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Operation Mechanism of Exciton Blocking Layer in Organic Photovoltaic Cell

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Abstract: The operation mechanism of exciton blocking layer (EBL) in organic photovoltaic (PV) cells was demonstrated, the EBL materials with higher electron-transporting ability were used such as bathocuproine (BCP), bathophenanthroline (Bphen), and so on. However, it was interestingly found that copper phthalocyanine (CuPc) widely used as donor of the PV cells also can be used as EBL materials and under thicknesses of larger than 10 nm the EBL property even is higher than that of traditional EBL consisting of BCP and Bphen, due to its stronger hole transporting ability from the cathode to the CuPc layer.

Key words: organic photovoltaic; electron blocking layers; power conversion efficiency

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1 Introduction

Organic photovoltaic (PV) devices are considered to be promising devices because of their mechanical flexibility, ease of fabrication and potential for low-cost solar energy conversion[1~4]. In these devices, excitons are generated in the photoactive layers under illumination, and then some excitons would be dissociated into electrons and holes at the donor/acceptor heterojunction (DA-HJ), subsequently were collected by two electrodes to contribute to the photocurrent. At the same time, other excitons far from DA-HJ may be recombined, substantially leading to lower the power conversion efficiency (η_p)[5,6]. Excitons, however, must be generated sufficiently close to the DA-HJ such that they can diffuse to this interface before recombining. Bathocuproine (BCP) was typically used as an EBL material in organic PV cells[7]. However, its large energy gap and resistance make it unsuitable for being used as a thick EBL layer, which increases cell series resistance degrades device performance. Doping, or using low-resistance compounds, has also proven to be a way for using thicker EBL layers[8~10].

In this letter, we introduce an EBL composed of CuPc which can be used as thicker EBL in PV cell without a loss in power-conversion efficiency (PCE). Finally, we confirmed that work mechanism of CuPc allows hole transport to leads to direct recombination with electrons and luminescence can generate in the acceptor layer. It is different from the previous BCP EBL which damage can be induced during deposition of the Ag cathode[7], but is similar to the operation mechanism of EBL reported in Ref. [11].

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2 Experiments

In multisource thermal evaporation vacuum chamber with base pressure of 2×10^{-4} Pa, organic layers and metal electrode were evaporated. Current-voltage characteristics were measured under AM 1.5 solar illuminations at intensity of 100 mW/cm^2 with a 150 W solar simulator using a programmable source meter (Keithley-2400).

3 Results and Discussion

Fig. 1 shows the *I-V* curves like PV devices with structures like ITO/CuPc (20 nm)/C_{60} (40 nm)/EBL (10 nm)/Al in which EBL is BCP, BPhen and CuPc, respectively. We note that effect of EBLs on the PV device indicates, minor difference on PV performance. Relatively, the device with Bphen as EBL shows the highest $J_{sc}=6.5$ mA/cm^2 among the three devices due to higher electron mobility of Bphen. It was reported that the PV performance is related neither to the exact position of the lowest unoccupied orbital (LUMO) level[11, 12] nor to the band gap of the EBL material[13]. This is because the free electron transport in the devices does not dependson LUMO levels of the ETL, which is through the defect states induced during cathode damage, which is below the LUMO of EBL[12]. So, the electron mobility and the spectral response of EBLs could be the main factors to affect the performance of the PV diodes.

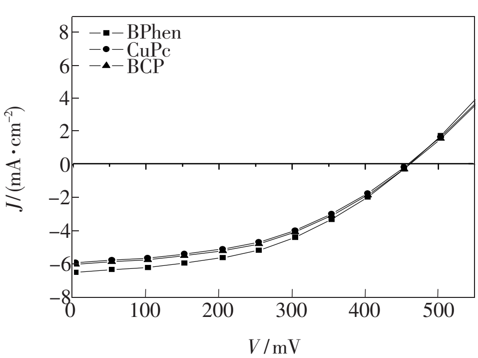

Fig. 1 *I-V* curves of ITO/CuPc/C_{60}/EBL/Al devices with different EBL of BCP, BPhen, CuPc under illumination with an intensity of 100 mW/cm^{-2}.

Fig. 2 plots J_{sc} as a function of thickness of BCP, BPhen and CuPc EBL materials under illumination with an intensity of 100 mW/cm^2. It was found that the devices with different EBLs show the peak PV performance located at a thickness of 10 nm. However, it is noted that under larger EBL thickness J_{sc} of the BCP and Bphen devices decrease rapidly, whereas J_{sc} of the CuPc device falls off more gently with increasing thickness, as showed in Fig. 2. The CuPc EBL devices under thickness of 10 ~ 30 nm shows higher J_{sc} than that of BCP and BPhen.

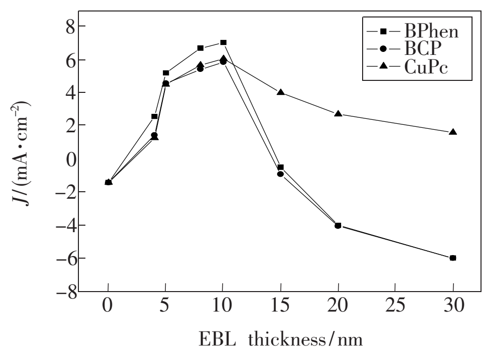

Fig. 2 J_{sc} as a function of BCP, BPhen, CuPc thickness under illumination with an intensity of 100 mW/cm^2.

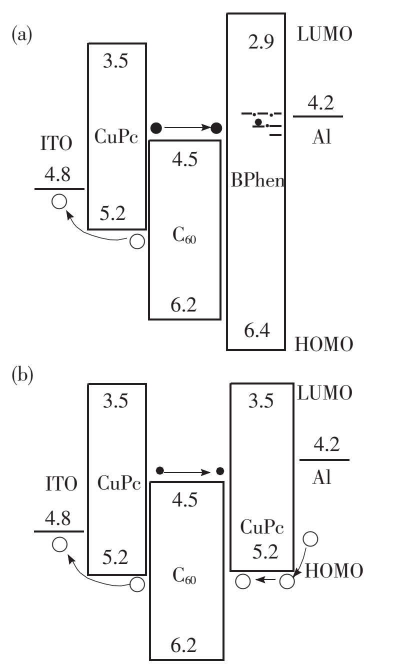

Fig. 3 Schematic energy-level diagram and proposed PV process for double-heterostructure devices using (a) BPhen or (b) CuPc as EBL. Holes are shown as open circles and electrons as filled circles. Energy levels are given in units of eV.

The possible operation mechanism is shown in Fig. 3, we can see that CuPc device offers hole to lower the highest occupied orbital (HOMO) level of CuPc, while BCP device does not have the similar property with CuPc due to its higher HOMO level.

4 Conclusion

In summary, we demonstrated that CuPc exhibits larger J_{sc} with 10 ~ 30 nm thickness EBL in PV device, while BCP does not do it. The difference would be attributed to the difference of their HOMO levels.

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有机光伏器件的激子阻挡层的工作机制

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摘要: 研究了有机光伏器件的激子阻挡层(EBL)的工作机制,对于像 bathocuproine (BCP)和 bathophenanthroline (Bphen)这样的电子阻挡层,主要利用的是他们的强的电子传输能力。而像copper phthalocyanine (CuPc)作为电子阻挡层则可利用它大的空穴传输能力和较低的HOMO能级。我们还发现当CuPc厚度为10~30 nm时,CuPc表现出比BCP和Bphen高的EB特性。文中还较为详细地叙述了CuPc作为电子阻挡层的运行机制。

关 键 词:有机光伏;激子阻挡层;能量转换效率

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