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Investigation of Inverted Polymer Solar Cells with AZO-nanorod Array

Hung-Lin Huang[1], Ching-Ting Lee[2], and Hsin-Ying Lee[1*]

[1]Department of Photonics, National Cheng Kung University, Tainan, Taiwan, Republic of China
[2]Institute of Microelectronics, Department of Electrical Engineering, National Cheng Kung University, Tainan, Taiwan, Republic of China

*Tel: 886-6-2082368 Fax: 886-6-2082368 E-mail: hylee@ee.ncku.edu.tw

1. Introduction

The polymer solar cells have attracted attention over the past decade due to the inherent advantages of flexibility, low cost, large scale production, and easy fabrication [1-3]. Recently, the polymer solar cells with inverted structure using a high work function metal worked as the anode and indium tin oxide (ITO) worked as the cathode exhibited better stability and flexibility [4]. However, the inverted polymer solar cells based on the composite blends of a conjugated polymer, such as poly(3-hexylthiophene) (P3HT) and a soluble form of [6,6]-phenyl-C61-butyric acid methyl ester (PCBM), only have a power conversion efficiency (PCE) of 3 % [5]. This low PCE was attributed to the lower probability of charge carrier collection and electronic transportation. In this study, to improve the performances of inverted polymer solar cells, the laser interference lithography method and the wet-etching process were used to fabricate the Al-doped ZnO (AZO)-nanorod array as the electronic collection layer and the electronic transportation layer.

2. Experimental procedure

Figure 1 shows the schematic configuration of the inverted polymer solar cells. A 125-nm-thick AZO film was deposited on the ITO-coated glass substrate as the charge carrier collection layer using a radio-frequency (RF) magnetron sputter system. The He-Cd laser (λ=325 nm) interference lithography method was utilized to define the pattern on the AZO film. The patterned sample was then dipped into the diluted HCl solution (0.1 %) to form the AZO-nanorod array. The length of the AZO-nanorod array was about 100 nm. After the formation of AZO-nanorod array, the thickness of the residual AZO film was about 25 nm. The AZO-nanorod array worked as electronic collection layer. The AZO film worked as electron transportation layer and hole blocking layer. The 200-nm-thick active layer of the inverted polymer solar cells consisted of P3HT and PCBM dissolved in 1,2-dichlorobenzene (DCB) (with 1:0.8 wt% P3HT:PCBM) was fabricated by spin-coating with spin speed of 800 rpm for 60 sec. The sample was then thermal-annealing at 110 ^{o}C for 20 min in the nitrogen glove box. Finally, a 10-nm-thick MoO_3 layer and a 100-nm-thick Ag layer worked as cathode electrode were deposited onto the active layer through a shadow mask using a thermal evaporator sequentially. The active area of the solar cells was 2 $\times$ 2 mm^2. To investigate the function of the AZO-nanorod array, the inverted polymer solar cells without AZO-nanorod array were fabricated using the same fabrication process.

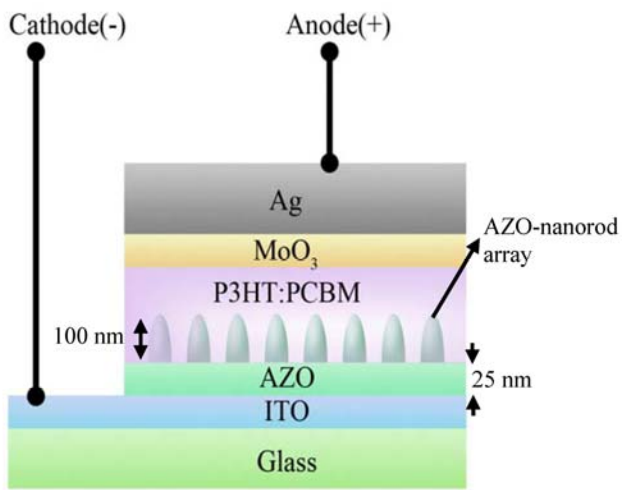

Fig. 1 Schematic diagram of inverted polymer solar cells structure with AZO-nanorod array.

3. Experimental Results and Discussion

Figure 2 shows the current density-voltage (J-V) characteristics of the inverted polymer solar cells with and without AZO-nanorod array under AM 1.5G illumination with an intensity of 100 mW/cm^2. According to the experimental results, the short-circuit current density (J_{sc}), open circuit-voltage (V_{oc}), fill factor (FF), and power conversion efficiency (η) were calculated and shown in the inset of Fig. 2. The J_{sc} of the solar cells with and without AZO-nanorod array was 13.8 mA/cm^2 and 10.2 mA/cm^2, respectively. Furthermore, the V_{oc} and FF of the inverted polymer solar cells with the AZO-nanorod array were slightly deceased. These phenomena were attributed to carrier recombination in the AZO-nanorod array and a larger AZO/active layer interface area [6]. By using the AZO-nanorod array, the power conversion efficiency of the inverted polymer solar cells was 4.13 %, which was larger than 3.12 % of the solar cells without AZO-nanorod array.

