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INVERTED BULK HETEROJUNCTION ORGANIC SOLAR CELL WITH ZnO NANOROD ARRAYS

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ABSTRACT

Inverted bulk heterojunction organic solar cells based on a blend of poly[2-methoxy-5-(2-ethylhexyloxy)-1,4-phenylenevinylene] (MEHPPV) as donor and (6,6)-Phenyl-C61 butyric acid methyl ester (PCBM) as acceptor with a structure of FTO/ZnO nanorods array/MEHPPV:PCBM/Au utilizing ZnO nanorods array as electron collecting layer and gold as a hole collecting electrode were investigated. The organic layer consisting of MEHPPV and PCBM was spin-coated on ZnO nanorod arrays. ZnO nanorod arrays were grown on fluorine-doped tin oxide (FTO) glass substrates which were pre-coated with ZnO nanoparticles using a low temperature chemical solution method. The device gave a short circuit current density of 0.18 mA/cm^2 and an open circuit voltage of 0.38 V under illumination of a simulated AM 1.5 G sunlight at 100 mW/cm^2. The power conversion efficiency of the solar cell was increased from 0.0015 % to 0.016 % through the introduction of ZnO nanorods arrays.

Keywords: ZnO; nanorod; current density;

INTRODUCTION

Organic solar cells have attracted considerable interest due to their great potential for the production of flexible and large-area solar cells at relatively low costs and easy-processing fabrication properties [1-2]. Most commonly, organic solar cells are fabricated on transparent conductive oxide (TCO) covered glass substrates using a hole injection layer between TCO and the bulk heterojunction organic layer and a low work function metallic electron contact. An Al metal has often been used as the anodic electrode of a normal type organic solar cell. However, there is a problem for its durability because the Al surface is easy to react with oxygen and water to form insulator Al_2O_3 [3]. These issues could be solved by fabrication of inverted structure organic solar cells with non-corrosive electrode such as gold (Au) instead of the Al anode [4-5]. For an inverted type solar cell, photo-generated electrons flow through external circuit from the TCO electrode to Au electrode.

The environmental friendly and low-cost ZnO nanorods arrays are particularly promising candidate for electron collector electrodes of the inverted type solar cells since they can be grown using a low-temperature chemical solution method [6-7] as well as provide a direct and ordered path for photo-generated electrons to the collecting electrode [8-9]. It has been reported that ZnO nanorods arrays played an important role in collecting and transporting electrons in an inverted type organic solar cell based on a blend of donor of poly(3-hexylthiophene) (P3HT) and acceptor of (6,6)-phenyl C61 butyric acid methyl ester (PCBM) blend [10-11].

The present work reports on the fabrication of an inverted bulk heterojunction organic solar cell based on a blend of poly[2-methoxy-5-(2-ethylhexyloxy)-1,4-phenylenevinylene] (MEHPPV) as donor and (6,6)-Phenyl-C61 butyric acid methyl ester (PCBM) as acceptor with a structure of FTO/ZnO nanorods array/MEHPPV:PCBM/Au utilizing ZnO nanorods array as electron collecting layer and gold as a hole collecting electrode. The device gave a short circuit current density of 0.18 mA/cm^2 and an open circuit voltage of 0.38 V under illumination of a simulated AM 1.5 G sunlight at 100 mW/cm^2.

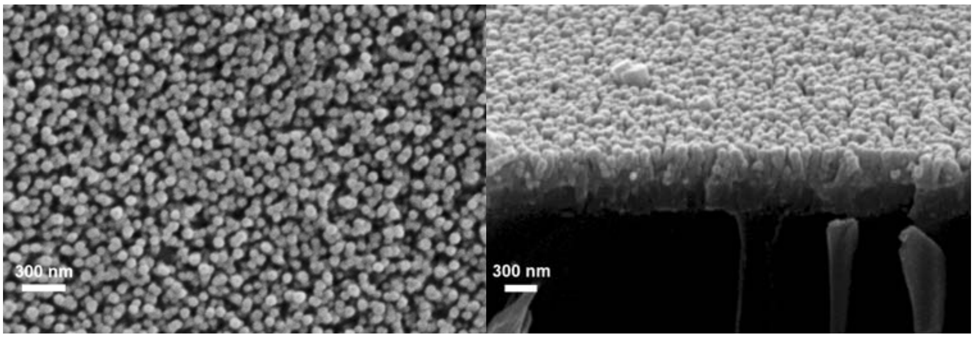
EXPERIMENTAL DETAILS

The ZnO nanorod arrays were grown on FTO glass substrates which were pre-coated with ZnO nanoparticles using a low temperature chemical solution method. The details of the ZnO nanorods synthesis processes were described elsewhere [12]. The donor polymer, MEHPPV with an average molecular weight of 40,000-70,000 g/mole and the acceptor, PCBM was purchased from Aldrich Chemical Company and Luminescence Technology Corporation, respectively. All materials were used as received without further purification. The inverted bulk heterojunction organic solar cell with FTO/ZnO nanorods array/MEHPPV:PCBM/Au structure was fabricated. The organic layers made of MEHPPV and PCBM were spin-coated on the top of the ZnO nanorods arrays from chloroform solution with a concentration of 10 mg/mL for MEHPPV and 20 mg/mL for PCBM at 1000 rpm for 40 s. Finally, the top gold electrodes were sputter-coated to a thickness of 50 nm, giving an active area of 0.07 cm^2.

