Study of organic solar cells with stacked bulk heterojunction structure*

ZHANG Xin-fang[1,2], XU Zheng[1], ZHAO Su-ling[1], ZHANG Fu-jun[1], LI Yan[1], WU Chun-yu[2], and CHEN Yue-ning[2]**

1. Institute of Optoelectronics Technology, Key Laboratory for Luminescence and Optical Information of Ministry of Education,Beijing Jiaotong University,Beijing 100044, China

2. Department of Physics,Liaoning University, Shenyang 110036, China

(Received 2 March 2008)

Organic solar cells with stacked bulk heterojunction(BHJ) are investigated based on conjugated polymer. By using the solution spin-coating method, Poly[2-methoxy, 5-(2' -ethyl-hexyloxy) -1,4-phenylene vinylene] (MEH-PPV) and ZnO nanoparticles (50 nm) are mixed as the optical sense layer. Ag is used as inter-layer to connect the upper BHJ cell and the lower cell. The structures are ITO/PEDOT:PSS/MEH-PPV /Ag / MEH-PPV:ZnO /Al. The open circuit voltage (V_{OC}) of a stacked cell is about 3.7 times of that of an individual organic solar cell (ITO/PEDOT:PSS/MEH-PPV /Al). The short circuit current (J_{SC}) of a stacked cell is increased by about 1.6 times of that of individual one.

CLC numbers: TM914.4 **Document code:** A **Article ID:** 1673-1905(2008)04-0257-3

DOI 10.1007/s11801-008-8028-0

Organic solar cells have been paid a great attention because of their promising cost effectiveness and environmental benignity. Over the last 20 years, the development of organic or "plastic" solar cells made significant progress from the first working device[1-3] to more and more refined concepts[4,5]. Thus traditional Si solar cells meet competition from organic ones.

Due to strong Coulomb interaction in organic materials, photoexcited charged carriers quickly form singlet excitons [6-8], which are dissociated and collected by the electrodes. Donor-acceptor-type heterojunctions are demonstrated to be effective for exciton dissociation[9,10]. But the diffusion length of singlet excitons is short, usually 5-10 nm[11,12] in most photovoltaic materials, which are much shorter than the absorption depth required for efficient light absorption.

Although special solar cell structures, such as bulk heterojunction, can be used to achieve efficient light absorption and charge separation, they will impede severely charge transport and are difficult to use in multilayered structures. This paper investigates the bulk heterojunction organic solar cells with stacked structure to overcome the difficulty. A possible way to stack different solar cells is proposed to extend the spectral sensitivity over a broader wavelength region. In this structure, an organic-inorganic compound intermingle system is adopted. Our experiment indicates that this structure improves the performance of the solar cells effectively.

In stacked structure, two separate single PV cells are jointed by a transparent electrode (Ag). This stacked structure is equal to two single cells in series, so the open circuit voltage is improved, and the short circuit current is also improved by applying ZnO nanoparticles.

Stacked cells with three structures are prepared for the comparison: a. ITO/PEDOT:PSS/MEH-PPV /Al; b.ITO/PEDOT:PSS/MEH-PPV /Ag / MEH-PPV /Al; and c.ITO/PEDOT:PSS/MEH-PPV /Ag / MEH-PPV:ZnO /Al.

Fig.1 shows the schematic structure of device c.

ITO substrates are cleaned by ultrasonication in acetone and isopropyl alcohol, and are dried by dry nitrogen. A 40 nm-thick hole conductive layer of poly (3,4-ethylenedioxythi ophene):poly(4-styrene sulfonate)(PEDOT: PSS) is spin-coated on this substrate. Then a 80 nm-thick photoactive layer of MEH-PPV is spin-coated on top of the PEDOT: PSS layer. Then as the interlayer, a 15 nm Ag layer is deposited by thermal evaporation at a vacuum of 1.33×10^{-4} Pa. Following the interlayer, MEH-PPV layer or MEH-PPV: ZnO (the quality proportion is 4:3) layer are formed in the same way as the underneath layers (structure c). Finally, a 120 nm-thick aluminum layer is deposited by thermal evaporation at a vacuum

* The work has been supported by the National Natural Science Foundation of China (60576016 and 10774013), National "863" Program (2006AA03Z0412) and "973" Program(2003CB314707).

** E-mail: zhengxu@bjtu.edu.cn.

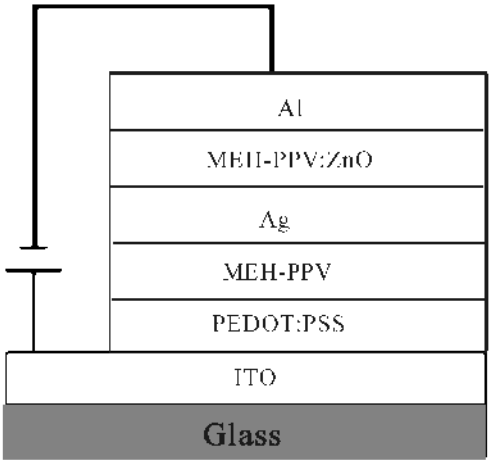

Fig.1 The schematic structure of device c

of 1.33x10^{-4} Pa. The active electrode area of the cell is 6 mm^2.

Current-voltage curves are measured by a Keithley 2410 source Measure Unit both in the dark and in the illumination. The incident light is of the wavelength of 500 nm with an intensity of 16.7 mW/cm^2. The cells are illuminated from the ITO side with a 450 W Xe lamp.

