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Effect of organic solar cells using various sheet resistances of indium tin oxide and different cathodes: Aluminum, silver

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ABSTRACT

The effect of different electrodes on organic solar cells (OSCs) performance was studied. Various sheet resistances of indium tin oxide (ITO) were used as an anode to find out which is suitable for OSCs application. The efficiency of OSCs based on small molecule material using different ITO substrates is almost the same due to the low absorption efficiency of active layer. In contrast, the efficiency of device based on polymer material using ITO (15 Ω/sq) has a better efficiency, which is attributed to reaching the optimal balance between the light transmittance and the carrier extraction. In cathode, the commonly used for OSCs are aluminum (Al) and silver (Ag), respectively. When substituting Ag for Al as a cathode, the efficiency of device based on copper phthalocyanine and C_{60} increased from 0.71% to 0.86% and the efficiency of device based on boron subphthalocyanine chloride and C_{60} increased from 2.61% to 2.96%. The performance enhancement is mainly ascribed to the current density (J_{sc}) improvement which is resulted from the difference of optical characteristic between the Al and Ag. The reflectance of Ag is higher than that of Al above wavelength of 405 nm, indicating that the light reflected from the Ag is more than that of Al. As a result, the more light can be absorbed in the active layer, leading to the efficiency of device using Ag as a cathode have above 10% improvement. However, the most commonly used cathode in OSCs is Al rather than Ag, which is also investigated.

1. Introduction

In recent years, organic solar cells (OSCs) have received much attention due to their potential applications, including printable fabrication, lightweight, low-cost, and mass-production [1–5]. Many ways have been proposed to enhance the efficiency of OSCs, such as developing the new materials [6,7], using different structures [8–11], inserting buffer layer between the active layer and the electrode [12–16]. The synthesis of new materials is focused on the absorption of infrared region to broaden absorption range [6,7]. At present, the most commonly used structure is bulk heterojunction which have more exciton dissociation, leading to the higher current density (J_{sc}) [17]. In buffer layer research of OSCs, it can be divided into anode buffer layer and cathode buffer layer. The function of anode buffer layer is to enhance the work function of ITO and smooth the roughness of surface, which lead to the carrier extraction easily. The function of cathode buffer layer is to reduce the work function of cathode, block exciton recombination at the interface, and prevent the metal diffusion when thermal deposition [16]. In aspect of electrode, indium tin oxide (ITO) is wildly used anode in the OSCs due to its high transparency and conductivity. However, seldom study reports that the optical and electrical characteristic of ITO influence on the OSCs performance [18]. In addition, the commonly used cathode in OSCs is aluminum (Al) and silver (Ag). The comparison of devices fabricated with Al or Ag cathode is few [19–21].

In this study, the efficiency of devices using various sheet resistances of ITO was investigated. From the external quantum efficiency (EQE) measurement, it can be seen that the variation of the percentage of light convert into the electrons in device with different ITO substrates. Furthermore, the materials of small molecule and polymer were separately used as an active layer for comparison. In cathode, the effect of device using Al or Ag was studied. The result showed that the device using Ag as cathode have a better efficiency. However, the most commonly used cathode in OSCs is Al rather than Ag. The reason might be ascribed to the metal diffusion depth difference between the Al and Ag. A systematic analysis and discussion of device using Al or Ag as a cathode is presented.

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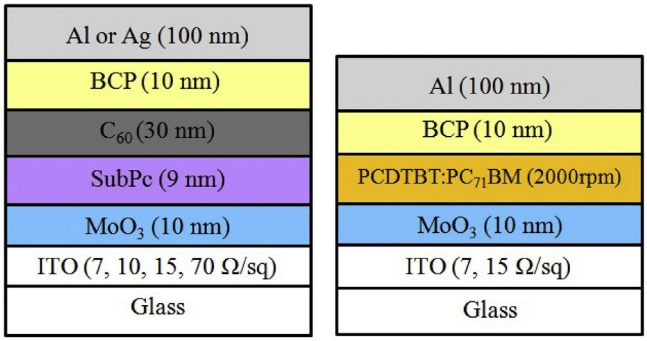

Fig. 1. Schematic diagrams of device architecture used in the study.

2. Experimental

The materials of boron subphthalocyanine chloride (SubPc) (99%, Lumintec), copper phthalocyanine (CuPc) (99%, Aldrich), poly [*N*-900-hepta-decanyl-2,7-carbazole-alt-5,5-(40,70-di-2-thienyl-20,10,30-benzothiadiazole)] (PCDTBT) (99%, Lumintec) were used as electron donor. The C_{60} (99.95%, Aldrich) and [6,6]-phenyl C71-butyric acid methyl ester ($PC_{71}BM$) (99.9%, Nano C) were used as electron acceptor, and the bathocuproine (BCP) was used as exciton blocking layer. All the materials were used without further sublimation. The planar heterojunction devices consist of SubPc and C_{60} were fabricated on the ITO-glass substrates with a sheet resistance of 7–70 Ω/sq. The ITO substrates are sequentially cleaned by ultrasonic treatment in acetone, methanol, deionized water for 5 min each, and dried with nitrogen blow. The organic materials and cathode (Al, Ag) were deposited by vacuum thermal evaporation below the pressure of 4.8×10^{-6} Torr. The deposition rate of organic materials was at 0.02–0.04 nm/s, and the cathode was deposited through a shadow mask, giving an active area of 6 mm^2 at a deposition rate of 0.2–0.3 nm/s. Deposition rate and film thickness were monitored by using quartz crystal oscillator. The bulk heterojunction device was composed of PCDTBT:$PC_{71}BM$ fabricated on the ITO (7 Ω/sq and 15 Ω/sq) by using spin coating method (2000 rpm for 20 s). The PCDTBT:$PC_{71}BM$ layer was composed at a ratio of 1:4 in dichlorobezene solvent with a concentration of 7 mg/ml, and the thickness of active layer was approximately at 70 nm. The film was annealing at 75 °C for 50 min. The device architectures used in study are shown in Fig. 1.

