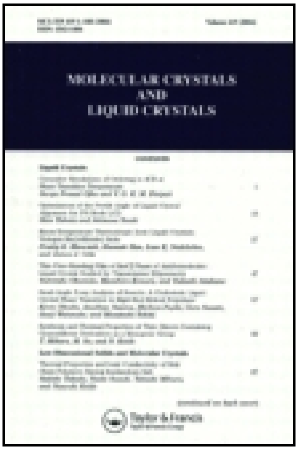

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

Organic Photovoltaic Effects Using CuPc/C $_{60}$ LAYER

Hyun Oh [a], Dong Chung [a], Chung Kim [a], Joon Lee [a], Sung Hur [b], Sang Kim [b], Tae Kim [b] & Jong Park [c]

[a] Department of Electrical Engineering, Kwangwoon University, Seoul, Korea

[b] Department of Physics, Hongik University, Seoul, Korea

[c] Department of Chemistry/Center for Nonotechnology Research, Catholic University, Pucheon, Korea

Version of record first published: 18 Oct 2010

Mol. Cryst. Liq. Cryst., Vol. 424, pp. 225–232, 2004

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400490506225

ORGANIC PHOTOVOLTAIC EFFECTS USING $CuPc/C_{60}$ LAYER

Hyun Seok Oh, Dong Hoe Chung, Chung Hyeok Kim, and Joon Ung Lee
Department of Electrical Engineering, Kwangwoon University, Seoul 139-701, Korea

Sung Woo Hur, Sang Keol Kim, and Tae Wan Kim
Department of Physics, Hongik University, Seoul 121-791, Korea

Jong Wook Park
Department of Chemistry/Center for Nonotechnology Research, Catholic University, Pucheon 420-743, Korea

We have fabricated two types of photovoltaic cells using $CuPc/C_{60}$ layer, and studied photovoltaic effects of these devices using xenon light source. One type of device is ITO/CuPc/C_{60}/BCP/Al and the other is ITO/PEDOT:PSS/CuPc/C_{60}/BCP/Al. The PEDOT:PSS layer was made by spin coating, and the other organic layers were made by thermal vapor deposition. By measuring the current-voltage characteristics under an illumination intensity of light in the range of $10 \sim 400\,mW/cm^2$, we have obtained open-circuit voltage V_{OC}, short-circuit current density J_{SC}, fill factor and efficiency of the device. As the light intensity increases, the J_{SC} increases as well in the both devices. The V_{OC} remains to be constant 0.31 V in the device without PEDOT:PSS layer irrespective of the light intensities. However, there is a little variation of V_{OC} in device with PEDOT:PSS layer depending on the light intensity.

Keywords: CuPc; organics; photovoltaic effects; solar cells

Received 1 October 2003; accepted 7 January 2004.

This work was supported by grant No. R01-2002-000-00347-0 from the research program of KOSEF.

Address correspondence to Prof. Tae Wan Kim, Department of Physics, Hongik University, 72-1 Sangsu-Dong, Mapo-Gu, Seoul 121-791, Korea. Tel.: +82-2-320-1626, Fax: +82-2-3142-0335. E-mail: taekim@wow.hongik.ac.kr

1. INTRODUCTION

Recently, there is a growing concern on the photovoltaic effects using organic materials. Organic photovoltaic effects become attractive because of potential applications in industry of solar cells. This is a phenomenon which converts the solar energy into the electrical one. Natural resources such as petroleum and coal are expected to be exhausted over the next few generations. However, it is not easy to find efficient substituted energy sources. To overcome such circumstances, lots of efforts are being progressed to use solar energy which is indefinite in nature and environmentally friendy.

Even though the efficiency of present organic photovoltaic device is less than a few %, organic photovoltaic cell is still a promising candidate. In fact, organics have an advantage in cost, thin-film formation, and flexibility [1,2]. In 1986, Tang developed the photovoltaic devices using CuPc/PV organic materials with an energy conversion efficiency of about 1% [3]. Since then, the conversion efficiency of organic photovoltaic device is being improved with a use of low molecule or polymeric materials [3–9].

In this paper, we report the photovoltaic effects in device structures with and without PEDOT:PSS layer. We have made two types of photovoltaic devices. One is ITO/CuPc/ C_{60}/BCP/Al and the other is ITO/PEDOT:PSS/CuPc/C_{60}/BCP/Al under the illumination of xenon lamp. The polymer PEDOT:PSS is a well-known material in organic light-emitting diodes in improving the efficiency of devices.