Fig.2 shows the current density (*J*)-voltage (*V*) characteristics of the solar cells with various structure. Tab. 1 shows open-circuit voltage (V_{OC}), short-circuit current (J_{SC}) and filling factor (*FF*) of the solar cells with different structures.

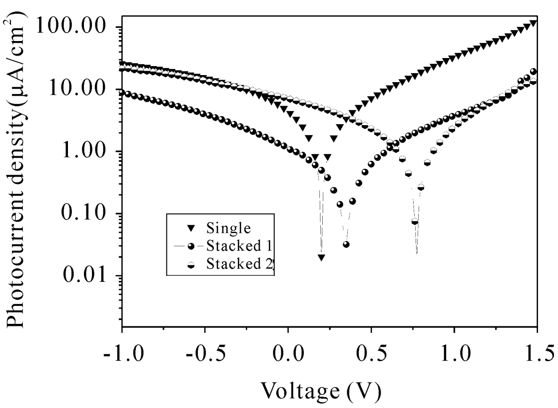

Fig.2 The density (*J*)-voltage (*V*) characteristics of three structures of solar cells

Tab.1 Open-circuit voltage (V_{OC}), short-circuit current (J_{SC}) and filling factor (*FF*) of the solar cells with different structures

	Structure a	Structure b	Structure c
J_{SC} (iA/cm^2)	4.39	1.13	7.07
V_{OC} (v)	0.21	0.34	0.77
FF	0.24	0.27	0.23

In Tab.1, V_{OC} of structure b is about 1.6 times of that of structure a. V_{OC} of the stacked cell with ZnO used as the upper cell (structurec) is about 3.7 times of that of structure a. J_{SC} of the stacked cell with MEH-PPV used as both upper cell and lower cell (structure b) is reduced, but J_{SC} of the stacked cell with ZnO used as the upper cell (structure c) is about 1.6 times of that of structure a.

The basis of our stacked cells are the bulk heterojunction made of MEH-PPV:ZnO (50 nm) blends as photoactive layers. Nanostructured metal oxides such as TiO_2, ZnO and SnO_2 are interesting inorganic semiconductors because of the ease of fabrication and control of film morphology, as well as perfect interfacial properties. The polymer-inorganic hybrid solar cells integrate the advantages of solution spin-coating, high-hole mobility, photosensitivity of conjugated polymers and highelectron mobility of inorganic semiconductors.

In our experiments, the optimal proportion of 4:3 of MEH-PPV and ZnO are chosen as the active layer of stacked cells. When the ZnO nanoparticles are blended with MEH-PPV as shown in Fig.3, the electrons can cross through it very easily and quickly, while only a few holes can cross through it, and most of the holes are left in the active layer. Therefore, the charge recombining ratio is reduced and the charge extraction efficiency is enhanced significantly. So the short circuit current is improved.

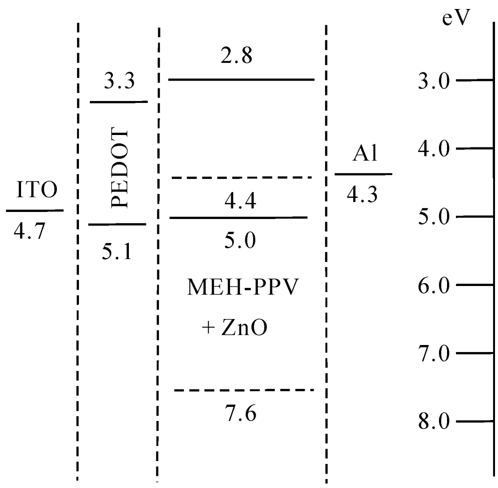

Fig.3 The energy level diagram of the device with MEH-PPV and ZnO as the active layer

In summary, the stacked structure of bulk heterojunction (BHJ) organic solar cells is studied based on conjugated polymer, Poly[2-methoxy, 5-(2' -ethyl-hexyloxy) -1,4-phenylene vinylene] (MEH-PPV) and ZnO nanoparticles by the solution spin-coating method. Ag as inter-layer is used to connect the upper BHJ cell and the lower cell. In this work, V_{OC} and J_{SC} of the stacked cell increase by about 3.7 times and 1.6 times than that of single organic solar cell, respectively.

References

[1] C.W. Tang, Appl. Phys. Lett., **48** (1986), 183.

[2] D. Wohrle and D. Meissner , Adv. Mater., **3** (1991), 129.

[3] N.S. Sariciftci, D. Baun, and C. Zhang , Appl. Phys. Lett., **62** (1993), 585.

[4] P. Peumans, A. Yakimov, and S.R. Forrest, J. Appl. Phys., **93** (2003), (7) 3693.

[5] D. Gebeyehu, M. Pfeiffer, and B. Maennig, , Thin Solid Films, **29** (2004), 451.

[6] M. Deussen, M. Scheidler, and H. Bässler, Synth. Met., **73** (1995), 123.

[7] R. Kersting, U. Lemmer, and M. Deussen, Phys. Rev. Lett., **73** (1994), 1440.

[8] U. Rauscher, H. Bässler, and D. D. C. Bradley, Phys. Rev. B, **42** (1990), 9830.

[9] N. S. Sariciftci, L. Smilowitz, and A. J. Heeger, Science, **258** (1992), 1474.

[10] G. Yu, J. Gao and J. C. Hummelen, Science, **270** (1995), 1789.

[11] J. J. M. Halls, K. Pichler, and R. H. Friend, Appl. Phys. Lett., **68** (1996), 3120.

[12] D. E. Markov, C. Tanase, and P. W. M. Blom, Phys. Rev. B, **72** (2005), 045217.