The current–voltage (*I–V*) characteristics were measured with a power sourcemeter (Keithley 2400) under an illumination of 100 mW/cm^2 with an AM1.5G sun simulator (Oriel 96000 150 W Xe lamp, Newport). The light intensity was calibrated by using a reference solar cell and meter (Oriel 91150, Newport). All devices were encapsulated and the aperture mask was not used for the *I–V* measurement. The transmittance spectra of ITO and absorption spectra of organic materials were measured by using a UV–vis–NIR spectrophotometer (UV3900, HITACHI) in the 300–800 nm wavelength range. The EQE measurements were carried out by using Solar Cell QE/IPCE measurement system (QE3000, TEO).

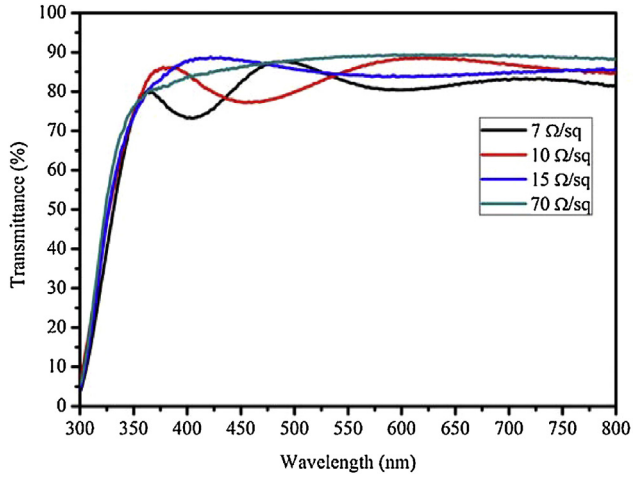

Fig. 2. The transmittance spectra of various sheet resistances of ITO.

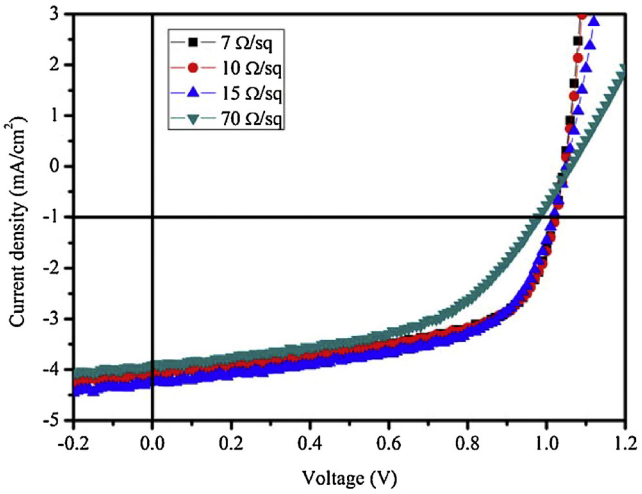

Fig. 3. The *J–V* characteristics of device based on SubPc/C_{60} using various sheet resistances of ITO.

3. Results and discussion

Fig. 2 shows the transmittance spectra of ITO with various sheet resistances. The sheet resistance is inversely to the film thickness, resulting in the difference of transmittance spectra. Fig. 3 shows the current density–voltage (*J–V*) characteristics of devices fabricated using different ITO substrates. Table 1 lists the cell performance parameters of the devices. The variation of J_{sc} is consistence with the transmittance spectra except the device using 70 Ω/sq of ITO. Despite the transmittance of ITO (70 Ω/sq) is higher than that of other ITO films, the J_{sc} of device decreased rather than increased. The result is due to the fact the series resistance (R_s) of device using 70 Ω/sq of ITO dramatically increased to 77.92 Ω cm^2, causing the carriers in the device hard to extract and the fill factor of device decreased. Furthermore, it can be seen that the efficiency of devices using 7–15 Ω/sq of ITO are almost the same. Fig. 4(a) shows the EQE spectra of devices using 7–70 Ω/sq ITO substrates. The EQE can be interpreted as follows [22]:

$$\eta_{EQE} = \eta_A \eta_{ED} \eta_{CT} \eta_{CC}$$

where η_A is absorption efficiency of incident photon, η_{ED} is the efficiency of photogenerated excitons that diffuse to the hetero-junction interface, η_{CT} is the charge transfer efficiency, and η_{CC} is

Table 1
Photovoltaic performance parameters of SubPc/C_{60} based OSCs using various sheet resistances of ITO.

Sheet resistance of ITO (Ω/sq)	J_{sc} (mA/cm^2)	V_{oc} (V)	FF	R_s (Ω cm)	η (%)
7	4.05	1.04	0.62	20.37	2.61
10	4.06	1.05	0.61	18.77	2.63
15	4.23	1.05	0.60	29.19	2.66
70	3.91	1.06	0.52	77.92	2.17