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The Effect of Bathocuproine (BCP) buffer layer in boron subphthalocyanine chloride (SubPc)/fullerene (C_{60}) Organic Solar Cells with inverted structure

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Abstract

Inverted organic solar cells (OSCs) based on boron subphthalocyanine chloride (SubPc) and fullerene (C_{60}) were fabricated and the performance was optimized by inserting a buffer layer of bathocuproine (BCP). The power conversion efficiency was greatly improved from 0.9 % to 1.5 % by this buffer layer. The role of BCP buffer layer was investigated by photoluminescence and transient photocurrent (TPC) measurements. The results show that the exciton quenching at the interface of C_{60}/ITO (Indium Tin Oxide) was greatly suppressed by the insertion of the BCP buffer. Besides, the TPC measurement confirmed that the trap assisted recombination was the main reason of the energy loss in the device without BCP buffer layer. This work identified an efficient buffer layer of BCP in inverted organic solar cell with a function of not only blocking exciton quenching, but also suppressing the recombination path of the charge carriers.

1. Introduction

In a conventional organic solar cell (OSC), there are serveral reasons for the degradation: the employment of a conductive poly (3, 4-ethylenedioxythiophene): poly (styrenesulfonate) (PEDOT:PSS) layer as the hole-transport layer, the adaption of a low work function metal as a cathode, the deterioration of the fullerene (C_{60}) adjacent to the top cathode, and so on. These hinder the application of OSCs [1,2]. To overcome the instability issue associated with the conventional structure OSCs, one feasible approach is to construct an inverted structure, where indium tin oxide (ITO) serves as the cathode and a high work function metal as the anode.

Bathocuproine (BCP) is an effective electron transport layer between the C_{60} acceptor and the metal cathode in the conventional structure OSC, since it can effectively block excitons, eliminate metal diffusion, and avoid the formation of the C_{60}/metal interface [3,4]. In this work, we fabricated inverted structure OSCs based on SubPc and C_{60} as the active layers by incorporating BCP between C_{60} and ITO. A great improvement of the device's performance has been witnessed. The effect of BCP on the performance of solar cells was investigated.

2. Experiment

Inverted structure OSCs with structure of ITO/with or without BCP/C_{60}/SubPc/MoO_3/Ag, represented by the device A and the device B, were fabricated by thermal evaporation. The area of each device is 4mm^2. The devices are without any further encapsulation after fabricating. The steady-state characteristics were examined by measuring the current density-voltage (*J-V*) characteristics under AM1.5G 100mW/cm^2 illumination. The transient photocurrent (TPC) measurement was performed using a high brightness 525nm green LED (Kingbright, L-7104VGC-H) pulsed by an Agilent 33220A function generator. The transient photocurrent was recorded by connecting the solar cells under test in series with an Agilent DSO-x2024A digital storage oscilloscope.

3. Results and discussion

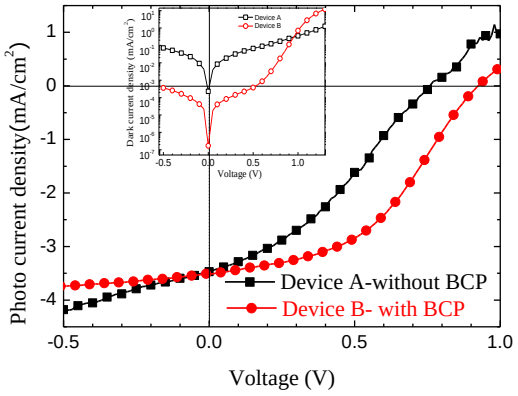

Fig. 1 *J-V* curves of devices without (square) or with BCP (circle). The inset is the dark *J-V* characteristics on a semi logarithm scale.

The *J-V* characteristics of devices without and with BCP buffer layer, as shown in Fig. 1, suggest a great improvement in device efficiency when BCP is used, characterizing by an increased open circuit voltage (Voc) from 0.76 V to 0.92 V, fill factor (FF)from 34.3 % to 45.1 % and power conversion efficiency (PCE) from 0.90 % to 1.47 %. From the dark *J-V* characterizations of the two devices (the inset of Fig.1), the (reverse bias) saturation current density of the device A (without BCP) is higher than that of device B (with BCP), leading to a lower V_{OC}. The series resistance (*Rs*) was estimated from the inverse of the slope of the tangential line of the *J-V* curve at V_{oc} [5]. The insertion of the BCP layer decreases the *Rs* from 5.6Ω/cm^2 in device A to 1.3Ω/cm^2 in device B, which leads to higher *FF* in device B.