Top-view and cross-sectional scanning electron microscopy (SEM) images of ZnO nanorods array were taken using a LEO 1450VP SEM. The absorption and photoluminescence (PL) properties of the relevant blend films were investigated by using Perkin Elmer LAMBDA 900 UV-VIS spectrophotometer and Perkin Elmer LS55 luminescence spectrometer, respectively. The organic solar cells were also characterized by current–voltage measurements in dark and under 100 mW/cm^2 simulated AM 1.5 G sunlight using Keithley 237 source measurement unit.

RESULTS AND DISCUSSION

The SEM image of top view of a dense array of hexagonal ZnO nanorods having a diameter from 60 nm to 80 nm is shown in Figure 1a. It can be seen that there are many pores and apertures existing among ZnO nanorods. The cross-section image of ZnO nanorod arrays is shown in Figure 1b. It was found that all ZnO nanorods grew almost perpendicularly to the seeded-substrate, and the length of ZnO nanorods is about 150-200 nm.



(a) (b)

Figure 1: a) Top-view and b) cross-sectional SEM images of ZnO nanorod arrays grown on seeded-FTO substrate

Figure 2 shows the absorption spectra of ZnO nanorods, MEHPPV:PCBM blend film and ZnO nanorods/MEHPPV:PCBM hybrid blend films. The MEHPPV:PCBM blend film exhibited a broad absorption spectrum ranging from 300 nm to 600 nm. The enhanced optical density of the absorption spectra below 380 nm in the hybrid mainly results from the contributions of ZnO nanorods.

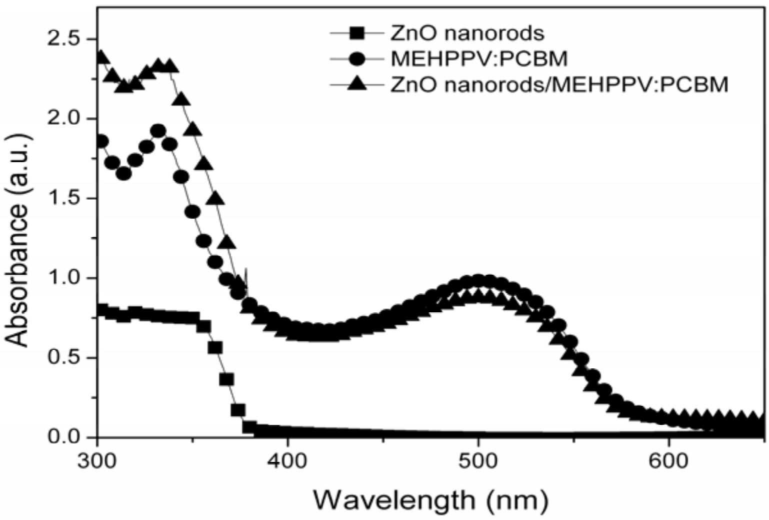


Figure 2: Absorption spectra of ZnO nanorods, MEHPPV:PCBM blend film and ZnO nanorods/MEHPPV:PCBM hybrid film

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The PL quenching in blend of donor–acceptor is a useful indication for the efficient charge transfer between the materials [13]. Figure 3 shows the PL spectra of the MEHPPV, ZnO nanorods/MEHPPV, MEHPPV:PCBM and ZnO nanorods/MEHPPV:PCBM under 500 nm monochromatic excitation. For the pure MEH-PPV, there is an emission peak at the wavelength of 586 nm. When the MEHPPV deposited onto ZnO nanorods arrays, the PL quenching was not significant. However, the PL emission was significantly quenched in the MEHPPV:PCBM and ZnO nanorods/MEHPPV:PCBM. The strong PL quenching observed for MEHPPV:PCBM is an evidence of the efficient photo-induced charge transfer at the interface between MEHPPV and PCBM even without the presence of ZnO nanorods array.

