The Enhanced Electronic Properties of $P3HT-WO_3$ Hybrid Thin Film Transistors

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INTRODUCTION

Conjugated polymers have drawn great attention for several applications such as thin film transistors, light emitting diodes or solar cells. Organic electronics can be coated with vacuum-free, solution-based methods at low temperatures which make production cheaper and application areas wider. However, most organic semiconductors exhibit lower device performance than inorganic semiconductors due to their low mobility. For example, while the charge carrier mobility of silicon is > 1 $cm^2.V^{-1}.s^{-1}$, the mobility of 3-polyhexylthiophene (P3HT), the most commonly used conjugated polymer, is in the range of 10^{-1}-10^{-3} $cm^2.V^{-1}.s^{-1}$ [1]. To overcome this disadvantage, inorganic dopant molecules such as ZnO and TiO_2 can be added into the organic polymer structure[2–6]. Hence, it is possible to improve important transistor parameters including threshold voltage (V_{th}), current on-off ratio (I_{on}/I_{off}) and field-effect mobility (μ_{FET}).

Among the inorganic dopant molecules, tungsten oxide (WO_3) has aroused a research interest in the field of electronic devices due to its wide band gap and high work function. In this study, this is the first time we dispersed WO_3 nanoparticles into the P3HT polymer matrix. Since there is no study in the literature about the effect of WO_3 on electronic properties of organic polymer based transistor, this this will be a great interest for both basic research and application.

EXPERIMENTAL/THEORETICAL STUDY

In this work, pre-fabricated OFET test chips containing p-doped silicon/silicon dioxide substrates were used (purchased from Ossila Ltd.). Pristine P3HT and varying amounts (20 wt. %, 30 wt. % and 50 wt. %) of WO_3 containing P3HT were dissolved in 1,2-dichlorobenzene. The surface of the chips was treated with self-assembled monolayers to increase the surface wettability. Both pristine and hybrid solutions were spin coated on the pre-treated test chips to fill the transistor channel and annealed in glovebox ambient. The current-voltage characteristics of all devices were measured by Agilent B1500A semiconductor device analyzer. Homogeneous distribution of WO_3 nanoparticles in the channel was confirmed by Atomic Force Microscopy (AFM). The effect of WO_3 incorporation on the charge carrier concentration and conductivity was investigated by Hall Effect measurement.

RESULTS AND DISCUSSION

Considering the current-voltage characteristics, it was observed that increasing amount of WO_3 nanoparticles in the P3HT polymer increased the drain current and conductivity up to four times. The best transistor performance was obtained in 30 wt. % WO_3 containing device due to the well distribution of nanoparticles into the polymer matrix. The field-effect mobility of pristine P3HT based transistors improved from 10^{-4} to $3x10^{-2}$ $cm^2.V^{-1}.s^{-1}$ for 30 wt. % of WO_3. The threshold voltage of pristine P3HT improved from 40V up to around 20V for all concentrations and it was seen to be independent of the WO_3 amount in P3HT polymer. The on/off current ratio of P3HT based device increased from 10^2-10^3 to $4x10^4$ at 30 wt. % WO_3 concentration. However, we observed that I_{on}/I_{off} ratio decreased since 50 wt. % WO_3 concentration also increases the off currents.

CONCLUSION

In this work, first time we doped WO_3 into the P3HT to improve transistor performance. A comparative study was performed to investigate the effect of WO_3 amount as a dopant molecule. It was obtained a remarkable increase of transistor performance at P3HT containing 30 wt. % WO_3 compared to pristine P3HT. Also, it is worth to say that both P3HT and WO_3 show electrochromic properties. Hence, results presented here may be a good candidate for brand new electrochromic transistor applications building a suitable device architecture.

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