

INFLUENCE OF GALLIUM DOPING CONTENT ON ZINC OXIDE FILM MORPHOLOGY AND DEVICE PERFORMANCE OF MEH-PPV/ZNO HYBRID SOLAR CELLS

Kasin Kasemsuwan¹, Varong Pavarajarn² and Chanchana Thanachayanont¹

¹National Metal and Materials Technology Center, 114 Thailand Science Park, Paholyothin Rd., Klong 1, Klong Luang, Pathumthani 12120, Thailand

²Department of Chemical Engineering, Faculty of Engineering, Chulalongkorn University, Bangkok 10330, Thailand

Introduction

Hybrid solar cells assembled from blending n-type inorganic nanoparticles with p-type conjugated polymers have a potential of bridging the efficiency gap that exists between organic and inorganic photovoltaic material [1]. Polymer solar cells that consist of conducting polymer alone have low minority carrier mobility. For example, MEH-PPV has a high hole mobility but low electron mobility [2]. The intrinsic carrier mobility imbalance in the poly(2-methoxy,5-(2'-ethylhexyloxy)-p-phenylene vinylene (MEH-PPV) severely limits the performance of pure polymer based solar cells. To overcome this imbalance, a second material is often incorporated to act as an electron acceptor and pathway for electron transport. For polymer-nanoparticle bulk hetero junction solar cells, a power conversion efficiency of 5% under AM 1.5 has been reported [3]. Zinc oxide is a semiconductor material which has several merits, ZnO is a cheap and environmentally friendly material, good optical, electrical and piezoelectrical properties. Zinc oxide can be used in various fields and also has good potential for high temperature electronic applications. Moreover, nanostructured ZnO is expected to have properties suitable for applications in light-emitting diode (LED), photodetector and solar cells. Gallium doping resulted in increasing of bandgap. In this study, gallium doped Zinc oxide nanoparticles 0.5% (ZnO(Ga0.5%)) have been used as an electron-accepting material, in combination with hole-transport MEH-PPV.

Experimental

Materials

In this experiment, ZnO (Ga0.5%) nanoparticles were prepared using zinc acetate and gallium acetyl acetonate as precursor for the solvothermal preparation in 1,4-butanediol at 220 °C. The ZnO nanoparticles were blended with MEH-PPV having molecular weight in a range of 150,000-250,000. The MEH-PPV was purchased from Sigma-Aldrich. The front transparent conducting oxide (TCO) electrode used was a commercial glass substrate coated with an indium-tin-oxide (ITO) thin film. For contact improvement and enhanced hole transportation, the TCO electrodes were coated with a ~35 nm-thick layer

of poly(3,4-ethylenedioxythi-ophene)/ (poly (styrene sulfonate)) (PEDOT:PSS). Blends of ZnO(Ga0.5%) content of 0%, 10%, 30% by weight and MEH-PPV in 1,2-dichlorobenzene were prepared and fabricated as active layers of the solar cells. An active layer thickness of ~100 nm was obtained. The PEDOT:PSS and the active layers were spin coated onto the ITO-coated glass substrate.

Apparatus and Procedure

Spin coating (Laurell Technologies Corporation, WS-400B-6NPP/LITE) was performed at room temperature. Spin speeds of 1,500 and 3,000 rpm with ramp 0.15 were used for MEH-PPV and PEDOT:PSS respectively.

Results and Discussion

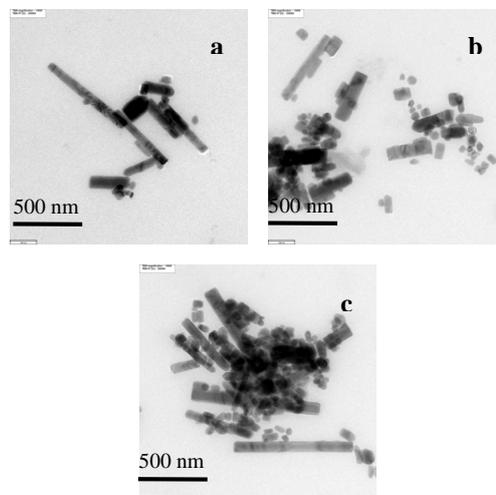


Fig. 1: TEM images of blends of MEH-PPV with ZnO (Ga0.5%) particles at content (a) 10%, (b) 20% and (c) 30% by weight.

Fig. 1 shows TEM images of blends of MEH-PPV and ZnO(Ga0.5%) particles. The TEM results revealed that ZnO(Ga0.5%) nanoparticles consist of a mixture of sphere and rod-shaped nanoparticles, which have sizes ranging from 30-120 nm and 30-189 nm, respectively. The inconsistency in size and shape of the particles is resulted from continuous nucleation and crystal growth of ZnO(Ga0.5%) during the solvothermal synthesis. It should be noted that the synthesized particles are indeed single crystals. The nanorods observed grow, along the preferential 001 direction, from the small

particles formed in the early stage of the solvothermal process. The nanoparticle network observed in Fig. 1(b) and 1(c) provides such pathway. It can be observed from Fig. 1(a) that with a low solid content of nanoparticles, the sizes of the nanoparticle network are small. Therefore, only electrons generated in the particle network very close to the aluminum electrode will diffuse to the electrode. It was observed that the nanoparticles formed a connected network whose size increased with an increase in ZnO(Ga0.5%) solid content. It should be noted that the actual direction of transport of electrons in the device to the aluminum electrodes is perpendicular to the plane shown in the TEM images.

