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Photovoltaic Properties of Ultramicrostructure-Controlled Organic Co-Deposited Films

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1. Introduction

Ability of the photocarrier generation of organic semiconductors can be enhanced by mixing two kinds of organic molecules. For example, we observed high photo-electric conversion efficiency in the mixed organic films of metal-free phthalocyanine (H_2Pc) and perylene (Me-PTC) pigments (Fig. 1), which were fabricated by the co-deposition technique [1, 2]. However, carrier generation in such co-deposited films is expected to be crucially affected by the nano-level structure of mixed two pigments. From this standpoint of view, we have tried to control the ultramicrostructure of co-deposited films by the substrate temperature. Remarkable improvements of photovoltaic properties was achieved for the films co-deposited on the cooled substrate.

2. Experiment

Mixed layers were prepared by the co-deposition of H_2Pc and Me-PTC from two separate controlled sources onto the substrate at temperatures of 50, 25, -80, and -170°C. Mixing ratio of two pigments was always 1:1. Photovoltaic properties were evaluated by the single-layered cells (Fig. 2) and by the three-layered cells (Fig. 3). Three-layered cells, in which the co-deposited layer was incorporated as an interlayer sandwiched between p-type H_2Pc and n-type Me-PTC layers, have quasi-pin energy structure [2]. Ultramicrostructure of co-deposited films were evaluated by atomic force microscopy (AFM) and by X-ray diffraction (XRD).

3. Results

3.1 Photovoltaic Properties of Co-deposited Films

Figure 2 shows the substrate temperature dependence of the short-circuit photocurrent (J_{sc}) of single-layered H_2Pc:Me-PTC (1:1) cells. Interestingly, the co-deposited film evaporated on the substrate cooled at -170°C revealed to be able to generate 15 times larger photocurrent compared to that evaporated on the substrate at room-temperature. High performance of low-temperature fabricated film was also appeared in the three-layered cells, i.e., about 5 times larger J_{sc} of 2.42 $mAcm^{-2}$ (100 $mWcm^{-2}$, AM1.5) compared to the room-temperature fabricated film was observed (Fig. 3). Maximum quantum efficiency of J_{sc} reaching 50% was observed for the monochromatic light of 420 nm irradiated on the Au electrode.

3.2 Ultramicrostructure of Co-deposited Films

Enhancement of the photocurrent was revealed to be closely related to the ultramicrostructure of co-deposited films. Figure 4 shows the AFM images for the surface of co-deposited films fabricated at room temperature (a) and at -170°C (b). The former film was considerably flat and revealed to be amorphous. On the contrary, the latter film contains a lot of nanoparticle of the diameter of about 20 nm. XRD measurements showed that these particles are Me-PTC nanocrystals and H_2Pc is amorphous.

4. Discussion

We concluded that room-temperature fabricated films have structure of molecular-level mixture of two pigments, while low-temperature fabricated films have structure containing Me-PTC nanocrystals surrounded by amorphous H_2Pc (Fig. 5). Efficient photocurrent generation seems to be due to the large area contact between two pigments and the formation of individual routes for photogenerated electrons and holes. Advantage of low-temperature fabricated films is conspicuous for the thicker films (Fig. 6). Since considerable portion of the incident light can be absorbed by the 100 nm-thick co-deposited film, we think that the present co-deposited films with both high photocarrier generation efficiency and sufficient thickness for light absorption have a potential to make efficient photovoltaic cells.

References

[1] M. Hiramoto, H. Fujiwara, and M. Yokoyama, Appl. Phys. Lett., **58**, 1062 (1991).
[2] M. Hiramoto, H. Fujiwara, and M. Yokoyama, J. Appl. Phys., **72**, 3781 (1992).

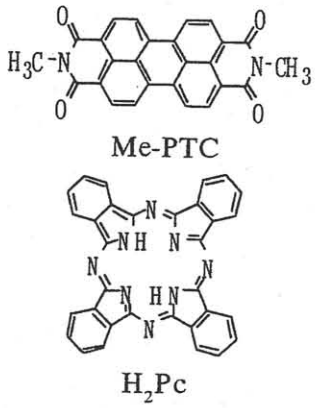

Fig. 1 Organic semiconductors used.

