Effects of ZnO nanoparticles/nanoflakes buffer layer on the performance of organic solar cells

P.S. Mбуле\textsuperscript{1a}, T.-H. Kim\textsuperscript{2}, B.-S. Kim\textsuperscript{2}, H.C. Swart\textsuperscript{1} and O.M. Ntwaeaborwa\textsuperscript{1b}

\textsuperscript{1} Department of Physics, University of the Free State, Bloemfontein, ZA9300, South Africa
\textsuperscript{2}Solar Cell Center, Korea Institute of Science and Technology, P.O. Box 131, Cheongryang, Seoul 136-791, Republic of Korea

Abstract
It has been reported that the performance of organic solar cell (OSC) can be improved by adding a buffer layer of a wide band gap semiconducting material such as ZnO that facilitates the electron transport from the active layer (P3HT:PCBM blend) to the metal electrode (Al) while, at the same time, blocking holes. In this study we compare the effects of ZnO nanoparticles and nanoflakes buffer layer on the performance of OSC devices. The OSC comprising of an active layer of P3HT:PCBM blend and ZnO buffer layer, sandwiched between a transparent conductive oxide (ITO) coated glass as an anode and a top metal layer (Al) as a cathode giving the device configuration of ITO|PEDOT:PS|P3HT:PCBM|ZnO|Al were fabricated. The concentration of ZnO was varied. The OSC device with ZnO nanoflakes buffer layer and a concentration of 0.5mg/ml gave highest power conversion efficiency of 3.08 \% compared to similar device with ZnO nanoparticles that gave the power conversion efficiency of 2.37 \%.

Keyword: Organic Solar cells, Zinc Oxide, Photovoltaic

1. INTRODUCTION

Renewable energy sources such as organic solar cells (OSCs) have gained popularity as promising alternative to conventional silicon based solar cells because of their cost-effectiveness, printability, lightweight, large area and flexibility[1-3]. Bulk-heterojunction (BHJ) OSCs consisting of a polymer donor (P3HT) and fullerene acceptor (PCBM) blend inserted between a high transparent semiconducting oxide anode and a metal cathode have attracted considerable attention of several researchers [3]. The OSC devices made from the blend of these materials have attained the power conversion efficiency of 5-6\% [3-5] thereby increasing the chances for commercialization.

Because of its relatively high electron mobility and environmental stability[6,7] zinc oxide (ZnO) is used as buffer layer in BHJ-OSC devices serving as electron transporting and hole blocking layer to improve efficiency of the OSC devices. The overall performance of the OSCs is sensitive to the electrical properties of the interfaces between the buffer layer and the photoactive layer. The contact resistance between the ZnO buffer layer and the photoactive layer can strongly impact the charge collection. Moreover, the morphology of the ZnO buffer layer plays a critical role in determining the contact quality because of the significant difference in surface energy between the ZnO buffer layer and the photoactive layer [7].

Among the effects associated with ZnO buffer layers in OSCs, the appearance of the shunts and inflection points in the cell’s J-V curves have been reported [8]. These inflection points are reported to originate from low ZnO conductance and poor charge extraction [8]. The aim of this study was to investigate the influence of the morphology (nanoparticles versus nanoflakes) of the ZnO buffer layer on photovoltaic properties of OSCs. Furthermore, the effects of ZnO concentration on the photovoltaic properties of OSCs are also investigated.

2. EXPERIMENTAL AND RESULTS

Device Fabrication:
The conventional geometry of organic solar cell comprises of ITO patterned glass substrate, PEDOT:PSS (hole transporting polymer), P3HT:PCBM blend (photoactive layer), ZnO nanoparticles/nanoflakes buffer layer and Al cathode electrode. A glass substrate was cleaned ultrasonically using isopropanol, acetone and isopropanol again, consecutively for 10 minutes, dried at ~80 \degree C for 20 minutes and then treated in an ultraviolet ozone generator for 20 minutes. A thin layer of poly(3,4-ethylenedioxythiophene):polystyrenesulfonic acid (PEDOT:PSS) (CLEVIOS™ Al 4083) was spin coated on a substrate at the speed of 4000rpm for 35 seconds then followed by drying at 110 \degree C for 10 minutes. The active layer, P3HT:PCBM blend (P3HT, Aldrich/PCBM, Nano-C), weight ratio of 1:0.6 layer was spin coated from a blend solution of chlorobenzene at the speed of 1000 rpm for 15 seconds followed by the deposition of the layer of ZnO nanoparticles/nanoflakes (0.5, 1, 2, 5 and 20 mg/ml concentrations), methanol solution at 4000 rpm for 35 seconds. Finally the Al layer (~100 nm) was thermally evaporated at ~1x10\textsuperscript{-6} Torr pressure through a shadow mask defining the device area of 0.12 cm\textsuperscript{2}. The devices were then heat treated at 155 \degree C for 10 minutes.

Fig 1(a-d), shows the FE-SEM images of ZnO nanoparticles/nanoflakes obtained by spin coating and their respective device cross-sectional view. Figure 1(a) shows that fine ZnO nanoparticles are spherical and uniformly distributed throughout the substrate area and the high density nanoflakes 1(c), are randomly oriented. Cross-sectional images show the device layers with different
thickness. Fig 2 compares the current-density (J-V) characteristics of devices with ZnO nanoflakes, nanoparticles buffer layers and standard device under 1 sun (= 100mW/cm²) AM1.5G solar illumination. The photovoltaic performance parameters (Jsc, Voc, FF and PCE) of the devices strongly depended on the morphology and concentration of ZnO. The device with the ZnO nanoflakes buffer layer showed a significant enhancement of power conversion efficiency (PCE) (from ~1.38 to 3.08 %) as the concentration the ZnO concentration is decreased from 20 mg/ml to 0.5 mg/ml. Similarly the device with ZnO nanoparticles showed an increase of PCE (from ~ 0.17 to 2.37 %) as the concentration is decreased.

3. SUMMARY

In conclusion, BHJ organic solar cells were fabricated using solution based method with ZnO nanoparticles and nanoflakes buffer layers. The enhanced exciton dissociation and efficient electron transfer from PCBM to the ZnO lead to a high photocurrent and power conversion efficiencies for devices with ZnO nanoflake buffer layer as compared to nanoparticles. This suggested that the performance of the devices strongly depended on the ZnO buffer layer morphology and concentration as demonstrated when the concentration was varied from 0.5, 1, 2 and 20 mg/ml. However, it is worth mentioning that the device without ZnO buffer layer (standard device) showed higher photovoltaic response compared to that of devices with ZnO buffer layers. This means that introducing the ZnO buffer layer couldn’t enhance the efficiency of the standard device as expected but showed that higher efficiencies can be achieved by having less dense and thinner layers of ZnO buffer layers by varying the concentration and having two different nanostructures.

4. REFERENCES