2. EXPERIMENTAL

The indium-tin-oxide (ITO) glass, having a sheet resistance of $15\Omega/\square$ and 170 nm thick, was received from Samsung Corning Co. A 5 mm wide ITO strip line was formed by selective etching in vapor of solution made with hydrochloric acid (HCl) and nitric acid (HNO_3) with a volume ratio of 3:1 for $10 \sim 20$ minutes at room temperature. Then, the patterned ITO glass was cleaned by sonicating it in chloroform for 20 minutes at 50°C. Then, the ITO glass was heated at 80°C for 1 hour in solution made with second distilled deionized water, ammonia water and hydrogen peroxide with a volume ratio of 5:1:1. We sonicated the substrate again in chloroform solution for 20 minutes at 50°C and in deionized water for 20 minutes at 50°C. After sonication, the substrate was dried with N_2 gas stream and stored it under vacuum.

Figure 1 shows a structure of photovoltaic devices used in our experiment. The PEDOT:PSS layer was fabricated onto pre-cleaned ITO by static spin-casting method for 40 seconds at 4000 rpm using photo-resist spinner

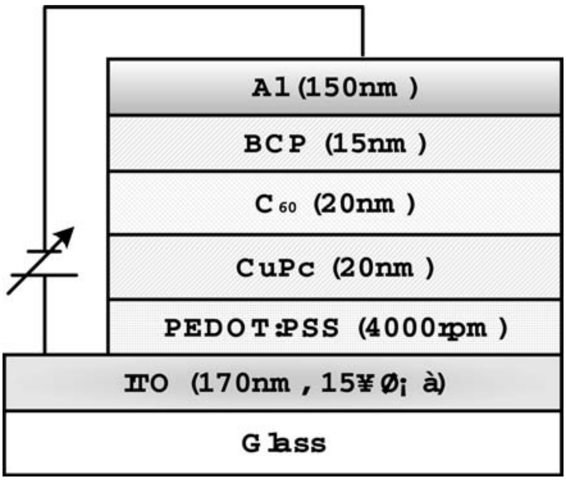

FIGURE 1 Structure of photovoltaic formed onto ITO glass.

of Headway Research Inc. It was dried for 15 minutes at 90°C in vacuum. We have used CuPc (copper phthalocyanine) as a n-type donor, C_{60} (fullerene) as a p-type acceptor and BCP (bathocuproine) as an exciton-blocking layer. The BCP transports electrons to the cathode from the adjacent acceptor layer and it effectively blocks excitons as well. The organic materials were successively evaporated under 10^{-6} torr at a rate of about $0.5 \sim 1$ Å/s. The film thickness of CuPc was made to be 20 nm, and that of C_{60} and BCP was 20 nm and 15 nm, respectively. Al cathode(150 nm) was deposited at 1.0×10^{-5} torr. Light-emitting area was defined using a shadow mask to be $0.3 \times 0.5\,cm^2$.

Photovoltaic effects of organic cells were measured using Keithley 236 source-measure unit and a 500 W xenon lamp (ORIEL 66021). Light intensity of lamp was measured by radiometer/photometer of International Light Inc (IL14004). All measurements were carried out at room temperature.

3. RESULTS AND DISCUSSION

Figure 2 shows current-voltage characteristics of ITO/CuPc/C_{60}/BCP/Al device when the light from xenon lamp is illuminated to the device. The light intensity of the beam was adjusted to be 10, 25, 100, and 400 mW/cm^2. From the current-voltage characteristics, we can obtain two important parameters, which are x- and y-intercept in the curve. One is open-circuit voltage V_{OC} (x-intercept) and the other is short-circuit current density J_{SC}

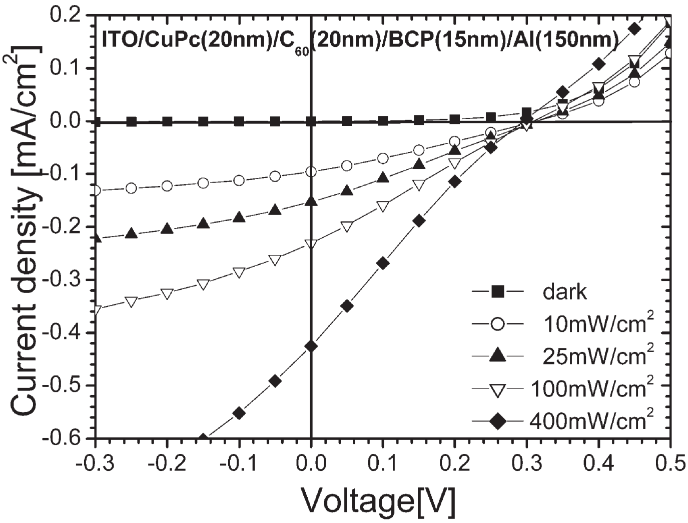

FIGURE 2 Current density-voltage characteristics of ITO/CuPc/C_{60}/BCP/Al device at four different light intensities.

