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# Study of anode modification and bias voltage treatment on organic solar cells with Rubrene/ C60 heterojunctions

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**Keywords:** Organic solar cells; Anode modifying layer; Bias voltage treatment

**Abstract.** The organic solar cells with a structure of ITO/Rubrene(35 nm)/$C_{60}$(35 nm)/BCP (6 nm)/Al(150 nm) was fabricated and the influence of anode modifying layer($MoO_3$) and 3V bias voltage treatment on device performance were investigated. The experiment results show, inserting anode modifying layer, the open-circuit voltage and the power conversion efficiency were almost increased by a factor of 5.3 and 11.3, respectively. The anode modifying layer can effectively enhance the built-in electric field and improve dissociation and transport excitons. The bias voltage treatment can improve the performance of defective devices by burning partial defects, but there is little effect for too few defective devices.

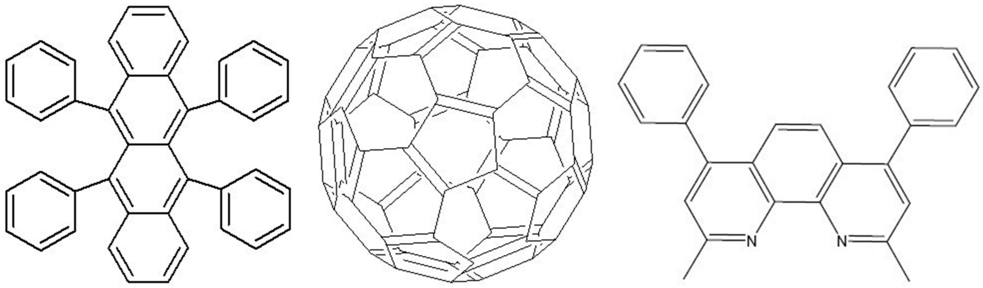
## Introduction

Organic solar cells(OSCs) have attracted attention in the past few years with their potential as low cost, light weight, and easy of fabrication[1,2]. The highest power conversion efficiency(η) has been reported to exceed to 8.13%, which is close to the lower limit for practical applications. Under the condition of energy shortage, OSCs are promising new energy cells.

The energy conversion of organic solar cell mainly depends on dissociation and transport of electron-hole pair(excitons) which are obtained after the absorption of photons. It has been shown that the open-circuit voltage(Voc) depends on the energy difference between the lowest unoccupied molecular orbital(LUMO) of the electron acceptor material and the highest occupied molecular orbital(HUMO) of the electron donor material[3]. In addition, the electode modifying layer can effectively enhance the built-in electric field and improve dissociation and transport of excitons. At the same time, it is beneficial to improve the cells' open circuit voltage, short circuit current(Jsc) as well as fill factor(FF). Electrode modifying materials have been reported with NiO[2], $VO_x$, $MoO_x$[4], $Cs_2CO_3$, LiF[5], etc. However, the research mainly focus on electron donor and acceptor blend solar cells (such as P3HT: PCBM) which must be producted through lots of process steps such as spin-coating, annealing and electrode deposition. Solar cells of non-blend structure only need film deposition, reproducible and the thickness can be precisely controlled. There is a substantial increase in performance of CuPc/$C_{60}$ solar cells with PEDOT: PSS as anode modifying layer, reported by Peumans[6]. But the PEDOT: PSS will corrode the ITO anode[4], and spin-coating will lead to a discontinuous film, resulting in pinholes, leakage current and reducing the device performance[2]. The power conversion efficiency and open circuit voltage of solar cells with Rubrene/$C_{60}$ heterojunction reached to 3% and 0.94 V, which was reporte by Pandey[7] and was one of the highest efficient solar cells with the simple structure of single-layer. Moreover, the open circuit voltage is much better than solar cells with P3HT: PCBM heterojunction at about 0.64 V[2]and CuPc/$C_{60}$ heterojunction at about 0.58 V[6]. In this letter, the organic solar cells were prepared with the structure: ITO/Rubrene(35 nm)/$C_{60}$(35 nm)/BCP (6 nm)/Al(150 nm). The $MoO_3$ with the work function of 5.3 eV[8]was inserted between the ITO and Rubrene as the anode modifying layer. The influence of anode modification and 3V bias voltage treatment on device performance were studied.

