ZnO NANOWIRES FOR NANOCOMPOSITE ORGANIC THIN FILM TRANSISTORS

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Large area and flexible electronics is a rapidly expanding research area, where much attention has been focused on the use of organic semiconductors. These have attracted much interest by virtue of their solution processability. However, the performance of the field effect mobility and conductivity of organic thin film transistors (TFTs) limits their application. While organic TFTs often exhibit reasonably high ON/OFF current ratios, attempts to improve their mobilities (typically < 0.1 cm^2/Vs) and stability, remain a subject of ongoing research [1-2]. The limitations of organic materials have thus prompted the pursuit of alternative material systems/options for use in large area and flexible electronics.

One-dimensional nanostructures, such as carbon nanotubes (CNTs) and nanowires, present feasible alternatives; these nanostructures can be used as the sole material in a device structure, or can be implemented as a complement to organic semiconducting material to form nanocomposite-based devices [3,4]. Several groups have recently considered CNTs for fabrication of solution-processed p-type composite TFTs; they were incorporated into poly(3-hexyl-thiophene) (P3HT) and poly[5,5'-bis(3-dodecyl-2-thienyl)-2,2'-bithiophene] (PQT-12) which are organic semiconducting polymers [5,6]. However, there are few reports concerning solution-processed n-type organic TFTs with high field effect electron mobility [7-9]. Here we report a means of enhancing n-type organic TFT devices by introducing random arrays of stamped semiconducting zinc oxide (ZnO) nanowires (Figure 1). An n-type solution-processed organic semiconductor, [6,6]-phenyl C_{61}-butyric acid methyl ester is utilized as the organic host matrix in this study, where PCBM exhibits typical field effect electron mobility of 10^{-3}-10^{-2} cm^2/Vs [8,9]. The performance of these composite ZnO-PCBM TFTs is presented alongside that of the pristine organic PCBM TFTs.

Our preliminary results reveal that the effective field effect mobilities of ZnO nanowire-PCBM composite TFT devices are increased by 20-40 times compared to pristine PCBM organic TFT, while the ON/OFF current ratio is maintained in the range of 10^5. Figure 2 shows the transfer characteristics of pristine PCBM TFT and ZnO-PCBM TFT. In the saturation regime (V_{DS} = 40V), the saturation field effect mobility of the ZnO-PCBM TFT is increased to 0.561 cm^2/Vs, representing an improvement of > 17 times over pristine PCBM TFT (0.034 cm^2/Vs). The ON/OFF current ratio remains in the same order for both composite and pristine TFTs. When the measured transfer characteristics are close to the linear regime (V_{DS} = 10V), the field effect mobility is improved markedly by 40 times, by incorporating ZnO nanowires into the organic matrix (Table 1). We suggest that the increase in the field effect mobility is due to the superior semiconducting properties of the ZnO. The nanowires can be viewed as conducting bridges which serve to enhance electron transport between crystals in the PCBM film. There may also be an increased number of charge carriers in the transport channel. For a better understanding of the role of each material, further experiments will examine the effect of different network densities of ZnO nanowires on the field effect characteristics.

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Figures:

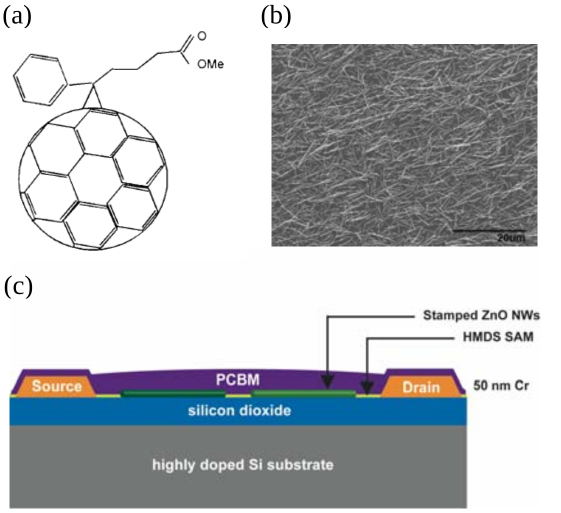

Figure 1. (a) Chemical structure of [6,6]-phenyl C_{61}-butyric acid methyl ester (PCBM). (b) Network of stamped ZnO nanowires (c) Schematic cross-section of the composite ZnO-PCBM TFT structure employed in this study.

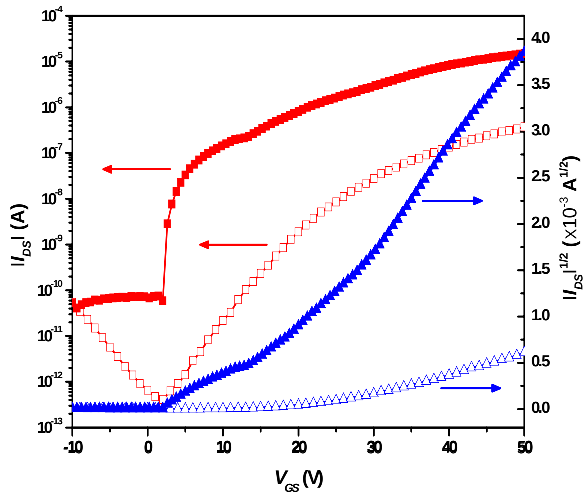

Figure 2. Transfer characteristics I_{DS}-V_{GS} and $I_{DS}^{1/2}$-V_{GS} of pristine PCBM and ZnO-PCBM TFT devices in the saturation regime at V_{DS} = 40 V.

Table 1. Field effect mobility (μ_{FE}), ON/OFF current ratio, OFF current (I_{OFF}), threshold voltage (V_T) and subthreshold swing (V/dec) of pristine PCBM and ZnO-PCBM TFT devices at V_{DS} = 40V and at V_{DS} = 10V, respectively.

Bias Regime	TFT	μ_{FE} (cm^2/Vs)	*ON/OFF Current Ratio*	I_{OFF} (A)	V_T (V)	*S* (V/dec)
V_{DS} = 40V (saturation)	Pristine PCBM	0.0334	9×10^5	4×10^{-13}	~ 12	4.606
	ZnO-PCBM	0.561	4×10^5	5×10^{-11}	~ 4	0.356
V_{DS} = 10V (linear)	Pristine PCBM	0.0071	9×10^4	1×10^{-13}	~ 15	2.810
	ZnO-PCBM	0.285	1×10^5	6×10^{-11}	~ 5	0.898