(y-intercept). In the figure, when the light intensity is 10 mW/cm^2, the J_{SC} and V_{OC} are 0.10 mA/cm^2 and 0.31 V, respectively. As the intensity of the light increases, the short-circuit current density J_{SC} increases as well. However, the open-circuit voltage V_{OC} remains to be constant 0.31 V, irrespective of the light intensity.

Figure 3 shows the current-voltage characteristics in ITO/PEDOT:PSS/CuPc/C_{60}/ BCP/Al devices under the same illumination of light as in Figure 2 to see the effect of PEDOT:PSS layer in the device. In these devices, the short-circuit current density J_{SC} increases as the intensity of the light increases, which is the same trend as in Figure 2. However, the J_{SC} increases by 50% or so when the PEDOT:PSS layer is introduced to the device at the same intensity of light.

Figure 4 shows the open-circuit voltage V_{OC} depending on the intensity of light in two device structures we used. The V_{OC} is a potential different across the electrodes of photovoltaic cell when there is no current flow in the device. The V_{OC} is originated from the Fermi energy difference of the electrodes, and energy level (HOMO/LUMO) of the organics. Thus the V_{OC}, in first approximation, is independent of the light intensities. As is seen in the figure, the value of V_{OC} is almost constant 0.31 V in the device without PEDOT:PSS layer irrespective of the light intensity. When the PEDOT:PSS layer is introduced to the device, there is a little variation of V_{OC} from 0.26 V to 0.38 V as the intensity of the light increases. It is thought that this

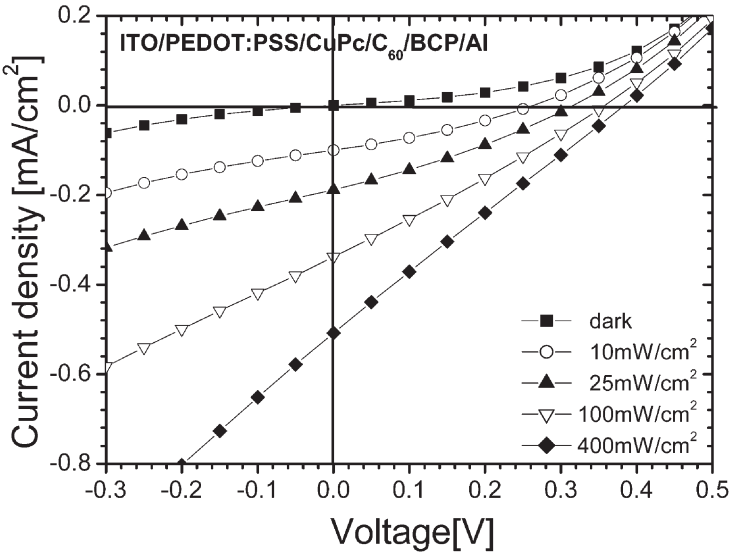

FIGURE 3 Current density-voltage characteristics of ITO/PEDOT:PSS/CuPc/C_{60}/BCP/Al device at four different light intensities.

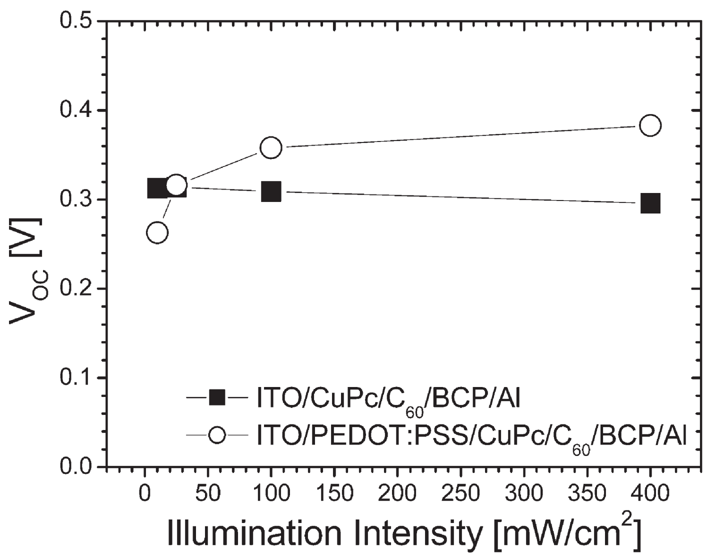

FIGURE 4 Open-circuit voltage V_{OC} as a function of illumination intensity of light in two types of photovoltaic devices.

