Dependence of Photovoltaic Effects in Organic Semiconductors on the BCP Layer Thickness

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We fabricated solar-cell devices based on zinc-phthalocyanine (ZnPc) as a donor (D) and fullerene (C$_{60}$) as an electron acceptor (A) with doped charge transport layers and with bathocuproine (BCP) an exciton blocking layer (EBL). We measured the photovoltaic characteristics of the solar-cell devices by using a Xenon lamp as a light source. Several thicknesses of BCP were made between C$_{60}$ and Al, and we obtained characteristic parameters such as the short-circuit current, the open-circuit voltage, and the power conversion efficiency of the device. With an EBL, the fill factor and the power conversion efficiency were 0.57 and 0.435 %, respectively, at 100 mW/cm$^2$.

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I. INTRODUCTION

In recent years, the power conversion efficiency of thin-film organic photovoltaic (PV) cells have increased steadily and rapidly. These improvements have come from the introduction of device concepts, such as the donor-acceptor (DA) heterojunction, the exciton-blocking layer (EBL), and highly doped crystalline materials. The photovoltaic effect is a way of converting solar radiation into electricity, which was first discovered by Becquerel [1]. These days, the solar power conversion efficiency of a monocrystalline silicon solar-cell can reach up to 24 % [2]. However, a production of this kind of inorganic device requires difficult manufacturing processes with high temperatures and numerous lithographic steps [3,4].

Most of the small molecules used in organic photovoltaic cells are deposited using thermal evaporation to obtain a desired film thickness [5,6]. These photovoltaic cells have been intensively studied for the last ten years. In 1986, Tang developed a photovoltaic cell using CuPc/PV organic materials and obtained a solar power efficiency of about 1 % with corresponding external quantum efficiency of about 30 % [7]. Thus, we studied the dependence of the photovoltaic effects on the photoactive organic layer’s thickness and the EBL. In this paper, we report the photovoltaic effects for an ITO/ZnPc/C$_{60}$/BCP/Al device structure.

II. EXPERIMENTS

Indium-tin-oxide (ITO) glass having a sheet resistance of 15 Ω/□ was received from Samsung Corning Co. The
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Fig. 1. Schematic of the energy band diagram in a PV cell.

Fig. 2. Current density-voltage characteristics of an ITO/ZnPc(20 nm)/C60/Al device for various thicknesses of C60 at 100 mW/cm².

Fig. 3. Current density-voltage characteristics of an ITO/ZnPc(20 nm)/C60(40 nm)/BCP(10 nm)/Al device under illumination.

Fig. 4. Power conversion efficiency-thickness characteristics of an ITO/ZnPc(20 nm)/C60(40 nm)/BCP/Al under illumination.

line-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 h in a solution made with twice distilled deionized water, ammonia water, and hydrogen peroxide with a volume ratio of 5 : 1 : 1. We sonicated the substrate again with chloroform for 20 minutes at 50 °C and in deionized water for 20 minutes at 50 °C. After sonicating the substrate, we dried it with N2 gas stream and stored it under vacuum.

Figure 1 shows a schematic structure of a photovoltaic cell and an energy band diagram of the materials used in our experiment. Double-layered organic photovoltaic cells of ITO/ZnPc/C60/Al were fabricated to see the correlation between the photovoltaic performance and the layer thickness of ZnPc (or C60). The thickness was varied from 10 nm to 50 nm, and the layer was deposited using thermal-vapor deposition at 7 × 10⁻⁶ Torr. To compare the performance with that of a photovoltaic cell with an exciton blocking layer, we fabricated a device structure of ITO/ZnPc/C60/BCP/Al. The layer thickness of BCP was varied from 0 nm to 60 nm, and the Al cathode (100 nm) was deposited at 7.0 × 10⁻⁶ Torr by using thermal evaporation. The active cell area of the device was made by using a shadow mask and was 3 mm × 5 mm.

The current density-voltage characteristics of the organic photovoltaic cells were measured by using a Keithley 236 source-measure unit and a 500W xenon lamp (ORIEL 66021). The light intensity on the device was measured by using a radiometer/photometer from International Light Inc. (IL14004). All measurements were carried out at room temperature.

III. RESULTS AND DISCUSSION

Figure 2 shows the current density-voltage characteristics of the ITO/ZnPc(20 nm)/C60/Al device for various thicknesses of C60 under a light intensity of 100 mW/cm². Figure 2 shows that the short-circuit current density for a thickness ratio of 1 : 2 is higher than it is for other ratios.

Figure 3 shows the current density-voltage characteristics of the ITO/ZnPc(20 nm)/C60(40 nm)/BCP(10 nm)/Al device, and Figure 4 shows the power conversion efficiency-illumination intensity characteristics of
ITO/ZnPc/C_{60}(20 nm)/BCP/Al. The BCP transports electrons to the cathode from the adjoining acceptor layer while effectively blocking excitons in the lower-energy-gap acceptor layer from recombining at the cathode. From the current density-voltage characteristics under light illumination, we can obtain two important parameters, the \(x\)- and the \(y\)-intercept of the curve. One is the open-circuit voltage \(V_{OC}\) (\(x\)-intercept), and the other is the short-circuit current density \(J_{SC}\) (\(y\)-intercept). When the BCP layer thickness is increased by 20 nm, there is a big improvement in the conversion efficiency of the device by using a BCP layer, as is seen in Figure 4.

Figure 5 shows the current density-voltage characteristics of an ITO/ZnPc/C_{60}(40 nm)/BCP/Al device for various thicknesses of ZnPc at 100 mW/cm\(^2\). Figure 6 shows the fill factor, and Figure 7 shows that the power conversion efficiency in the device for a thickness ratio of 1 : 2 is much higher than it is for other thickness ratios. Thus we observed that the optimum thickness ratio of the ZnPc : C_{60} layer was 20 nm : 40 nm. We obtained some important parameters.

The short-circuit current density was 1.82 mA/cm\(^2\), the open-circuit voltage was 0.42 V, the fill factor was 0.57, and the power conversion efficiency was 0.435%.

IV. CONCLUSIONS

We studied the dependence of the photovoltaic effects in the device structure of ITO/ZnPc/C_{60}/Al and ITO/ZnPc/C_{60}/BCP/Al on the ZnPc and the C_{60} layer thickness. The ZnPc/C_{60} heterojunction device with a ZnPc/C_{60} thickness ratio of 1 : 2 gives a higher conversion efficiency than the other devices. We confirmed the optimum thickness ratio of the DA heterojunction with a ZnPc : C_{60} layer to be about 1 : 2.

We determined the electrical properties and the photovoltaic properties of organic solar cells employing an EBL layer. We found that the use of a BCP exciton blocking layer improved the conversion efficiency of photovoltaic cells and that the proper layer thickness of BCP was 10 nm. We obtained some important parameters, the short-circuit current density was 1.82 mA/cm\(^2\), the open-circuit voltage was 0.42 V, the fill factor was 0.57, and the power conversion efficiency was 0.435%.

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REFERENCES