Zinc Oxide Nanowires for Organic Bulk Heterojunction Photovoltaic Cells

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Motivation

Organic solar cells have the same theoretical maximum efficiency as *pn*-junction solar cells but their production requires less energy than traditional *pn*-junction cells.(1) Organic photovoltaic devices with tandem structures have achieved efficiencies of at least 5.7%.(2) One way to improve the efficiency of organic solar cells is to improve the charge carrier mobility, or conversely, decrease the distance between charge separation and the charge collector. Another way to improve efficiency is deposit a thicker active layer, allowing for more light to be absorbed.(2) Using nanostructured transparent conducting oxide materials helps achieve both these goals.

(1) S.E. Shaheen, D.S. Ginley, G.E. Jabbour, *MRS Bulletin*, 30 (2005) 10-19
(2) S.R. Forrest, *MRS Bulletin,* 30 (2005) 28-32

Transparent Conducting Oxides

Transparent conducting oxides (TCOs) are wide-bandgap semiconductors that are intrinsically or extrinsically doped. Generally, a material is considered a TCO if it has a conductivity of at least 10^3 S/cm and transmits at least 80% of incident visible light.(3)

(3) K.L. Chopra, S. Major, D.K. Pandya, *Thin Solid Films*, 102 (1983) 1-46

ZnO as a TCO

ZnO is a wide-bandgap semiconductor with a bandgap of 3.3 eV. Its intrinsically *n*-type behavior is attributed to oxygen vacancies. (4) ZnO can be doped with gallium (GZO) and aluminum (AZO) to improve its electrical properties.(4) AZO has TCO properties comparable to ITO, the most common commercially available TCO, but does not contain expensive indium (Table 1). (5)

(4) S.J. Pearton, D.P. Norton, K. Ip, Y.W. Heo, T. Steiner. *J. Vac. Sci. Technol. B* 22(3) (2004) 932-948
(5)Tadatsugu Minami, *Semicond. Sci. Technol.* 20 (2005) S35–S44

Table 1:Electrical properties of ITO and AZO.

	ITO	AZO
Resistivity (Ω cm)	7.2E-5	8.5E-5
Carrier concentration (cm^{-3})	2.5E21	1.5E21
Hall mobility (cm^2 / (V s))	33.2	47.6
Deposition Method	PLD	PLD

Source: Tadatsugu Minami, *Semicond. Sci. Technol*. 20 (2005) S35–S44

Growing the AZO TCO Film

AZO films are grown in an atomic layer deposition system with diethylzinc, trimethylaluminum, and water as the zinc, aluminum, and oxygen sources respectively. In atomic layer deposition, film growth can occur at temperatures near or below the glass transition temperatures of many polymers, allowing for growth on flexible plastic substrates.

ZnO Nanorods

Solution growth methods for growing nanorods have the advantage of being low energy, inexpensive processes compared to other nanorod growth methods.(6)

Seed films of ZnO improve the density and alignment of ZnO nanorods.(7) AZO seed films, however, do not cause the same good alignment as ZnO films. Because alignment is better on ZnO, a 20-40nm layer of ZnO is deposited atop AZO before nanorod growth (Figure 2).

(6) S. Yamabi, H. Imai. *J. Mater. Chem.*, 12 (2002) 3773–3778
(7) Q. Li, V. Kumar, Y. Li, H. Zhang, T.J. Marks, R.P.H. Chang. *Chem. Mater.* 17 (2005) 1001-1006

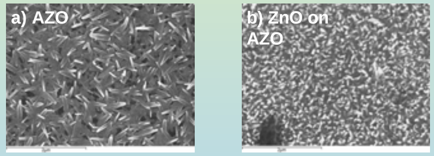

Figure 1. Effect of buffer ZnO NR grown on a) 450nm AZO and b) 450nm AZO with 40nm ZnO

TCO Properties of the Nanostructured Films

The AZO films on glass have a bulk resistivity of 1.6x10-3 Ω·cm. Films on PET have a bulk resistivity of 3.8x10x-3 Ω·cm. UV-Vis transmission measurements from the films on glass and PET are shown in Figure 2 a) and 2 b) respectively.

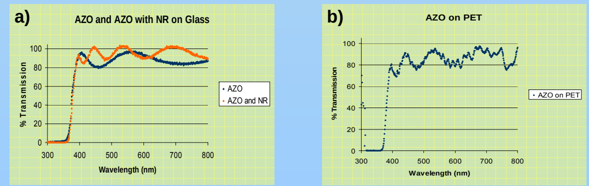

Figure 2. Transmission of a) AZO and AZO with nanorods on glass and b) AZO on PET

Photovoltaic Cell

The charge carrier mobility in the MDMO-PPV:PCBM active layer is small compared to the 200nm thickness needed to absorb visible light.(8) A nanostructured TCO means a shorter path length in the active layer, which allows for a thicker active layer to be deposited and a higher percent of the incident light to be absorbed. Increased light absorption should lead to a higher short-circuit current density.

(8) H. Hoppe, N.S. Sariciftci. J. Mater. Res., 19, 7 (2004) 1924-1945

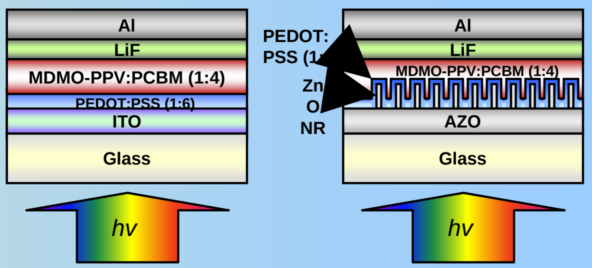

Figure 3: Cell architecture of organic bulk heterojunction photovoltaic cell with a) ITO as the TCO and b) with ZnO NR as the TCO. MDMO-PPV is 2-methoxy-5-(30,70-dimethyloctyloxy)-1-4-phenylene vinylene, PCBM is 1-(3-methoxycarbonyl)propyl-1-phenyl[6,6]methanofullerene, PEDOT is poly(3,4-ethylenedioxythiophene), PSS is polystyrene sulfonate, ITO is indium tin oxide, AZO is aluminum zinc oxide.

Cells with the device structure shown in Figure 3 a) and Figure 3 b) have been assembled. However, the cell with the nanostructured TCO layer had a short. Further tests will be done to isolate the cause of the short and improve device construction.

Future Work

The PEDOT:PSS (1:6) layer thickness may need to be optimized for the nanostructured TCO anode. ZnO nanorod length, alignment, and density will be varied.

Doping the nanorods with Al, Ga, or In in a solution process to improve their transport properties may lower cell's series resistance.

Cells can be constructed on PET substrates, so flexible solar cells can be realized.

This work was funded by NREL.