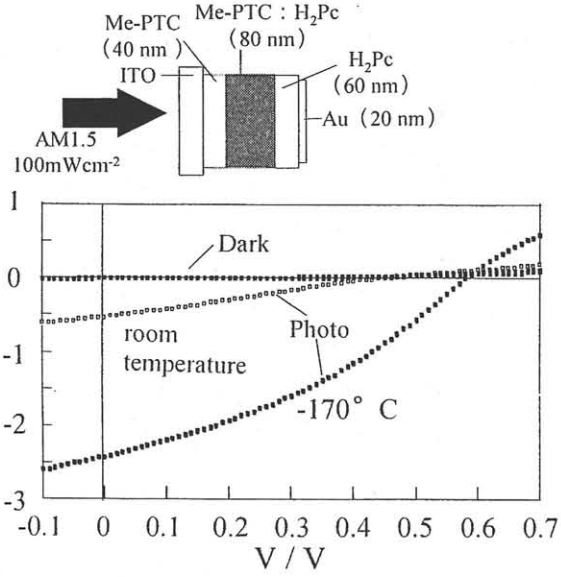

Fig. 3 Photocurrent-voltage (J-V) characteristics of three-layered cells.

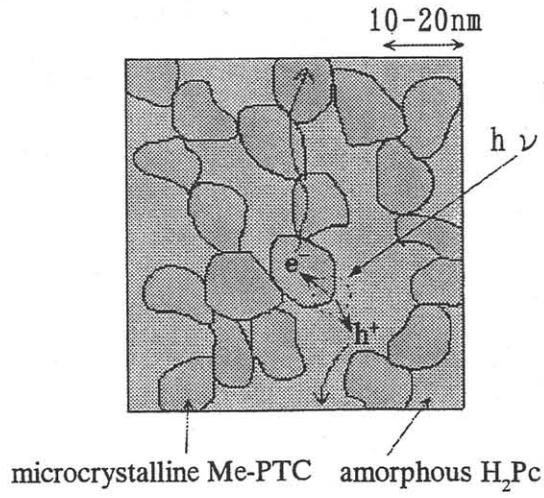

Fig. 5 Ultramicrostructure of H_2Pc:Me-PTC film co-deposited on cooled substrate.

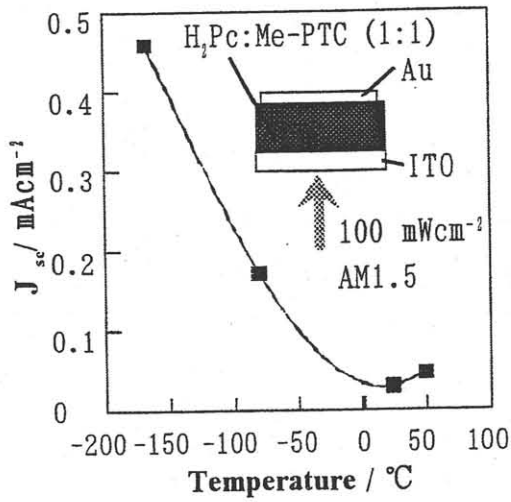

Fig. 2 Substrate temperature dependence of short-circuit photocurrent (J_{sc}) of single-layered H_2Pc:Me-PTC cell.

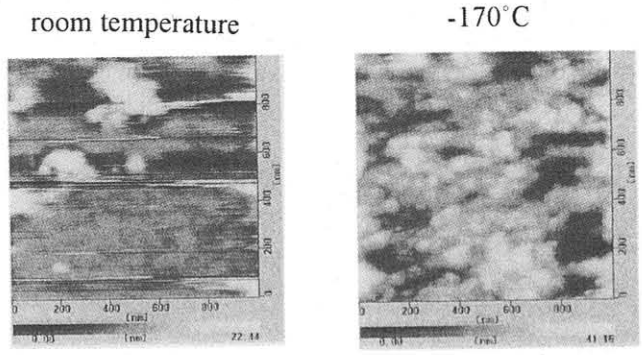

Fig. 4 AFM images (1000 x 1000 nm) of H_2Pc:Me-PTC films.

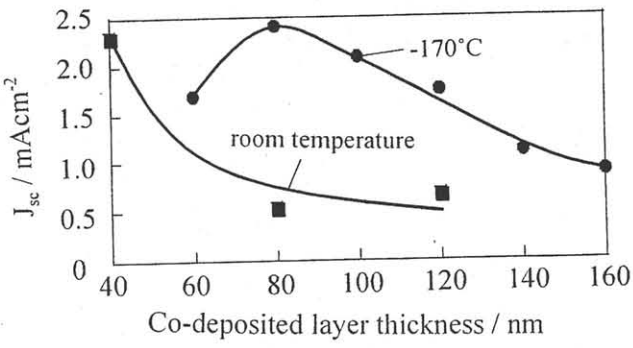

Fig. 6 Dependence of J_{sc} on the co-deposited layer thickness in three-layered cells.