Extended Abstracts of the 2013 International Conference on Solid State Devices and Materials, Fukuoka, 2013, pp504-505

Organic Solar Cells using Fullerene introducing Polymer as Cathode Buffer Layer

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Abstract

We investigated the cathode buffer efficiency of a fullerene-containing polymer, C_{60}P-DC, in organic solar cells (OSC). Open circuit voltage (*Voc*) and Power conversion efficiency (PCE) increased compared with the device without C_{60}P-DC. We found that C_{60}P-DC is effective cathode buffer material in bulk hetero junction (BHJ) OSCs.

1. Introduction

Organic solar cells (OSCs) are expected as low cost, printable, light-weight, flexible, and portable energy sources, and these advantages have encouraged intensive research on OSCs. The most important issue in OSCs is that the lower power conversion efficiency than Si-base or dye-sensitized solar cells. Various approaches for increasing efficiency and stability, low band gap donor materials, tandem OSC cell, inverted OSCs, controlling nanostructure of active layer have been proposed.[1]

Typical OSC has a stacked structure of the substrate / transparent anode electrode / hole transport layer / active layer / buffer and electron transport layer / upper cathode electrode, each layer has an important role. The cathode buffer layer provides a quasi ohmic contact between active layer and cathode, and electro transport and hole blocking effect. It has been reported that the PCE is improved by using lithium fluoride (LiF) as a cathode buffer layer. However, LiF can be formed by vacuum deposition, solution processable buffer material have been explored.

Herein, we report the effect of fullerene-introducing polymer (C_{60}P-DC) [2] as cathode buffer layer in OSCs. The chemical structure of C_{60}P-DC is shown in Fig.1.

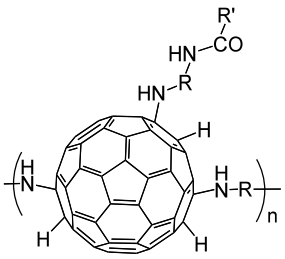

Fig.1 Possible chemical structure of C_{60}P-DC

2. Experimental

2.1 Fabrication of OSC

ITO coated glass substrates were cleaned sequentially with detergent, deionized water, acetone and ethanol, followed by boiling and steam cleaning by ethanol and UV-O_3 treatment for 20 min. Poly(3,4-ethylenedioxythiophene): poly(styrenesulfonate)(PEDOT:PSS) was spin-coated from the solution (Baytron P VP Al4083 from H. C. Stark, filtered through 0.45μm PVDF syringe filter) at 2000rpm for 30s, followed by annealing at 150°C for 10min. The active layer was spin-coated from the solution of Poly(3-hexyl thiophene)(P3HT):[6,6]-Phenyl-C_{61}-Butyric Acid Methyl Ester (PCBM) = 1:1 w/w in o-dichlorobenzene (3wt% , filtered with a 0.5μm PVDF syringe filter) at 500rpm for 60s, followed by thermal annealing at 120°C for 10min. C_{60}P-DC was deposited by Evaporated Spray Deposition using Ultra dilute Solution (ESDUS) [3] process because C_{60}P-DC is not soluble in polar solvent like ethanol. Normal wet process like spincoat is not possible to build a laminated structure because lower organic layer eroded by organic solvent. ESDUS process, which can solve this problem, was developed as novel deposition method. Features of ESDUS process are can be stackable multiple materials dissolved in the same solvent, and can deposit poorly soluble materials because it can deposit from dilute solutions of ppm order. Schematic diagram of ESDUS process shown in Fig.2 . The solution is supplied to the atomizer in the chamber by using a liquid feed pump. Solution is mixed with the N_2 carrier gas, and be aerosol of about 10 μm particle size. Because it can spray on the substrate in a state in which the solvent is almost evaporated by the heat of chamber, lamination of the organic layer is possible.

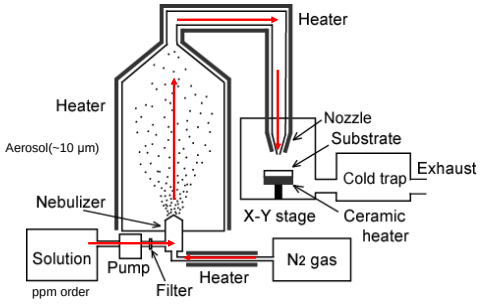

Fig.2 Schematic diagram of ESDUS process

Finally, Al (100nm) was fabricated by thermal deposition at a pressure of 10^{-7}Torr. The area of each device was 0.04 cm^2, as determined by the overlap of the ITO and the evaporated Al.

2.2 Characterization of OSCs

I-V characteristic of OSC was measured by Keithley 238 source meter and solar simulator. The light intensity was calibrated to be AM1.5 100mW/cm^2 using calibrated Si solar cell. And some parameters of solar cells was calculated from the fitting of equivalent circuit model [4].

3. Result and discussion

C_{60}P-DC was deposited from solution it was (1) 0, (2) 0.5, (3) 3.0ppm. The I-V characteristic of fabricated OSCs were shown in Fig.3 and Table.1.