On the other hand, the dark current of the device A is

on a smaller scale as compared to the device B. This may be caused by the charge trapping in device A.

For the organic heterojunctions in absence of traps, the bimolecular recombination is the only loss mechanism. The V_{OC} was given by the following equation [6]:

$$Voc = \frac{E_{gap}}{q} - \frac{kT}{q}\ln\left[\frac{(1-P)\gamma N_c^2}{PG}\right] \qquad (1)$$

where E_{gap} is the energy difference between the highest occupied molecular orbital (HOMO) of the electron donor and the lowest unoccupied molecular orbital (LUMO) of the electron acceptor, q is the elementary charge, k is Boltzmann constant, T is the absolute temperature, P is polaron-pairs dissociation probability into free carriers, γ is the bimolecular recombination constant, N_c is the density of the states in the conduction band, and G is the generation rate of polaron-pairs. Equation 1 predicts the V_{OC} scales with the natural logarithm of light intensity. Fig. 2 shows light intensity dependence of V_{OC} (logarithm) for the two devices. From Fig. 2, the device A and device B give slopes of S= 1.97 kT/q and S=1.09 kT/q. Considering an exponential trap distribution and trap-assisted recombination, the V_{OC} *v.s. lg (I)* gives a slope of nkT/q, where $n>1$ [7]. In case of device B, n is quite close to 1, while the device A gives n far more than 1, this is an evidence of charge trapping and trap-assisted recombination in the device without buffer.

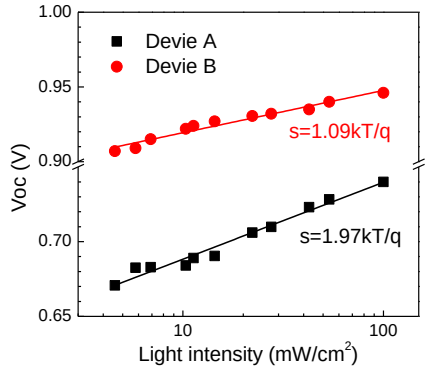

Fig. 2 Light intensity dependence of V_{OC} (logarithm) of the device A and the device B.

TPC measurement is a new class of measurement, which allows the time required for the device to reach the steady state to be investigated. By studying the response of solar cells to square-pulse optical excitation, the dynamics of turn-on and turn-off can be investigated, which can be related to carrier transit times, the buildup of trapped charge and the dynamics of the recombination.

To further understand the role of BCP in inverted device, the transient photocurrent was investigated. The photocurrent transients of the device A and the device B as a function of pulse light intensity are shown in Fig. 3. The total transient photocurrent response of both the devices is composed of a fast rise at the turn-on behavior, and then a slow increase involving into a plateau region, followed by a fast decay after turn-off, and a slow decay with a long-lived tail. Although the shape of both the devices is quite alike with each other, the detailed response of the device A is distinct with the other one: i) a smaller transient photocurrent at the turn-on behavior, suggesting the photo-generated excitons quenching in a very short time scale, in well agreement with the photoluminescence measurement, not shown here; ii) a comparable slower turn-on and turn-off behavior, implying the charge trapping as a result of buildup of traps; iii) a slightly modified photocurrent transient shape with highly intensity dependant. Based on the statements listed above, the BCP layer suppressed the recombination path in device B.

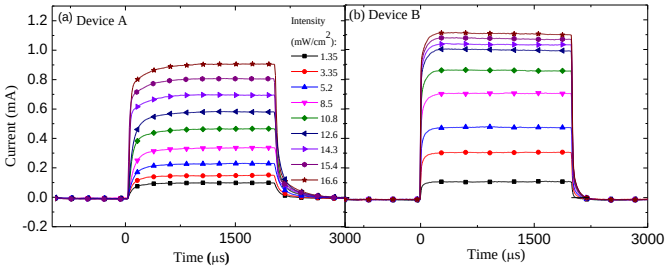

Fig. 3 Photocurrent responses of (a) the device A and (b) the device B to a 2000 micro square-pulse illumination as a function of pulse intensity (the figures share the same legend)

3. Conclusions

The BCP acts as an effective buffer layer in inverted OSCs, which not only eliminates exciton quenching, but also greatly suppress the recombination path by means of inhibiting the buildup of the traps. Therefore, the application of BCP buffer layer between C_{60} and ITO greatly improved the *PCE* by 63 %.

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