage were studied. In addition, we also investigated the effect of PEDOT layer thickness on the photovoltaic characteristics.

2. Experiment

First, precleaned ITO substrate was coated with polyethylene-dioxythiophene (PEDOT) layer by spin coating (at 4000 rpm for 40 s), followed by 30 min drying at 110 °C. PTCBI and CuPc, were purified by train sublimation. The PTCBI and CuPc layers were deposited by thermal evaporation in a vacuum of about 2×10^{-6} Torr, at a rate of 1-2 Å/s. For the purpose of simplification, we use notations, type-A and type-B devices based on the deposition sequence of organic layer: The deposition sequence of the HJ cell for type-A (PTCBI/CuPc) starts with the PTCBI layer, and followed by the CuPc layer, while for the type-B (CuPc/PTCBI) starts with the CuPc layer, and

followed by the PTCBI layer. In the cases for the fabrication of multiple HJ cells, an ultrathin (~ 1 nm) Ag or Au layer is inserted as an internal floating electrode between each single HJ cell. The triple-HJ cells were fabricated by repeating three times of individual-HJ. Top electrode (Ag or Au) was deposited through a shadow mask, so that the active area of the devices was $2 \times 2 \text{ mm}^2$. We also fabricated the similar devices with a thinner PEDOT layer at 6000 rpm for 60 s for comparisons. The current-voltage characteristics of the devices were measured with a Keithley 238 source-measure unit both under dark and under illumination of 100 mW/cm^2 white light provided from a 1.5 AM solar simulator in the air at room temperature.

3. Result and discussions

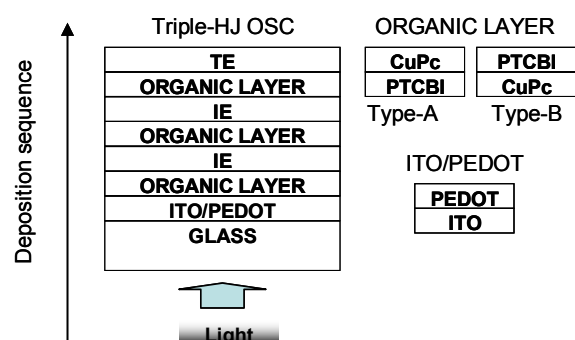


Fig. 1. Structure of triple-HJ organic solar cell. Type-A is a device which the deposition sequence is PTCBI/CuPc. While Type-B is a device which the deposition sequence is CuPc/PTCBI. IE and TE are internal floating electrode and top electrode respectively.

Figure 2 shows the current-voltage characteristics of three-HJ both type-A and type-B devices. For the type-A device, the highest Voc and PCE were achieved when both internal and top electrode is Au with order of 1.35 V and 1.61 % respectively. Meanwhile, for the type-B device, the highest Voc and PCE are order of 1.5 V and 1.86 % respectively. These highest performances were achieved when both internal floating and top electrode of devices is Ag. The values of Voc and PCE drastically decrease when the materials of internal and top electrode are different.

Similar device with a thinner PEDOT layer gave higher performance than it of the previous devices. For the type-A

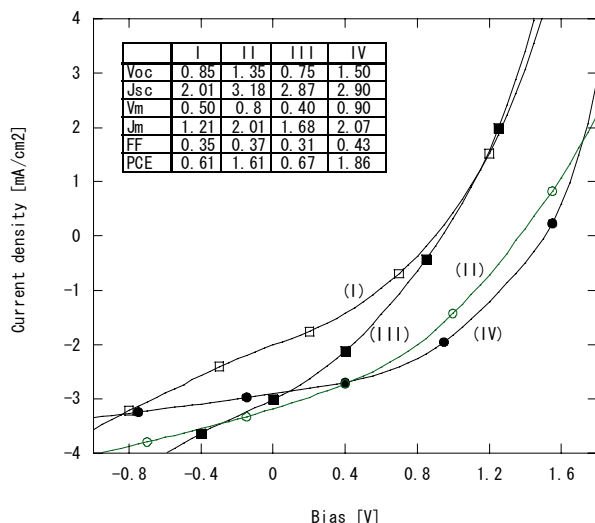


Fig. 2. J-V characteristic of triple-HJ cells by varying the electrode materials. For the type-A with Au top-electrode, and inserted by metal internal floating electrode: Ag (I) or Au (II). For the type-B with Ag top-electrode, and inserted by metal internal electrode: Au (III) or Ag (IV). Inset: table of current-voltage characteristics.

device (with Ag electrode material), the Jsc, Voc and PCE are order of 4.59 mA/cm², 1.5 V and 2.37% respectively. Meanwhile, for the type-B device (with Au electrode material), the Jsc, Voc and PCE are order of 4.92 mA/cm², 1.3 V and 2.27% respectively (Fig. 3).

