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Flexible solar cells based on copper phthalocyanine and buckminsterfullerene

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ABSTRACT

Flexible solar cells based on copper phthalocyanine (CuPc) and buckminsterfullerene (C_{60}) were fabricated on flexible indium-tin-oxide (ITO) coated polyethylene terephthalate (PET) substrates. Substrate temperature was found obviously affecting the molecular orientation of CuPc films and low substrate temperature should be adopted in order to transport charges perpendicular to substrate surface. For planar heterojunction cell PET-ITO/CuPc/C_{60}/CuPc (10 nm)/Al, the appropriate thickness of CuPc layer and C_{60} layer was 40 and 80 nm, respectively, in view of light absorption and power conversion efficiency. For hybrid planar-mixed molecular heterojunction cell PET-ITO/CuPc/CuPc:C_{60}/C_{60}/CuPc (10 nm)/Al, 33%(mole) of CuPc in CuPc:C_{60} blend layer resulted in well-distributed micro grains, which helped to improve photovoltaic performance. As the thickness of blend layer was increased to 90 nm, 0.85% of power conversion efficiency could be obtained. Bending test showed that no significant change happened in photovoltaic performance as tensile curvature up to 1.2 cm^{-1} and compressive curvature up to 1.35 cm^{-1}, respectively.

1. Introduction

Remarkable progress in power conversion efficiency of organic solar cell has been made, such as hybrid planar-mixed molecular heterojunction photovoltaic cell based on CuPc and C_{60} demonstrating a efficiency of 5% [1], bulk heterojunction of P3HT:PCBM reached 5.1% [2], CuPc/C_{60} hybrid planar-mixed heterojunction tandem structure improved further to 5.7% [3]. Recently, a high efficiency of 6.5% was achieved when connected front cell of PCPDTBT:PCBM and back cell of P3HT:PC70BM through transparent titanium oxide layer [4]. The efficiency of organic photovoltaic device could be improved by several ways, such as: (i) choose appropriate materials; (ii) achieve high interfacial area by introduction of donor–acceptor heterojunction; (iii) accomplish efficient electron/hole collection by inserting a buffer layer at anode/absorber and cathode/absorber interfaces [5,6]; (iv) obtain a board range of photon energies by varying device structure, like multiple layers [7], p-i-n structure and tandem cell [3,4]; (v) control the curvature of the work piece [8], etc. However, these high efficiency organic solar cells were fabricated on rigid substrate.

For roll-to-roll manufacture of solar cells, flexible substrates have attracted a great deal of attention because flexible substrates can reduce device thickness, leading to light weight, flexing and non-planar shaping [9,10]. However, the reported power conversion efficiency was still low, which was not only imputable to short exciton diffusion length of organic materials [11], but also low thermal distortion temperature of substrates and misalignment between different layers resulting from various stresses during manufacture process [12,13].

To improve power conversion efficiency and reduce manufacture cost of flexible organic solar cells, we fabricated flexible solar cells on flexible ITO-coated PET substrates, in which CuPc and C_{60} were adopted as electron donor and electron acceptor, respectively. The effects of substrate temperature, planar heterojunction and hybrid planar-mixed molecular heterojunction on photovoltaic performance were investigated and then bending was used to test the effect of curvature on the as-prepared cells.

2. Experimental

The configuration of flexible solar cells fabricated on semitransparent ITO-coated PET substrate (thickness 175 μm, transmittance 80% and surface resistance 90 Ω/□) is shown in Fig. 1. Taking light absorption efficiency into account, the thickness of the total photoconductive layer was fixed at 120 nm. The CuPc:C_{60} blend layer, sandwiched between pure CuPc layer and C_{60} layer, was prepared by co-evaporation under base pressure of 5×10^{-3} Pa and its content of CuPc was adjusted to improve the photovoltaic performance. Al cathode was deposited through a shadow mask to a thickness of 70 nm, given an active area of 5 mm × 5 mm. For all cells, 10 nm thick of CuPc buffer layer was inserted between pure C_{60} layer and Al electrode to deflecting

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exciton and protecting C_{60} layer from high temperature during the deposition of Al cathode [6]. The distance from crucible to substrate was fixed at 130 mm and substrate holder was continuously rotated to ensure uniform films. Quartz crystal microbalance (QCM) was used to monitor film thickness and deposition rate, which was adjusted by SEM. The flexibility of the as-prepared cell is shown in Fig. 2.

The flexible solar cells, 1.5 cm long and 1.3 cm wide, were bent to test the effect of tensile strain and compressive strain on photovoltaic properties, in which curvature was represented with the inverse of radius.

Current–voltage measurement was carried out under illumination intensity 10 mW/cm^2 at RT without any encapsulation. The crystallinity of CuPc layer was analyzed with X-ray diffraction (XRD) using Cu Ka radiation, $\lambda = 1.5405$ nm. The UV–vis absorption spectrum was measured with TU-1810 spectrophotometer. The surface morphology was observed with Quanta 400F thermal field emission environmental SEM-EDS-EBSD.