To investigate the influence factor of the improved current density, the reflectivity was measured using an UV-Visible spectrometer (Hitachi U4100). Figure 3 shows the reflectivity spectra of the inverted polymer solar cells with and without AZO-nanorod array. It could be found that the reflectivity of the solar cells with AZO-nanorod array was smaller. The reduced reflectivity was attributed to the light scattering caused by the roughened surface of the

AZO-nanorod array. Therefore, the lower reflectivity could be deduced as one of the influence factors for improving the J_{sc}.

The external quantum efficiency (EQE) of the inverted polymer solar cells with and without AZO-nanorod array was shown in Fig. 4. The inverted polymer solar cells without AZO-nanorod array exhibited a maximum EQE of 50 % at the wavelength of 550 nm. When the AZO-nanorod array was used in the inverted polymer solar cells, an increase in the maximum EQE of 60 % at the wavelength of 550 nm was observed. This EQE enhancement was attributed to the increased charge carrier extraction and the probability of charge carrier collection by using the AZO-nanorod array as the electronic collection layer and electronic transportation layer. Consequently, the enhanced EQE was the major improvement factor of the J_{sc} in the inverted polymer solar cells.

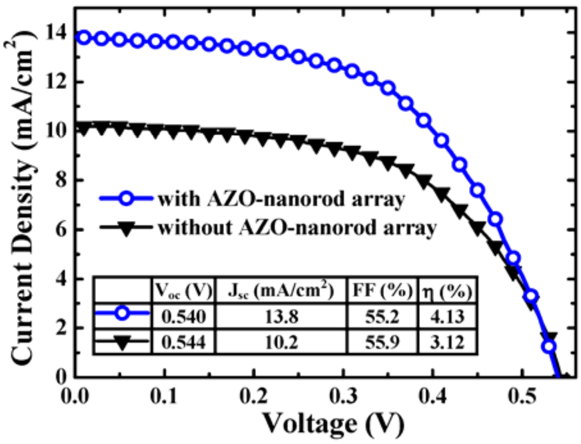

Fig. 2 Illuminated current density-voltage characteristics of the inverted polymer solar cells with and without AZO-nanorod array.

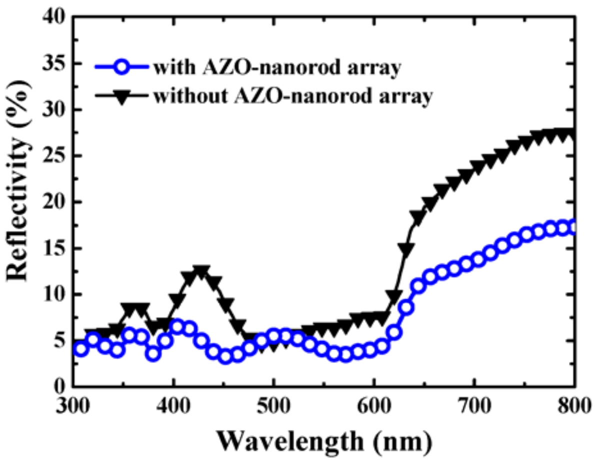

Fig. 3 Reflectivity spectra of inverted polymer solar cells with and without AZO-nanorod array.

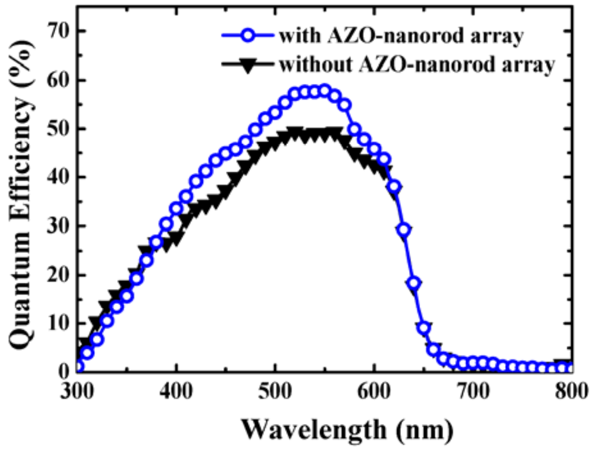

Fig. 4 External quantum efficiency spectrum of inverted polymer solar cells with and without AZO-nanorod array.

4. Conclusions

In summary, the AZO-nanorod array structure was used to enhance the power conversion efficiency of the inverted polymer solar cells. The AZO-nanorod array was fabricated using the laser interference lithography method and wet-etching process. According to the experimental results, the inverted solar cells with AZO-nanorod array can lead to a significant improvement in the short-circuit current density. By measuring the reflectivity and external quantum efficiency, the improved J_{sc} of the inverted solar cells with AZO-nanorod array was attributed to the increased probability of charge carrier extraction and charge collection by using the AZO-nanorod array. Therefore, the power conversion efficiency was increased from 3.12 % to 4.13 % using the AZO-nanorod array.

Acknowledgement

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