KPAN003: Application - OFET (Organic Field Effect Transistor) Research

“Poly (3,3‴-didodecylquarterthiophene) field effect transistors with single-walled carbon nanotube based source and drain electrodes” -

Yuan Yuan Zhang, Yumeng Shi, Fuming Chen, S. G. Mhaisalkar, Lain-Jong Li, Beng S. Ong and Yiliang Wu
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Keywords

Organic Field Effect Transistors, OFET, Work Function, WF, Kelvin Probe, KP020

Abstract

A solution processable method for employing single-walled carbon nanotubes (SWCNTs) as bottom contact source/drain electrodes for a significant reduction of contact resistance in poly (3,3‴-didodecylquarterthiophene) based organic field effect transistors (OFETs) is proposed. A two order of magnitude reduction in contact resistance and up to a threefold improvement in field effect mobilities were observed in SWCNT contacted OFETs as opposed to similar devices with gold source/drain electrodes. Based on Kelvin probe measurements, this improvement was attributed to a reduction in the Schottky barrier for hole injection into organic semiconductor.

Research Area

Organic field effect transistors (OFETs) that are solution processable and comprise excellent device properties are key requirements in their successful realisation into large area electronics such as active matrix displays as well as into low-cost electronic devices such as radio frequency electronic tags. Regioregular poly (3,3‴-didodecylquarterthiophene)s (PQTs) and thieno[3,2-*b*] thiophene polymers with high mobilities (~0.1–0.6 cm2 /V s) represent the most promising polymers for solution processable OFETs. Bottom contact (BC) structure and top contact (TC) structures are widely employed in OFETs, with the former preferred for its potential for lithography assisted miniaturisation. However, the mobility of BC OFETs is often lower compared with that of TC OFETs due to higher contact resistance and injection barrier between the source/drain (*S*/*D*) electrodes and the organic active layers.

Figure 1. KP Technology KP020 System.

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Use of Kelvin Probe

To investigate the contribution of the work function of the SWCNT, Kelvin probe force microscopy measurements were carried out on both SWCNT as well as Au contacts. By setting the Au electrode reference work function at 5.1 eV, the measured contact potential difference between SWCNT and Au of 0.67 eV yields SWCNT and Au electrodes work functions of 5.43±0.03 and 5.10±0.01 eV, respectively.

The ideal energy level alignment between electrode and PQT based on the measured work function data is illustrated in Figs. 2(a) and 2(b). It has, however, been noted that exposure to the ambient invariably reduces Au work function to values as low as 4.5 eV due to hydrocarbon adsorption. Therefore, the Fermi energies of Au and perhaps SWCNT electrodes are likely to be upshifted by up to ~0.5 eV. Nevertheless, the CNT-PQT hole injection barrier is expected to be smaller than that in the Au-PQT devices.

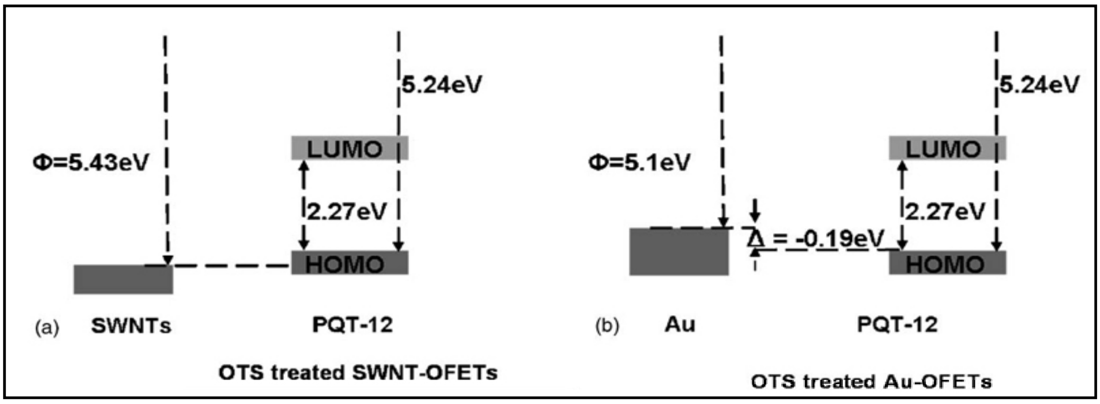

Figure 2. Schematic energy level diagram of (a) SWCNT/PQT (b) Au/ PQT interface after OTS treatment.

For the SWCNT OFETs, the field effect mobilities show maximum conductance at $VDS \rightarrow 0$ V and near constant mobility (μ~1.2 cm2 /V s) over the range of *L* from 75 to 150 μm [Fig. 3(c)]. These observations support the view that there is an absence of a significant Schottky barrier at the contact. The small decrease in mobility for *L* =50 μm may indicate that the contact resistance $R_C W$ (1.69x10^8 Ω μm at VGS=−40 V) is comparable to the $R_{CH} W$ (3.34x10^8 Ωμm at V_{GS}=−40 V for *L*=50 μm) for *L*<50 μm. Other device parameters for SWCNT OFETs (V_T=−10±0.62 V, *S*=0.65 V/decades and I_{on} / I_{off}>10^6) did not change with channel lengths. On the other hand, the Au OFETs display a large difference in the linear and saturation region field effect mobilities and an especially strong dependence on *L* is observed in the saturation regime [Fig. 3(d)]. These results support the view that the resistance of Au OFETs is dominated by large contact resistances.

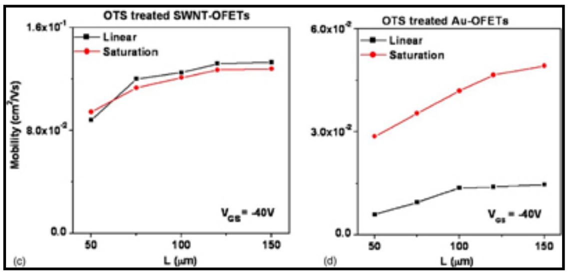

Figure 3. Extrinsic saturation (red) and linear (black) regime field effect mobility vs. channel length (*L*) for OTS treated (c) SWCNT OFETs; (d) Au OFETs.

KPAN003: Application - OFET (Organic Field Effect Transistor) Research

Conclusion

In summary, SWCNTs based bottom contact electrodes were observed to significantly improve device performance of PQT field effect transistors. Contact resistance and mobility of the SWCNT FETs were determined to be 1.69 x108 Ω μm and 0.14 cm^2 /V s, respectively, and represent a two orders of magnitude reduction in R_C and a threefold increase in mobility compared with control Au OFETs. Kelvin probe measurements suggested that this striking improvement in device performance is attributable to an absence of a Schottky barrier in the SWCNT OFETs.

Reference

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2. Correspondent Author: S. G. Mhaisalkar, School of Materials Science and Engineering, Nanyang Technological University, 50 Nanyang Ave., Singapore 639798, Singapore,
   E-mail Address– subodh@ntu.edu.sg.

Testimonial

"Workfunction engineering has clearly emerged as a critical strategic approach in improving or optimising the performance of OFETs, OLEDs, and also OPVs. The KP tool and methodologies available are a facile method of estimating the workfunctions and the Schottky barriers at multiple interfaces and greatly enhances our understanding of the performance of these printed electronics devices."

- **Professor Subodh Mhaisalkar**
School of Materials Science and Engineering, Nanyang Technological University, Singapore