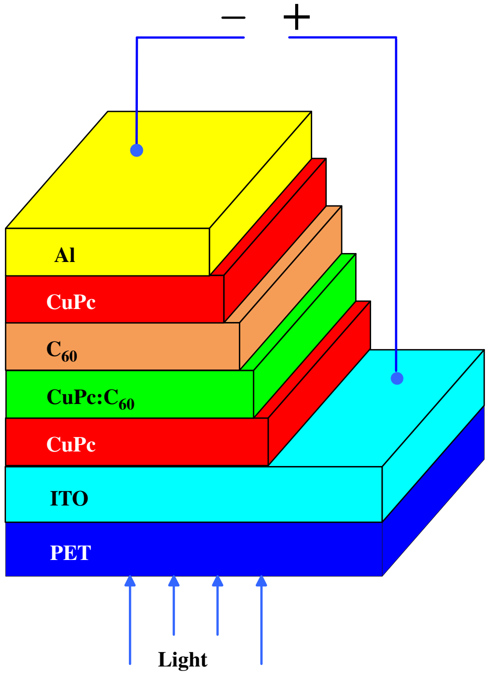

Fig. 1. Configuration of solar cell.

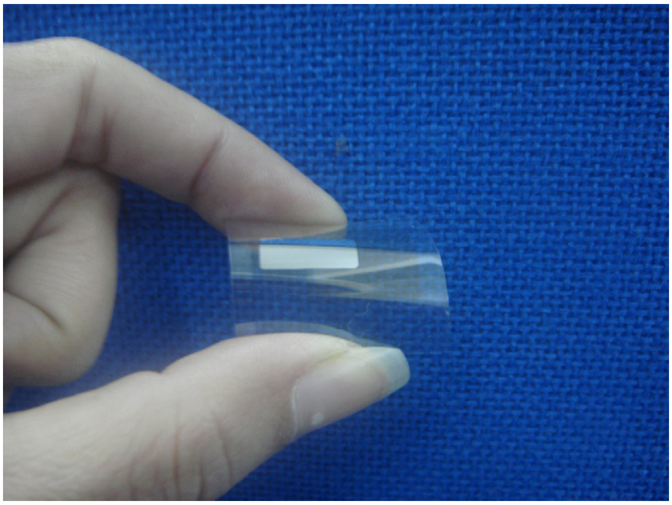

Fig. 2. Flexible solar cell.

3. Results and discussion

3.1. Effect of CuPc layers deposited at different substrate temperature

Because of the anisotropy of CuPc molecules, charge transport in CuPc layers significantly depends on molecular orientation, which in turn influences cell performance. The effect of substrate temperature on CuPc molecular orientation, investigated through XRD, is presented in Fig. 3, in which the CuPc layer grown at 10 nm/min and thickness was controlled at 100 nm. The broad peak at $2\theta = 26.03°$ was attributable to diffraction of ITO layer. No diffraction peak was found in CuPc layer deposited at 30 °C, which indicated amorphous CuPc layer. However, if CuPc layers were deposited at 50, 90 and 110 °C, there existed a peak at $2\theta = 6.92°$

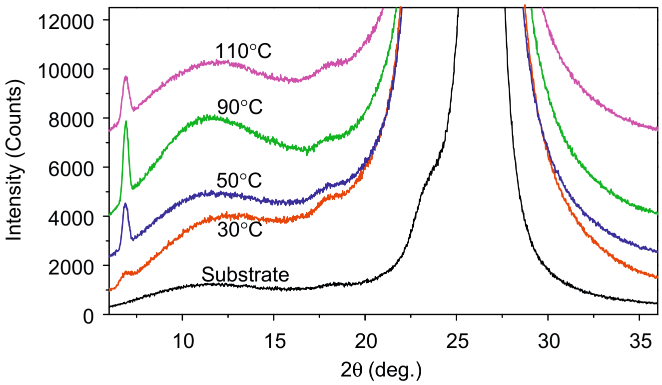

Fig. 3. XRD pattern of CuPc layers deposited at different substrate temperature.

Table 1
Photovoltaic parameters of cells structure PET-ITO/CuPc (10 nm)/CuPc:C_{60} (33% CuPc, 90 nm)/C_{60} (20 nm)/CuPc (10 nm)/Al prepared at different substrate temperature.

Substrate temperature (°C)	V_{oc} (V)	J_{sc} (mA/cm^2)	FF (a.u.)	η_p (%)
30	0.269	0.760	0.41	0.85
50	0.260	0.480	0.31	0.38
90	0.258	0.300	0.30	0.23
110	0.250	0	0	0

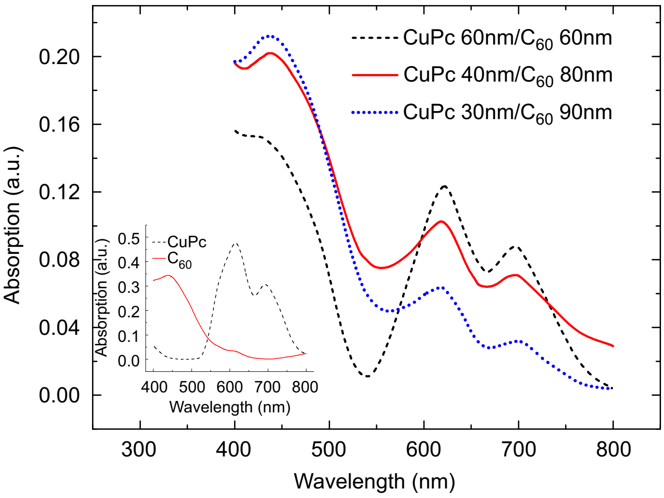

Fig. 4. Absorption spectra of CuPc/C_{60} heterojunctions. Inset: Absorption spectra of pure CuPc layer and pure C_{60} layer.