TÜBİTAK

Technical Note

Turkish J. Eng. Env. Sci.
34 (2010) , 261 – 264.

doi:10.3906/muh-1005-20

Manufacturing of inorganic-organic hybrid solar cells by screen printing method*

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Received 11.05.2010

Abstract

In this study, hybrid bulk heterojunction (BHJ) organic solar cells with a poly(3-hexylthiophene-2,5-diyl)(P3HT):(6,6)-phenyl C_{61}-butyric acid methyl ester ($PC_{61}BM$) active layer, a poly(3,4-ethylenedioxythiophene)-poly(styrenesulfonate)(PEDOT:PSS) buffer layer, and an electrochemically deposited zinc oxide (ZnO) n-type inorganic layer were produced. The PET/ITO/ZnO/PEDOT:PSS/P3HT:$PC_{61}BM$/Al device was manufactured and tested under solar illumination (AM1.5G, 100 mW/cm^2).

Key Words: Polymer solar cells, photovoltaic, screen printing, P3HT/PCBM blends, ZnO

Introduction

Much attention has been focused on organic solar cells that are based on BHJ architecture due to the potential of low-cost and large-area manufacturing compared to conventional photovoltaics (Brabec et al., 2005). Organic solar cells can be manufactured in large areas on flexible substrates (Krebs, 2007; Krebs, 2009a) from solution by printing and coating techniques (Krebs, 2008; Krebs et al., 2009), at low temperatures and with no need for vacuum coating steps (Krebs, 2009b). A promising efficiency, $\eta = 4.8\%$, was obtained in one of these basic organic solar cell structures, ITO/PEDOT:PSS/P3HT:PCBM/Al (Yoon et al., 2008), but this efficiency value is still not enough for use in commercial applications. The production of polymer-based photovoltaics via industrial screen printing has demonstrated the possibility of producing on the order of 1000-100,000 m^2 on a process line per day. The production of the same solar cell area based on silicon in a state-of-the-art production plant typically takes 1 year (Krebs, 2007).

In this study, hybrid bulk heterojunction (BHJ) flexible organic solar cells with a P3HT:$PC_{61}BM$ active layer, PEDOT:PSS buffer layer, and n-type zinc oxide (ZnO) inorganic layer were produced (Figure 1). The inorganic ZnO layer was deposited by the electrochemical deposition (ECD) method. ZnO is one of the most

*Paper presented at the 6th Nanoscience and Nanotechnology Conference (NanoTRVI), İzmir, Turkey, June 15-18, 2010.

promising semiconductor materials for manufacturing optoelectronic devices because it is a nontoxic, cheap, wide bandgap semiconductor. In addition, ZnO is a natural n-type semiconductor (Lare et al., 2009).

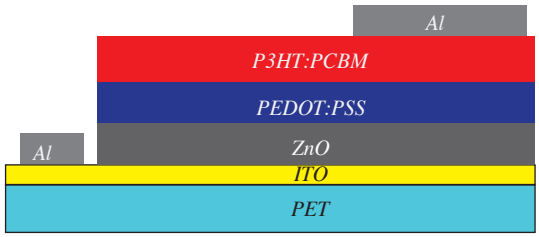

Figure 1. Schematic representation of the hybrid solar cell.

In this device, the ZnO layer was deposited between the top electrode, Al, and the ITO electrode (Park et al., 2009) to prevent short paths, which reduce device efficiency. The ZnO layer also acts as an n-type semiconductor layer to enhance open-circuit voltage. The organic layer was coated by the screen printing method on a PET/ITO substrate.

Experimental Details

The ITO-coated poly(ethylene terephthalate) (PET) substrates were sonicated in detergent, acetone, ethanol, and distilled water for 15 min at each step, and then the PET substrates were dried with argon. The ZnO coating was achieved in a 0.1 M aqueous zinc nitrate tetrahydrate ($Zn(NO_3)_2.4H_2O$) solution (Yoshida et al., 2004) with a Ag/AgCl reference electrode, ITO/PET as the working electrode, and a pure zinc metal sheet as the counter electrode under the previously obtained deposition potential of -0.850 V, and at 80 °C (Hames et al., 2010). PEDOT:PSS that had been preheated to 70 °C was coated onto the previously obtained ZnO/ITO/PET substrate by spin coating at 1200 rpm for 1 min. Samples were then annealed at 120 °C for 1 h. A polymer blend of P3HT:PCBM (1:1, wt/wt) was prepared in the chlorobenzene solution and the obtained solution was stirred at 1200 rpm, 70 °C, for 24 h. An evaporation system was designed for precision control of the evaporation process and also to reduce the evaporation time, which is demonstrated in Figure 2. In this system, chlorobenzene was evaporated at 110 °C for 100 min to obtain feasible viscosity.

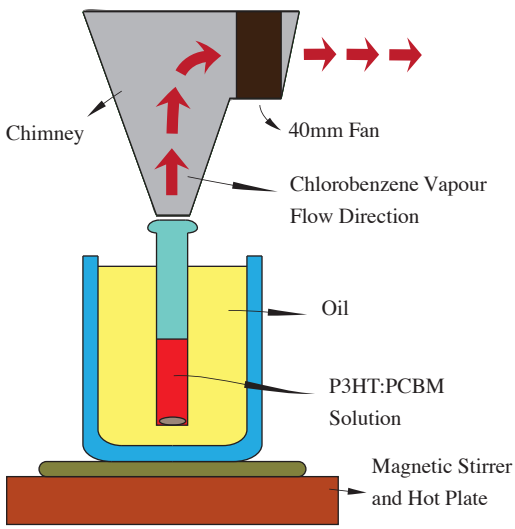

Figure 2. Schematic of the solvent evaporation system.

