Nanocomposite Field Effect Transistors based on Zinc oxide/polymer blends

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Abstract

Significant progress is being made in the realization of thin-film transistors (TFTs) for application in various electronic devices and circuits [1-5]. Currently, one of the important challenges in this area is to design low-cost and stable organic semiconductors that possess high field-effect mobilities for constructing low-power high-speed transistor devices. However, there are only limited stable and cheap organic semiconductors that are applicable for OTFT applications. Here, we report the work in our laboratory that focus on stable, inexpensive and high field-effect mobility nano-composite materials for the potential application in OTFT technologies. Solution processed polymer based nano-composite field effect transistors with wide band gap semi-conducting ZnO nano-tetrapods and nano-crystals dispersed in the polymer matrix were utilized to study the field effect behaviour. The electrical characteristics of polymer based wide band gap nano-crystal or nano-tetrapod composite devices exhibit an increase in the hole mobility up to two orders of magnitude higher than the pristine polymer.

The fabricated devices that contained a layer of MEH-PPV only exhibited p-channel behaviour with a hole mobility up to 10^{-4} cm^2/Vs, similar to previously reported.[3] Figures 1a and 1b show the TEM (transmission electron microscope) images of ZnO nanocrystals or tetrapods dispersed in MEH-PPV solutions, respectively. The size of the nanocrystals is around 5 nm (Figure 1a) and the legs of the tetrapods are around 100 nm in width (Figure 1b). Figure 2 shows the electrical behaviour of the devices fabricated from MEH-PPV and nanocomposite with ZnO nanocrystals or tetrapods. In Figure 2, the I-V characteristics and the transfer curves of the devices based on MEH-PPV (Figures 2a and 2b), 9 mg of ZnO nanocrystals in 10 mg of MEH-PPV or 47% of ZnO in weight (Figures 2c and 2d) and 9 mg of ZnO tetrapods in 10 mg of MEH-PPV or 47% of ZnO in weight (Figures 2e and 2f) are depicted. A saturation of the hole mobility is observed in the nanocomposite devices when the concentration of ZnO tetrapods or nanocrystal exceeds 40% in weight as shown in Figure 3. From the I-V characteristics, incorporation of ZnO nanocrystals or tetrapods in the polymer enhances the drain current and the mobility. The calculated hole mobility was up to 0.08 cm^2/Vs for the ZnO nanocrystals / MEH-PPV devices and up to 0.15 cm^2/Vs for the ZnO tetrapods / MEH-PPV devices, at the saturation regime. Where as in the linear regime, the hole mobility was up to 0.071 cm^2/Vs for the ZnO nanocrystals / MEH-PPV devices and up to 0.096 cm^2/Vs for the ZnO tetrapods / MEH-PPV devices. A decrease in the threshold voltage up to -15 V was found for both nanocomposite devices (ZnO nanocrystals or ZnO tetrapods / MEH-PPV). The sub-threshold swing was found to be 2 V per decade for the ZnO / MEH-PPV nanocomposite devices and up to 10 V per decade for the MEH-PPV devices. The on/off ratio was calculated as 10^5 for the nanocomposite devices where it was only 10^3 for MEH-PPV devices. Furthermore, a reduction in density of traps, given by $N_T = V_T C_{ox}/q$, has been observed, as shown in the inset of Figure 3, while the weight percentage of ZnO increases in the polymer. However, the trap density seems to saturate when the concentration of ZnO tetrapods or nanocrystal in the polymer exceeds 40% in weight. Incorporation of ZnO nanomaterials (nanocrystals or tetrapods) into the MEH-PPV polymer - a p-type semiconductor - did not change the nature of charge transport, as the nanocomposite devices were found to behave as p-channel transistors. However the hole mobility was enhanced in the nanocomposite devices. In addition, the band diagram of MEH-PPV and ZnO are well known. The highest occupied molecular orbital (HOMO, 5.3 eV) and lowest unoccupied molecular orbital (LUMO, 3.0 eV) levels of MEH-PPV and the valence (7.6 eV) and conduction (4.4 eV) bands of ZnO shows clearly that a huge energy barrier exists for holes to be transferred from ZnO to MEH-PPV for transport. Consequently, holes are confined in MEH-PPV and we suggest that the effect of ZnO is to reduce the density of traps in the polymer which probably is a reason for the enhanced mobility and the reduced threshold voltage.