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Inverted low band gap polymer solar cells integrated with a low-temperature-annealed sol–gel-derived ZnO: Active layer thickness effect on the recombination process

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ABSTRACT

Structural of thin film of ZnO elaborated by sol–gel ZnO method, annealed at different temperatures were investigated by means of Photoluminescence and Raman spectroscopy analysis. The results show the formation of crystalline layer of ZnO after annealing at 150 °C. This thin film provided an effective hole blocking layer and an increased interfacial area for electron collection. Inverted bulk heterojunction organic solar cells were fabricated using ZnO film as the electron collecting layer. The influence of spin coating speed of the active layer on the performance of inverted-type organic solar cells has been investigated. The organic photoactive layers consisted of Poly[N-9′-heptadecanyl-2,7-carbazole-alt-5,5-(4′,7′-di-2-thienyl-2′,1′,3′-benzothiadiazole)] (PCDTBT) and [6,6]-Phenyl-C71-butyric acid methyl ester ($PC_{70}BM$) were spin coated onto ZnO thin film with two spin coating speeds at 600 and 2000 rpm. Experimental results showed that the short-circuit current density (J_{sc}), the fill factor (*FF*) and power conversion efficiency (PCE) increase with increasing spin coating speed. This result may be attributed to reducing series resistance and recombination processes in thinner photoactive layer.

The impedance spectra of the devices were measured under illumination. A decrease in the charge recombination and the

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resistance of whole device were observed with the increase in the spin coating speed of the active layer.

1. Introduction

Rapid development in enhancing the performance of organic solar cells (OSCs) for the past few years by using bulk heterojunction (BHJ) devices has enabled power conversion efficiency (PCE) up to 10.6% to be achieved [1].

Recently, interest has focused on fabricating solar-cells using low energy-gap polymers as the light absorbing and electron donating material combined with an electron-accepting fullerene derivative [2]. In the case of BHJ conventional device structure the blend is normally sandwiched between indium tin oxide (ITO) anode and aluminium (Al) cathode [3]. Poly(3,4-ethylenedioxythiophene):poly(styrenesulfonate) or PEDOT:PSS which acting as conductive hole transport layer (HTL) is commonly introduced layer between organic photoactive layer and ITO anode. Poly[n-900-heptadecanyl-2,7-carbazole-alt-5, 5-(40,70-di-2-thienyl-20,10,30- benzothiadiazole)] (PCDTBT) is a promising conducting polymer for good PCE and high V_{oc} [4]. Previous research has revealed that polymer solar cells (PSCs) based on PCDTBT showed excellent performance with a conventional structure [5]. However, the conventional structure is sensitive to oxygen and humidity because of the low work function metal, which is easily oxidized. Moreover, in the conventional structure the hygroscopic and acidic nature [6–8] of poly(3,4-ethylenediox-ythiophene): poly(styrenesulfonate) (PEDOT:PSS), which is used to cover the anode as a buffer layer, raises stability issue in the as-fabricated PV cells. As a solution, inverted PSCs [9–13], where the positions of anode and cathode are reversed, with low work function metal or metal oxides materials as electron transporting layer and high work function metal (e.g., silver, gold) as hole collection electrode have been introduced to improve the stability of the device. Instead of PEDOT:PSS, *n*-type inorganic material such as ZnO thin film is used as the electron-selective layer (ESL) due to its relatively high electron mobility, environmental stability and high transparency [13]. A variety of fabrication methods have been employed to grow thin films of ZnO. Sol–gel method has been extensively investigated as a solution-based thin film deposition [14].

The aim of the electron selective layer is to provide hole blocking capability and a low resistive pathway for efficient electron extraction. However, the sol–gel derived ZnO thin films form rough surface, which may cause large leakage current and extremely high contact resistance. Despite the rough wrinkled ZnO surface, the ZnO based inverted structure show excellent performance with the novel P3HT:PCBM system [15]. The inverted solar cells can achieve comparable device performance.

Nevertheless, unlike the P3HT:PCBM system, the optimal thickness of the active layer is relatively thin for low band gap polymers (<100 nm) [5,16–19]. It is reported that PCDTBT:PCBM based organic solar cells in conventional configuration have decreased efficiencies with increasing thicknesses [20]. Therefore, it is expected that the thin active layer will not be able to completely cover the rough ZnO, which may cause large leakage current and extremely low open circuit voltage.

However, there are not many reports in literature studying the effect of the active layer thickness on the charge transport mechanism and the efficiency of PCDTBT:PC70BM based inverted type organic solar cells.

In the present work, to elaborate ITO/ZnO/PCDTBT:$PC_{70}BM$/MoO_3/Ag inverted type organic solar cells, we designed a simple annealing process of sol–gel ZnO electron-selective layer (ESL) to decease roughness and to promote crystallization of the layer. After optimizing the surface properties of ZnO films, we discussed the effect of the spin coating speed of the blend of PCDTBT and $PC_{70}BM$ on the performance of the inverted organic device. Careful analysis of experimental data of (UV)-visible absorption, current voltage characteristics in the dark and under light and impedance spectroscopy at different bias voltages were investigated.

The structural evolution of the ZnO films with annealing treatment was studied by Photoluminescence and Raman spectroscopy measurements. The results show an improvement in the crystalline properties of the ZnO layer annealed at 150 °C.