After evaporation, the printing process of the P3HT:PCBM blend was achieved with a 200-μm mask on the PET/ITO/ZnO/PEDOT:PSS substrate. Figure 1 reveals the schematic representation of the device's architecture. After the printing process, the device was annealed at 110 °C for 30 min.

Results and Discussion

Effects of 2 printing parameters, viscosity of solution and screen resolution on power conversion efficiency of devices, were investigated to obtain optimum conditions for highly efficient inorganic-organic hybrid solar cell production by the screen printing method.

The ZnO coating increases the roughness of the surface, as shown in Figure 3a. However, the PEDOT:PSS coating on the ZnO layer reduces that roughness (Garganourakis et al., 2009). Optimum evaporation time for printing proper film with the designed evaporation system (Figure 2) was obtained as 100 min from repeated experiments. For each mesh type, smooth surface morphology could not be obtained, so, like evaporation time, the mesh type was optimized as 200 μm, as shown by the SEM image of the device in Figure 3b.

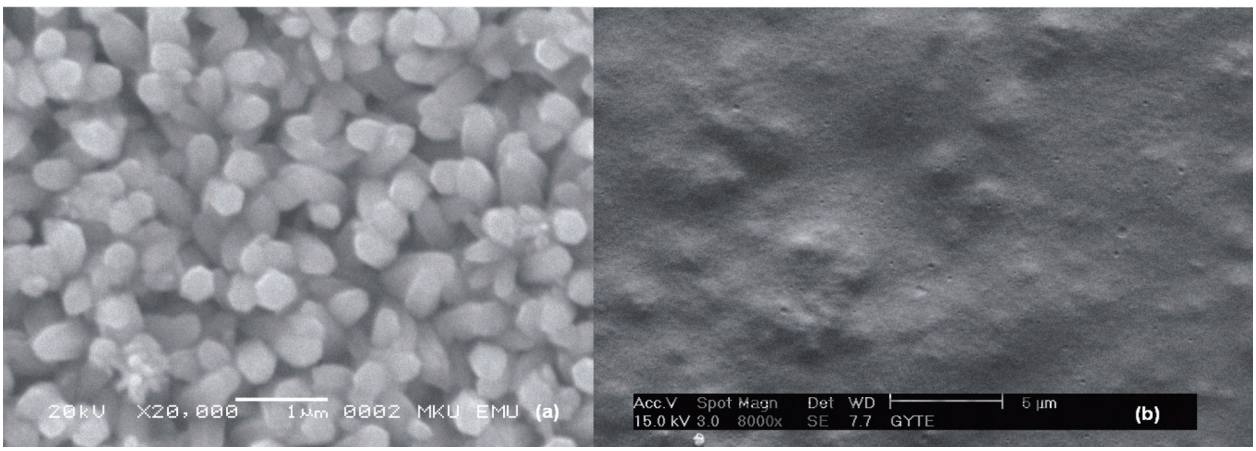

Figure 3. (a) SEM image of ZnO film, (b) SEM image of PET/ITO/ZnO/PEDOT:PSS/P3HT:PCBM device.

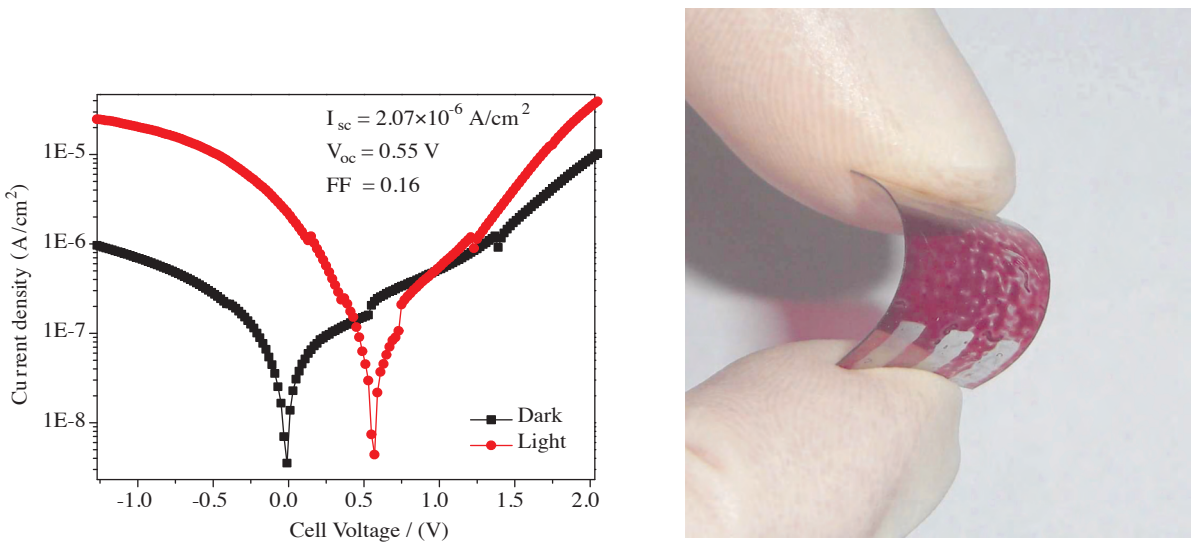

Figure 4. I-V characteristic of manufactured flexible solar cell by screen printing method.

Conclusions

In conclusion, the hybrid PET/ITO/ZnO/PEDOT:PSS/P3HT:$PC_{61}BM$/Al device was manufactured and tested under simulated solar illumination (AM1.5G, 100 mW/cm^2). The I-V curve illustrates that the produced device exhibits solar cell characteristics (Figure 4).

Acknowledgements

This study has been supported by the Scientific and Technological Research Council of Turkey (TÜBİTAK - Project Number 107M270).

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