## Experimental

The molecular structures of the organic materials used in the cells were showen in Fig.1. The Anode used in this study was unpolished ITO glass with a sheet resistance of 10Ω/square. The OSCs were fabricated in the following ways: glass substrates coated with an ITO layer were cleaned using ultrasonication in acrtone, followed by alcohol, isopropanol and pure water. $MoO_3$ and organic layers were successively vacuum-deposited under a base pressure of $10^{-4}$ Pa on the cleaned ITO layer. To complete the OSCs structures, an Al layer was vacuum deposited through a shadow mask to define the active area of the devices to be 36 $mm^2$. The current-voltage (J-V) curves were measured with a Keithley 2400 source-measure unit under illumination intensity of AM 1.5G, which was calibrated with standard silicon diode. The measurements were carried out in air at room temperature.



(a) Rubrene (b) $C_{60}$ (c) BCP

Fig.1 Molecular structures of the organic materials used in the cells

**Results and discussion**

The energy level diagram of the devices was given in Fig.2. It clearly indicated that inserting the $MoO_3$ layer markedly improved the work function of anode from 4.7 eV to 5.3 eV. Acoording to the metal-insulater-metal model[9], the Voc depends on the different of work function of electrodes. Since depositing the $MoO_3$ on the ITO surface increase the work function of the anodes, the increase in the Voc is attributable to an increase in the work function of the ITO/$MoO_3$ anodes. The anode modifying layer can effectively enhance the built-in electric field and improve dissociation and transport of excitons. In addition, it is noted that the energy gap between the highest occupied molecular orbital (HOMO) of Rubrene and the work function of $MoO_3$ sis only 0.1ev. So it is expected that holes can be collected by anode through the $MoO_3$ layer.

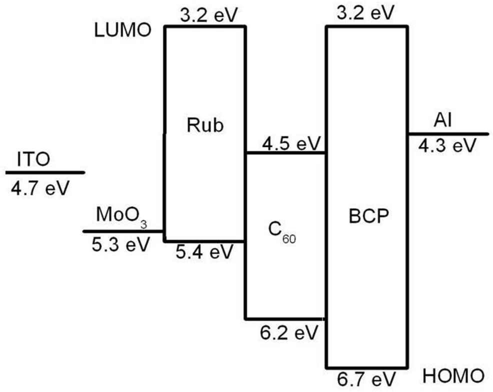


Fig.2 Energy level diagram of the devices

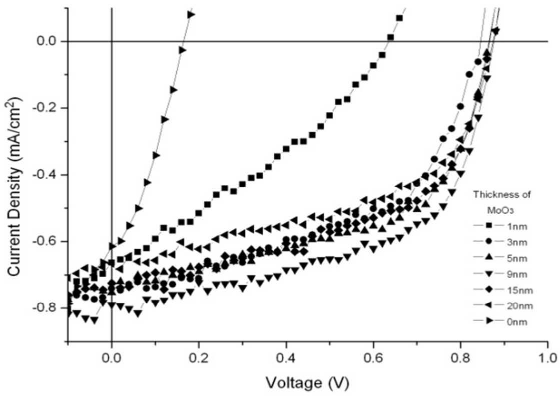


Fig.3 Current density – voltage curve of the devices

Fig.3 shows the current density-voltage (J-V) characteristics as a function of the film thickness of MoO3. We can see that the solar cell with 9 nm-thick MoO3 layer demonstrated the best performance in this study. The open-circuit voltage of 0.86 V, and the power conversion efficiency of 0.387% were almost increased by a facter of 5.3 and 11.3, respectively. As a result, the optimal thickness of MoO3 layer is 9 nm. Here, the MoO3 layer not only acts as a hole transporting layer, but acts as a protection layer preventing damage to the active layer caused by the rough ITO layer surface. Thus an appropriate thickness of MoO3 has a very smooth surface which can improve the surface of ITO layer smoothness. Meanwhile, MoO3 anode modifying layer is also essential to effectively prevent exciton quenching at the ITO anode and maredly improve the device stability[10], particularly, beneficial to a high photocurrent.

The result of the comparison among solar cells with different thickness of MoO3 is shown in Table 1. From these results, we can see that all performance parameters were enhanced substantially by the insertion of the MoO3 modifying layer.