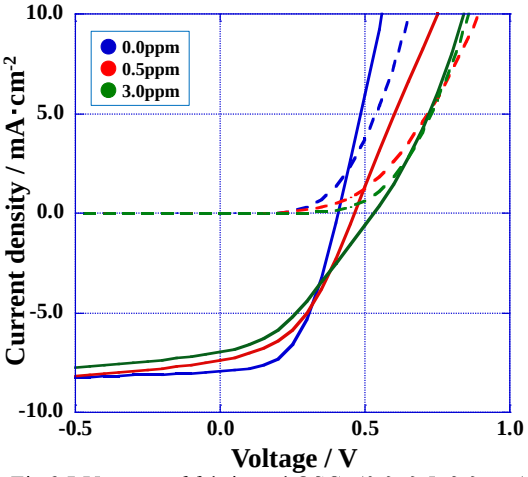

Fig.3 I-V curve of fabricated OSCs (0.0, 0.5, 3.0ppm)

Table.1 Characteristic of fabricated OSCs(1)

Sample	PCE [%]	Jsc [mA/cm^2]	Voc [V]	ff [-]
0.0ppm	1.650	7.96	0.406	0.511
0.5ppm	1.504	7.40	0.459	0.443
3.0ppm	1.322	6.97	0.533	0.356
3.0ppm optimize	2.096	8.14	0.565	0.456

Open circuit voltage (*Voc*) was increased with increasing concentration of C_{60}P-DC. However, fill factor (*ff*) and short circuit current density (*Jsc*) was decreased. As a result, power conversion efficiency (PCE) was decreased.

C_{60}P-DC deposition by ESDUS process was optimized at the conditions C_{60}P-DC concentration 3ppm showing the highest *Voc*. From atomic force microscopy (AFM) image, the surface of C_{60}P-DC is so rough (Ra = 25.65nm) (C_{60}P-DC:3.0ppm). It is aggregation of C_{60}P-DC because excess drying when ESDUS process. Prevent the aggregation of C_{60}P-DC by optimizing N_2 flow rate, and obtained smooth surface (Ra = 5.424nm) shown in Fig.4.

The I-V characteristic of fabricated OSCs which optimized was shown in Fig.5 and Table.1. *Voc* was increased, however Jsc was not decreased. As a result, PCE was increased.

Some parameters affect the solar cell characteristics of fabricated device was calculated from the fitting of single diode model as equivalent circuit model. The ideality factor *n* was especially increased. It was reported that n increase by dielectric presence between electrode and organic layer

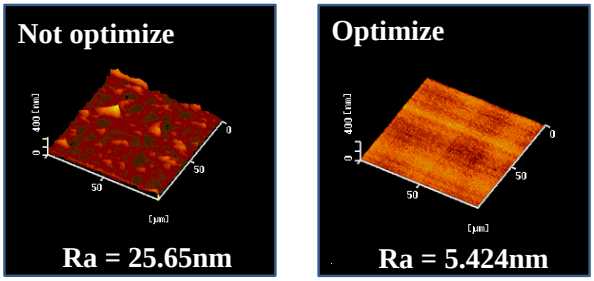

Fig.4 AFM images of C_{60}P-DC on P3HT:PCBM film

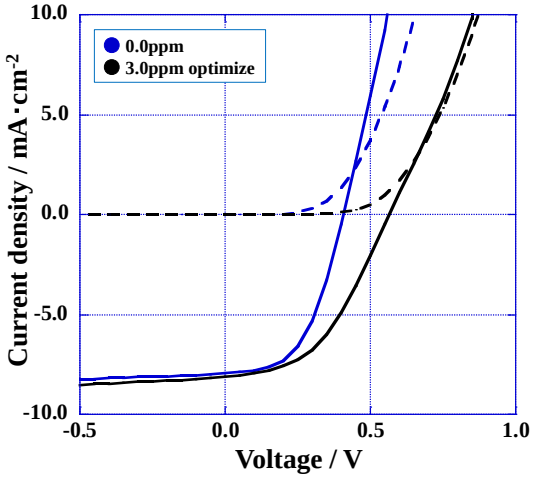

Fig.5 I-V curve of fabricated OSCs (0.0ppm and 3.0ppm optimize)

[5]and suggested C_{60}P-DC is functioning as dielectric layer. *Voc* was represented by Eq.(1).

$$Voc = \frac{nk_BT}{q}\ln\left(\frac{J_{ph}}{J_0}\right) \quad (1)$$

J_{ph}, J_0, q, n, k_B, and T are the photocurrent, the saturation current of the diode, the electron charge, the ideality factor, the Boltzmann constant, and the temperature, respectively. k_BT/q is constants. When the J_{ph} is substantially constant, *Voc* is greatly affected by the *n* and J_0. It is considered that the increase in *Voc* is due to the presence of the dielectric layer, and the vacuum level was shifted by the presence of the dielectric.

4. Conclusions

Voc is increased by deposition of C_{60}P-DC, and PCE was improved. It is suggested that C_{60}P-DC is effective solution processable cathode buffer material. It was considered that increasing Voc is due to shift of the vacuum level by C_{60}P-DC.

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