small variation of V_{OC} comes from the sensitive response of PEDOT:PSS layer to the light.

Figure 5 shows the absolute value of short-circuit current density J_{SC} depending on the intensity of the light. The J_{SC}, in general, depends on the intensity of illuminated light and the spectrum of light. In addition to these light conditions, it also depends on how effectively the electrons and holes transport to the external electrodes without having loss such as a recombination of carriers. The recombination loss is expected to be occurred inside or at the interface of the materials. In both type of devices we fabricated, the J_{SC} increases as the intensity of light increases as expected. It indicates that the more carriers are excited as the light intensity increases. When the light intensity is 10 mW/cm^2, the J_{SC} is about 0.10 mA/cm^2 in two devices. However, when the light intensity is 400 mW/cm^2, the J_{SC} is 0.43 mA/cm^2(without PEDOT:PSS layer) and 0.51 mA/cm^2(with PEDOT:PSS).

Figure 6 shows a measured fill factor (FF) of the devices depending on the light intensity. The FF is a measure how the current-voltage curve is close to the rectangular shape. While the open circle in the figure represents the FF in the device with PEDOT:PSS layer, the closed rectangle is the one in the device without PEDOT:PSS layer. As is seen in the figure, the FF at 10 mW/cm^2 is 0.28 in the device without PEDOT: PSS layer,

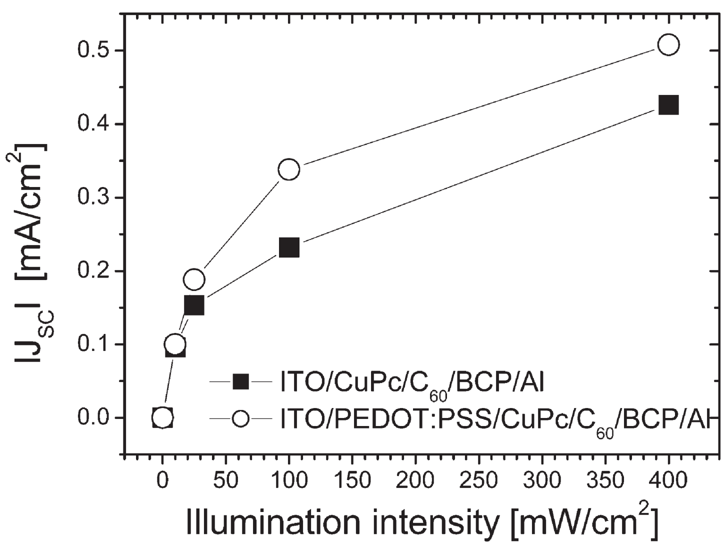

FIGURE 5 Short-circuit current density $|J_{SC}|$ as a function of illumination intensity of light in two types of photovoltaic devices.

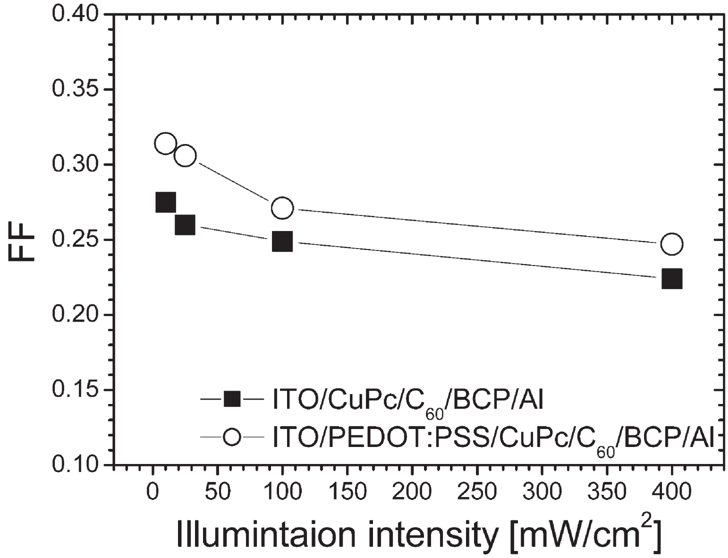

FIGURE 6 Fill factor (FF) as a function of illumination intensity in two types photovoltaic devices.