Tab.1 Solar cell characteristics with and without bias voltage treatment with different thickness of MoO3.

| MoO3 (nm) | Treated（3V） | Voc(V) | Jsc(mA/$cm^2$) | FF（%） | η（%） |
|---|---|---|---|---|---|
| 0 | NO | 0.16 | 0.614 | 34.68 | 0.034 |
| 0 | YES | 0.28 | 0.733 | 46.80 | 0.096 |
| 1 | NO | 0.62 | 0.663 | 33.29 | 0.137 |
| 1 | YES | 0.78 | 0.726 | 53.40 | 0.302 |
| 3 | NO | 0.84 | 0.740 | 52.18 | 0.324 |
| 3 | YES | 0.84 | 0.769 | 57.08 | 0.369 |
| 5 | NO | 0.86 | 0.752 | 54.55 | 0.353 |
| 5 | YES | 0.86 | 0.769 | 58.62 | 0.388 |
| 9 | NO | 0.86 | 0.789 | 57.02 | 0.387 |
| 9 | YES | 0.86 | 0.807 | 58.23 | 0.404 |
| 15 | NO | 0.86 | 0.724 | 54.38 | 0.338 |
| 15 | YES | 0.86 | 0.752 | 54.88 | 0.355 |
| 20 | NO | 0.86 | 0.665 | 52.07 | 0.297 |
| 20 | YES | 0.86 | 0.664 | 49.55 | 0.283 |

Fig.4 shows the current density-voltage (J-V) characteristics with and without bias voltage treatment as a function of the film thickness of MoO3（0，1，3 nm）. Obviously, in the absence or for a very thin layer of MoO3 (1 nm), while the OSCs with bias voltage treatment, the open-circuit voltage was evidently increase. At the same time, the efficiency was also increases significantly. We conclud that with a very thin MoO3 layer deposited, the ITO layer may not be covered completely by MoO3, leading to surface partial defects at ITO anode, and a smaller shunt resistance is arised. Therefore, the 3 V bias voltage treatment can improve the performance of defective devices by burning partial defects[11].

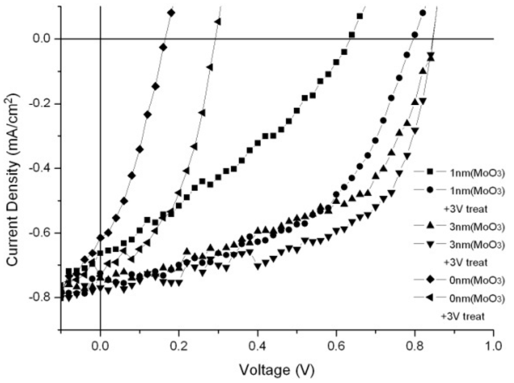


Fig.4 Current density – voltage curve of the devices

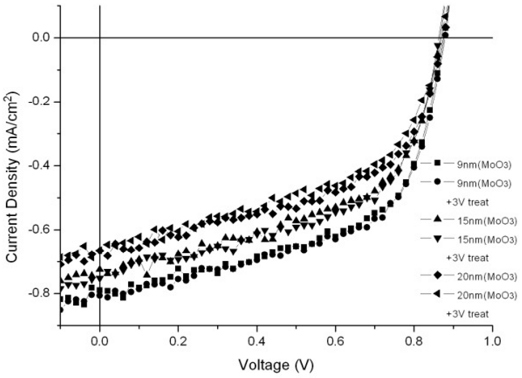


Fig.5 Current density – voltage curve of the devices

Fig.5 shows the current density-voltage (J-V) characteristics with and without bias voltage treatment as a function of the film thickness of $MoO_3$（9，15，20 nm）. With bias voltage treatment, the open circuit voltage does not change as the increase of MoO3 thickness. The short circuit current density, fill factor and the power conversion efficiency increase first and then decreae as the $MoO_3$ thickness increases. For the cell with 9 nm-thick MoO3 layer, with bias voltage treatment, the characteristics remarkably increases to with Voc=0.86 V, Jsc=0.807 mA/cm$^2$, FF=0.582, and η=0.404. Moreover, it can be seen clearly from Fig.5, as the thickness of $MoO_3$ layer increases to 15 nm, with the bias voltage treatment, FF and η were slightly increases. However, with further increase of the $MoO_3$ thickness to 20 nm, the solar cell exhibits a rather low of Jsc, FF and η. We conclud that as the thickness of $MoO_3$ layer increases to 15 or 20 nm, full and uniform coverage of the $MoO_3$ layer on the ITO is established and meanwhile partial defects are less. It has reported that series resistance is the determining factor of FF[12]. For a thicker $MoO_3$ layer 20 nm, a larger series resistance is introduced by $MoO_3$ layer itself, leading to a poor FF.

## Conclusions

In conclusion, We have studied the change in organic solar cells characteristics as a function of the film thickness of $MoO_3$ and investigated the influence of anode modification and bias voltage treatment on device performance.The experiment results show that the cell with 9 nm $MoO_3$ had the best performance. This can be mainly attributed to the merits brought by the anode modification layer. It can effectively enhance the built-in electric field and improve dissociation and transport of excitons. The bias voltage treatment can improve the performance of defective devices by burning partial defects, but not for too few defective devices.

## Acknowledgement

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