Properties of Photovoltaic Cell using ZnPc/C60 Double Layer Devices

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It has been a long time since organic solar cells were expected as a low-cost energy-conversion device. Although practical use of them has not been achieved, technological progress continues. Morphology of the materials, organic/inorganic interface, metal cathodes, molecular packing and structural properties of the donor and acceptor layers are essential for photovoltaic response. We have fabricated solar cell devices based on zinc-phthalocyanine(ZnPc) as donor(D) and fullerene(C_{60}) as electron acceptor(A) with doped charge transport layers, and BCP and Alq_3 as an exciton blocking layer(EBL). We have measured the photovoltaic characteristics of the solar cell devices using the Xe lamp as a light source. We were use of Alq_3 layer leads to external power conversion efficiency was 2.65 % at illumination intensity 100 mW/cm^2. Also we confirmed the optimum thickness ratio of the DA hetero-junction is about 1:2.

Keywords : Photovoltaic cell, EBL, Zinc-phthalocyanine(ZnPc), C60, Alq_3

1. INTRODUCTION

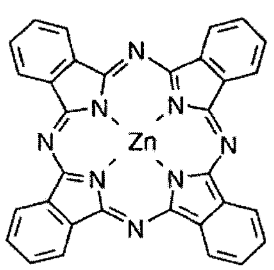
In recent years, the power conversion efficiencies of thin-film organic photovoltaic(PV) cells has increased steadily and rapidly[1,2]. These improvements have come from the introduction of device concepts such as the donor–acceptor(DA) heterojunction blended and laminated DA heterojunctions, the exciton-blocking layer(EBL), and highly doped crystalline materials. A photovoltaic effect is a way of converting solar radiation into electricity, which was first discovered by Becquerel[3,4]. These days, a solar power conversion efficiency of monocrystalline silicon solar cell reached up to 24 %[5]. However, a production of this kind of inorganic device requires difficult manufacturing processes such as high temperatures as well as numerous lithographic steps.

Most of the small molecules used in organic photovoltaic cells are deposited using thermal evaporation to obtain a desired film thickness. 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 %[6-8].

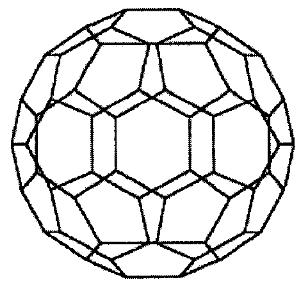
Thus, we have studied the photovoltaic effects depending on the photoactive organic layer thickness and EBL. In this paper, we report the photovoltaic effects in the ITO/ZnPc/C_{60}/BCP/Al and ITO/ZnPc/C_{60}/ Alq_3/Al device structure.

2. EXPERIMENTAL

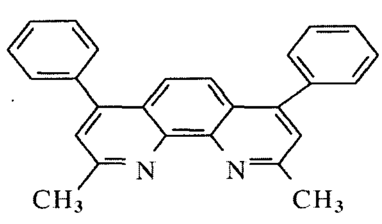
The indium-tin-oxide(ITO) glass, having a sheet resistance of 15 Ω/□ was received from Samsung Corning Co. The line patterned ITO glass was cleaned by sonicating it in chloroform for 20 minutes at 50 °C. And then the ITO glass was heated at 80 °C for 1 hour in solution made with second distilled deionized water, ammonia water and hydrogen peroxide with a volume ratio of 5:1:1. We sonicated the substrate again with a chloroform for 20 minutes at 50 °C and in deionized water for 20 minutes at 50 °C. After sonicating the substrate, it was dried with N_2 gas stream and stored it under vacuum[9].



(a) Zinc Phthalocyaine(ZnPc)



(b) C60



(c) BCP

Fig. 1. Schematic of molecular structure.

Figure 1 shows a schematic of a molecular structure and Fig. 1(a) is, Zinc Phthalocyaine(ZnPc), as an electron acceptor and (b) is C60 as an electron donor and (c) is BCP as an exciton blocking layer(EBL).