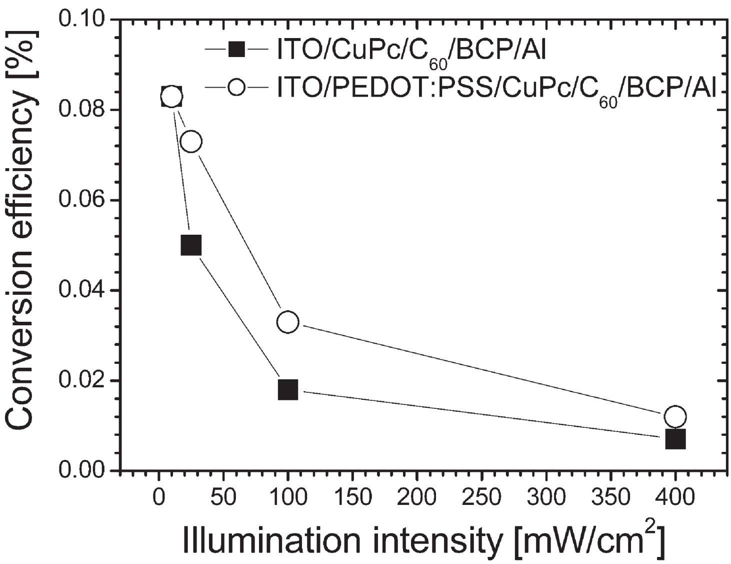

FIGURE 7 Conversion efficiency as a function of illumination intensity in two types of photovoltaic devices.

and 0.31 with PEDOT:PSS layer. The FF decreases as the light intensity increases.

Figure 7 shows the energy conversion efficiency as a function of the light intensity. The efficiency of device is the ratio between a maximum electrical power output and an incident light power. Both devices show the efficiency of 0.08% at 10 mW/cm^2 of illumination intensity. Then it decreases down to 0.01% as the incident light intensity increases to 400 mW/cm^2.

4. CONCLUSION

We have studied the photovoltaic properties of the organic devices using the CuPc/C_{60} heterojunction layer with a light source of xenon lamp. We have made two types of device structures to see the effect of PEDOT:PSS layer ; one is ITO/CuPc/C_{60}/ BCP/Al and the other is ITO/PEDOT:PSS/CuPc/C_{60}/BCP/Al. The short-circuit current density J_{SC} increases as the intensity of the light increases. In the device with PEDOT:PSS layer, the J_{SC} increases by 50% or so. The open-circuit voltage V_{OC} is about constant irrespective of the light intensity in the device without PEDOT:PSS layer. However, there is a small variation of V_{OC} in the device with PEDOT:PSS layer. The PEDOT:PSS layer improves the fill factor and efficiency a little bit.

5. REFERENCES

[1] Ziemelis, K. (1998). *Nature*, *393*, 619.
[2] Murgia, M., Biscarini, F., Cavallini, M., Taliani, C., & Ruani, G. (2001). *Synth. Met.*, *121*, 1533.
[3] Tang, C. W. (1986). *Appl. Phys. Lett.*, *48*, 183.
[4] Halls, J. J. M., Walsh, C. A., Greenham, N. C., Marseglia, E. A., Friend, R. H., Moratti, S. C., & Holmes, A. B. (1995). *Nature* (London), *376*, 498.
[5] Peumans, P., Bulovic, V., & Forrest, S. R. (2000). *Appl. Phys. Lett.*, *76*, 2650.
[6] Peumans, P. & Forrest, S. R. (2001). *Appl. Phys. Lett.*, *79*, 126.
[7] Yu, G., Gao, J., Hummelen, J. C., Wudl, F., & Heeger, A. J. (1995). *Science*, *270*, 1789.
[8] Schon, J. H., Kloc, Ch., Bucher, E., & Batlogg, B. (2000). *Nature* (London), *403*, 408.
[9] Schon, J. H., Kloc, Ch., & Batlogg, B. (2000). *Appl. Phys. Lett.*, *77*, 2473.