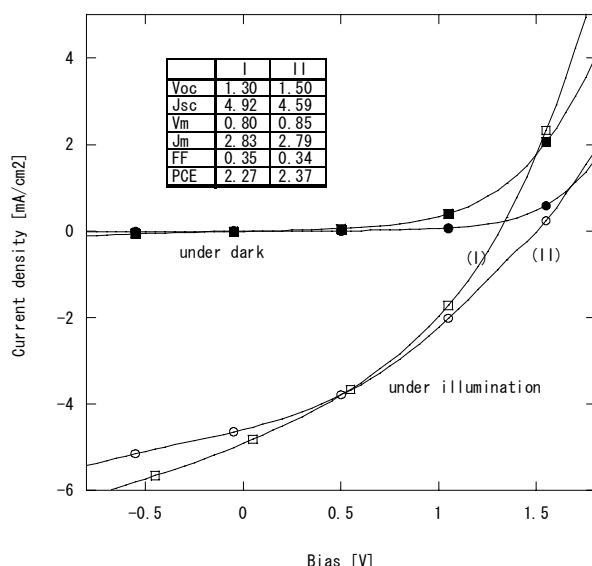


Fig. 3. J-V characteristics under dark and under illumination of triple-HJ cells using thinner PEDOT layer. Type-A device with Au electrode (I), and device type-B with Ag electrode (II). Inset: table of current-voltage characteristics.

It has been assumed that the Fermi level pinning mechanism is dominant for the contact formation between organic layer and top electrode. In the case of our devices, Au is favor as a top electrode for type-B device, while Ag is favor as a top electrode for the type-A devices [6,7]. The Voc is the difference between the Fermi level of acceptor and donor materials, so that the total of Voc in the multi-HJ cell is the sum of the voltage contributions from the individual cells follows from the alignment of Fermi levels both cells by the thin metal internal electrode [8]. It suggests that charge combination without voltage loss occurs in these internal floating electrodes. By using the thinner PEDOT layer, it leads to decrease the series resistance of devices without decreasing the Voc, so that increase the current density and PCE simultaneously.

4. Conclusions

Triple-HJ devices with metal internal floating electrodes have been prepared. The open-circuit voltages were nearly three times higher than it of the single-HJ devices. The high performance of triple-HJ cell can be achieved when the internal floating and top electrode are in the same material. Power conversion efficiency increased by stacking heterojunctions, but was less than three times due to the decrease of current density in multi-HJ devices. Optimization of layer thickness, selection of electrode materials, and stacking of different heterojunction materials may contribute the increase of efficiency.

Reference

- [1] C.W. Tang, Appl. Phys. Lett. 43, 183 (1986).
- [2] T. Tsutsui, T. Nakashima, Y. Fujita, and S. Saito, Synt. Met., 71, 2281 (1995).
- [3] P. Peumans, V. Bulovic, and S. R. Forrest, Appl. Phys. Lett. 76, 2650 (2000).
- [4] A. Yakimov and S.R. Forrest, Appl. Phys. Lett. 80, 1667 (2002).
- [5] M. Hiramoto, M. Suezaki, and M. Yokoyama, Chem. Lett., 327 (1990).
- [6] C. J. Brabec, A. Cravino, D. Meissner, N. S. Sariciftci, T. Fromherz, M.T. Ripens, L. Sanchez, and J. C. Hummelen, Adv. Funct. Mater. 11, 374 (2001).
- [7] C. Shen, and A. Khan, Org. Elect. 2, 89 (2001).
- [8] P. Peumans, A. Yakimov, and S. R. Forrest, J. Appl. Phys., 93, 3693 (2003).