Figure 2 shows a schematic structure of photovoltaic cells and energy band diagram of the materials used in our experiment. Double-layered organic photovoltaic cells of ITO/ZnPc/C_{60}/EBL/Al were fabricated to see a correlation between a photovoltaic performance and a ZnPc layer thickness varied from 10 nm to 50 nm made with thermal-vapor deposition at 10^{-6} torr. To compare a performance with exciton blocking layer photovoltaic cells, a device structure of ITO/ZnPc/C_{60}/BCP(or Alq_3)/ Al was also fabricated. The C_{60}, BCP and Alq_3 layer were also made using thermal evaporation. And Al cathode (150 nm) was deposited at 1.0×10^{-6} torr using thermal evaporation as well. An active cell area of device was made using a shadow mask to be 3 mm × 5 mm.

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

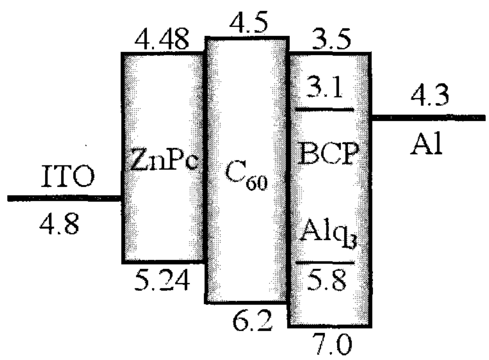


Fig. 2. Schematic the energy band diagram of the PV cell

3. RESULTS AND DISCUSSION

Figure 3 shows the current density-voltage characteristics of ITO/ZnPc/C_{60}/Alq_3/Al and ITO/ZnPc/ C_{60}/BCP/Al devices when the light is illuminated to the device(Light illumination intensity @ 100 mW/cm^2).

From the current density-voltage characteristics under the illumination of light, we can obtain two important parameters, which are x- and y-intercept of the curve. One is open-circuit voltage V_{OC}(x-intercept) and the other is short-circuit current density J_{SC}(y-intercept). So we observed that the optimum thickness ratio of the ZnPc : C_{60} layer was 1:2.

Figure 4 shows the open-circuit voltage of the two PV cells. It shows that the V_{oc}(open-circuit voltage) increases as the illumination intensity increases. The increment rate is higher in PV cell with Alq_3 layer.

Figure 5 shows the shot-circuit current of the two PV cell. The J_{sc}(shot-circuit current density) is almost the same in two PV cells with BCP and the Alq_3 layer. The fill factor(FF) and the power conversion efficiency(PE) are calculated from the Fig. 3 and Fig. 4, and the FF and PE equations are the following.

$$FF = \frac{P_m}{V_{OC} \times J_{SC}} = \frac{V_m \times J_m}{V_{OC} \times J_{SC}} \quad (1)$$

$$\eta = \frac{P_m}{P_{in}} = \frac{V_{OC} \times J_{SC} \times FF}{I_0} \quad (2)$$

Here, I_o is the incident solar power.

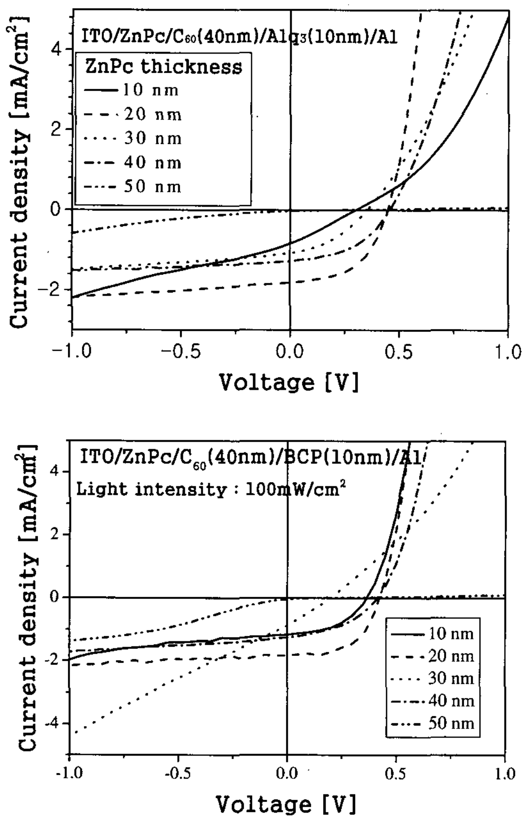


Fig. 3. Current density-voltage characteristics of the ITO/ZnPc/C_{60}/Alq_3/Al and ITO/ZnPc/C_{60}/BCP/Al devices(Light intensity @ 100 mW/cm^2).