An increase in short circuit current density with an increase in the ZnO(Ga0.5%) solid content (see table1) suggests that three-dimensional nanoparticle network was formed and allowed more electrons to diffuse to the aluminum electrode with an increase in the ZnO(Ga0.5%) solid content. This confirms that the morphology of the nanoparticles in the active layer affects the transport in the perpendicular direction [4].

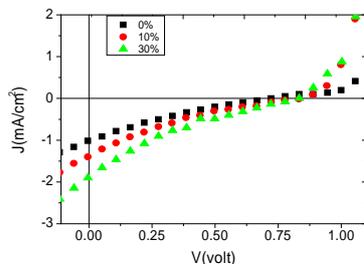


Fig. 2:Current density-voltage curve (J-V) of ITO/MEH-PPV:ZnO(Ga0.5%)/Al hybrid solar cells for different ZnO(Ga0.5%) solid content at 0%, 10% and 30% by weight.

Fig. 2 shows the current-voltage characteristics of the ITO/MEH-PPV:ZnO(Ga0.5%)/Al devices, while their performance is summarized in Table 1 and Table 2.

Table1:Open circuit voltages and short circuit current density of MEH-PPV/ZnO(Ga0.5%) hybrid solar cells.

ZnO(Ga0.5%) solid content (%)	Open circuit voltage ($10^{-1}V$)	Short circuit current density ($\mu A/cm^2$)
0	7.25 ± 0.07	1.00 ± 0.00
10	8.25 ± 0.42	1.21 ± 0.18
30	8.40 ± 0.14	1.75 ± 0.12

Table2:Fill factors and Efficiencies of MEH-PPV/ZnO(Ga0.5%) hybrid solar cells.

ZnO(Ga0.5%) solid content (%)	Fill factor (10^{-1})	Efficiency ($10^{-4}\%$)
0	2.07 ± 0.18	1.51 ± 0.15
10	1.80 ± 0.10	1.79 ± 0.24
30	1.80 ± 0.00	2.65 ± 0.14

Significant increases in short circuit current density and AM 1.5 power conversion efficiency with increasing ZnO (Ga0.5%) nanoparticles solid content was observed. Efficiency for these devices ranges from $(1.51 \pm 0.15) \times 10^{-4}$ to $(2.65 \pm 0.14) \times 10^{-4}\%$, with short circuit current density ranges from 1.00 ± 0.00 to $1.75 \pm 0.12 \mu A/cm^2$. It is expected that the higher ZnO(Ga0.5%) solid content, the greater will be the extent of the nanoparticle network and hence carrier transport will be increased. In this investigation, open circuit voltages and fill factors were found to be independent of increasing nanoparticles solid content. Breeze et al. [5], showed a similar behavior and demonstrated its relation to the film thickness. Since the thickness of active layers for all devices are in the same range which is around 100 nm, so all device were expected to show the similar fill factors and open circuit voltages. Although, thin devices are known to have higher fill factors and lower open circuit voltages than thick devices due to the lower loss due to lower resistivity, a thicker layer is required to accommodate a higher voltage across the device to achieve the same electric field needed to enable exciton dissociation.

Conclusion

We have investigated the performance of MEH-PPV:ZnO(Ga0.5%) hybrid solar cells as a function of ZnO(Ga0.5%) solid content. Increasing the ZnO (Ga0.5%) solid content was found to increase conduction pathways for electrons to travel to the aluminum electrode without recombination with holes that travel to the ITO electrode. TEM observations of film morphology were related to photovoltaic performance in that increasing the solid content of ZnO(Ga0.5%) nanoparticles to provide a network structure significantly improved photovoltaic efficiency.

References

- Huynh, W. U. and Dittmer, J. J. Hybrid nanorod-polymer solar cells. *Science* 295(2002) 2425-2427
- Antoniadus, H. and Abkowitz, M. A. Carrier deep-trapping mobility-lifetime product in poly(p-phenylene vinylene). *Appl. Phys. Lett.* 65(1994) 2030-2032
- Rene', A., and Jansen, J. Polymer-fullerene bulk heterojunction solar cells. *MRS Bulletin* (2005)30-33
- Greenham, N. C., Peng, X. and Alivisatos, A. P. charge separation and transport in conjugated-polymer/semiconductor-nanocrystal composites studied by photoluminescence quenching and photoconductivity. *J. Phys. Rev. B* 54(1996) 17628-17637
- Breeze, A. J., Schlesinger Z. and Carter, S. A. Charge transport in TiO₂/MEH-PPV polymer photovoltaics. *Phys. Rev. B* 64(2001) 125205-125209