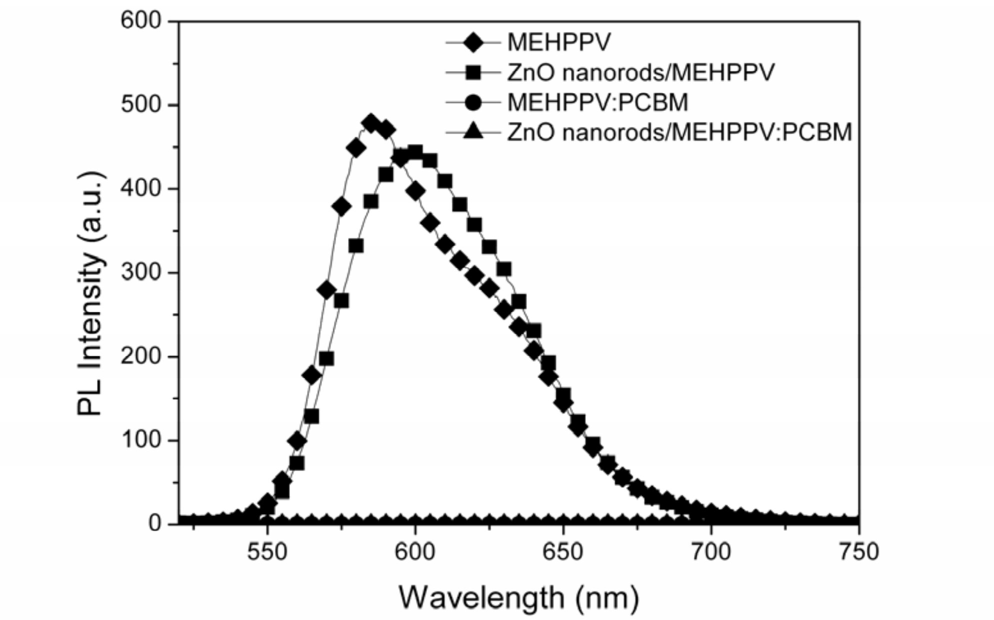

Figure 3: Photoluminescence spectra of MEHPPV, ZnO nanorods/MEHPPV hybrid film, MEHPPV:PCBM blend film and ZnO nanorods/ MEHPPV:PCBM hybrid film

Figure 4 shows the current density-voltage (J-V) of organic solar cell with and without ZnO nanorods array under illumination. Interestingly, the device with the ZnO nanorods array exhibited a significant improvement in the photovoltaic performance compared with the devices without the nanorods. Under illumination of a simulated AM 1.5 G sunlight at 100 mW/cm^2, the device without nanorods (with only the ZnO nanoseed layer) showed a short circuit current density (ISC) of 0.023 mA/cm^2, an open-circuit voltage (VOC) of 0.38 V, and a fill factor (FF) of 17 %, resulting in a power conversion efficiency (PCE) of 0.0015 %. With the array of ZnO nanorods, the PCE was improved of almost ten times to 0.016 % under the same conditions, as a result of the increased values for *I*SC of 0.18 mA/cm^2, VOC of 0.38 V, and FF of 23%.

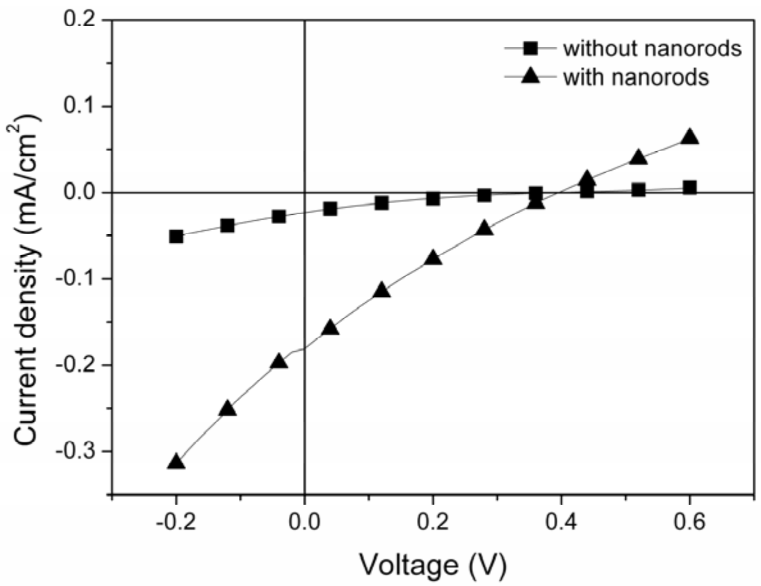

Figure 4: Current density-voltage (J-V) characteristics of solar cell without ZnO nanorods array and solar cell with ZnO nanorods array under illumination of simulated AM 1.5 G sunlight at 100 mW/cm^2

CONCLUSION

The inverted type bulk heterojunction organic solar cell based on MEHPPV:PCBM with ZnO nanorods array as electron collecting layer showed a short circuit current density of 0.18 mA/cm^2, an open-circuit voltage of 0.38 V, a fill factor of 23 %, and a power conversion efficiency of 0.016 %. More importantly, the power conversion efficiency of the solar cell with ZnO nanorods was almost ten times larger than that of the devices without the nanorods.

ACKNOWLEDGMENTS

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