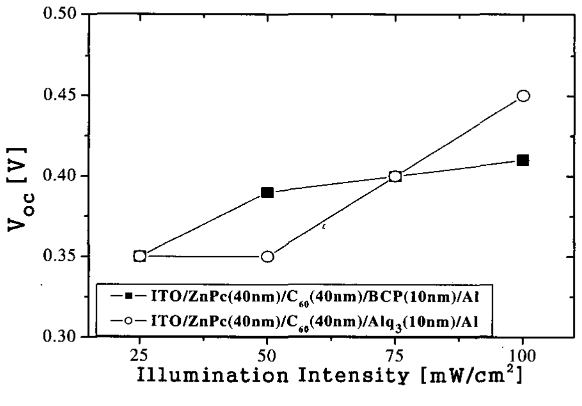


Fig. 4. Open-circuit voltage-illumination intensity characteristics of the two PV cells.

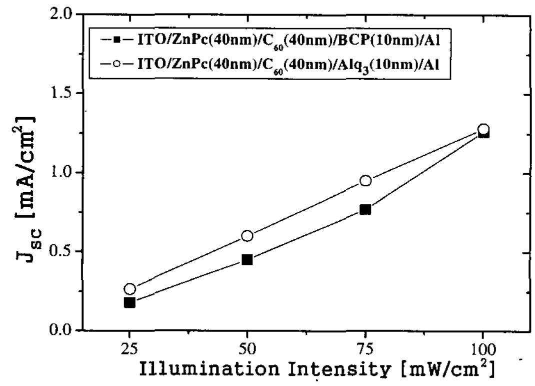


Fig. 5. Short-circuit current density-illumination intensity characteristics of the two PV cells.

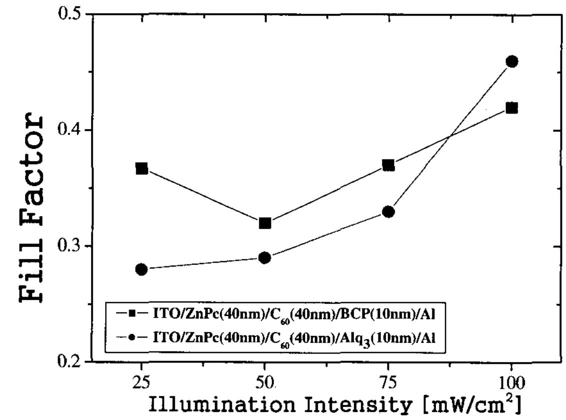


Fig. 6. Fill factor of the two PV cells as a function of illumination intensity.

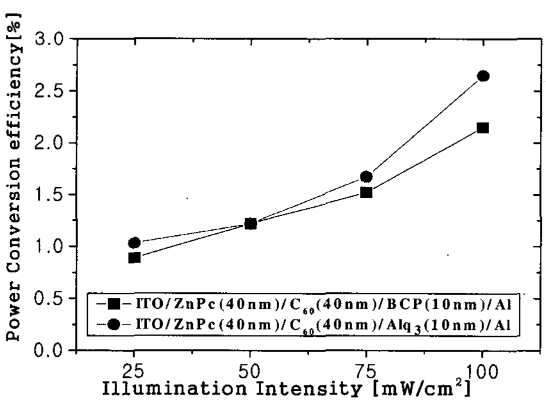


Fig. 7. Power conversion efficiency of the two PV cells as a function of illumination intensity.

Figure 6 shows the calculated fill factor of the two types PV cell using Eq.[1]. In PV cell with the Alq_3, the fill factor is somewhat lower than that with the BCP in the region of illumination intensity from 25 to 75 mW/cm^2. However, when the illumination intensity is 100 mW/cm^2, the fill factor is higher.

Figure 7 shows the power conversion efficiency of the PV cells. The efficiency increases as the illumi-nation intensity increases, especially the PV cell with Alq_3 layer is a little bit higher compared to the cell with BCP layer. Basically, we can say that the efficiency is mainly affected by $ZnPc/C_{60}$ layer.

4. CONCLUSION

We have seen the electrical properties and photovoltaic properties of the organic solar cells employing an EBL layer. The use of Alq_3 layer leads to external power conversion efficiency(2.65 % at illumination intensity 100 mW/cm^2). Also, we confirmed the optimum thickness ratio of the DA hetero-junction with $ZnPc/C_{60}$ layer is about 1:2. We are going to further works to introduce the buffer layer between ITO and ZnPc for improvement of efficiency.

ACKNOWLEDGMENTS

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