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Organic Thin Film Transistor with Carbon Nanotube Electrodes

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Abstract

The contact resistance between organic semiconductors and metallic electrodesaffectsthe performance of the organic thin film transistor (OTFT) negatively so that it may make thefield effect mobility of charge carrier seem small. In order to reduce the contact resistance weused conducting Carbon Nanotube (CNT) films, which consist of the same element as the basicmaterial of the organic semiconductors, as source or drain electrodes. The measurements oftransistor properties based on pentacene single crystals have been carried out by using both CNTfilm electrodes and metal electrodes.

Keywords*: Organic transistor, carbon nanotube, electrical characteristic*

1. Introduction

Finding good semiconducting organic materials is the first step for the high performance Organic Thin Film Transistor (OTFT), and some organic materials, like pentacene or rubrene, have already been found to be good candidates which could substitute the inorganic semiconductor [1, 2]. However, there are still difficulties to make application to the electronic device due to several factors, the incomplete understanding of the charge transport mechanism, the contact effects between the metallic electrodes and the organic active materials, the imperfection of the organic active layer- the insulating layer interface etc [3-5]. The contact barrier sometimes limits the charge carrier transport of the OTFT or gating effect, which results in Non-linear IV characteristics or the degradation of charge carrier's field effect mobility [4, 6]. Furthermore, it is unclear to distinguish between the intrinsic material property and the extrinsic deterioration caused by the contact regime. So, the technique to reduce the contact resistance is also an important part of the OTFT experiment in order to understand the essential nature of carriers in organic semiconductors, and to make applications of electronic devices [7-12].

We have recently fabricated TFT structure using anthracene single crystals in orderto study the grain boundary-free properties of the charge carrier transport [5]. In that TFTstructure the plate-shaped anthracene single crystal was put on the pre-patterned metalelectrodes of the SiO2/Si substrate, and then it was pressed down. The results showedthat the high contact resistance could be reduced by chemical treatment for the metalelectrodes. This means that charge injection was enhanced by the chemical reatment, i.e. modifying the electrode-surface-materials. Graciela B. Blanchet et.al. also showedthat non-metallic electrodes, namely printed organic conducting electrodes, couldreduce the contact resistance [4]. In this paper we will present the properties of pentacene single crystal Thin Film Transistor with the conducting CNT film electrodes and compare with the result of metal electrode TFT.

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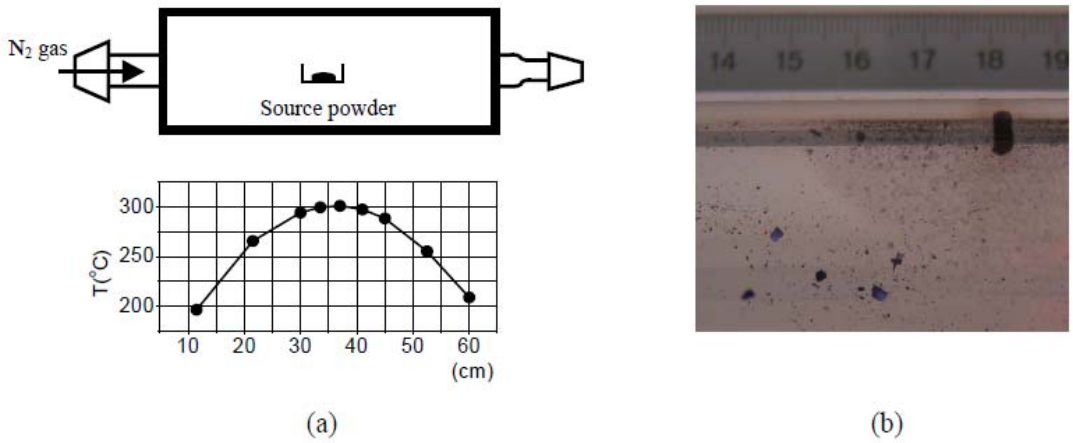

Figure 1. Schematic of crystal growth apparatus: (a) temperature profiles of quartz tube furnace and (b) Pentacene single crystal grown by physical vapor deposition method [8].

Figure 1. Schematic diagram of electrodes fabrication with different SWCNT densities. (i) Assembly of the aligned array SWCNTs by dielectrophoresis (DEP) between the Pd electrodes. (ii) SWNCT assembly with different densities, which were controlled by tuning the SWCNT solution concentration (iii) Opened a window on the SWCNTs array via electron beam lithography and (iv) Etch the SWCNTs by oxygen plasma.

2. Experimental Details

Commercial pentacene powder purchased from Aldrich was used to grow a single crystal in a quartz tube furnace, 65cm long, which shows temperature gradient of~100°C between the middle and the edge, as shown in Figure 1 (a). The crystals appeared at the 200~220°C temperature region after several hours keeping the temperature of the source zone at 300°C under slow nitrogen gas flow (20ml/min). Figure 1 (b) shows pentacene single crystals which are in the shape of plates with 2~5mm size. These palate-shaped crystals were put on CNT electrodes prepared as in Figure 2 (a).

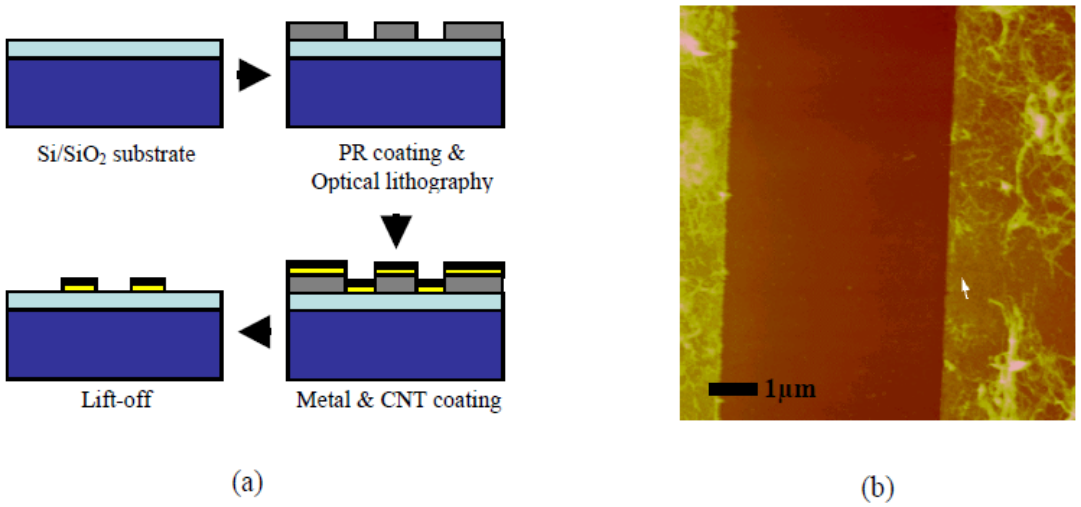

Figure 2. Procedure of the CNT electrodes fabrication on the Si/SiO2 substrates (a), AFM image of the metal based CNT electrodes (b).

The heavily doped Si substrate with SiO2 layer 200nm thick was prepared to beused as gate electrode and gate insulating layer. Optical lithography allows to makephoto resist masks of 5, 30, 50 μm channel length, shadowing metal evaporation andCNT film coating. After the evaporations of Cr 3nm thick and AuPd 17nm thick, CNTfilm was deposited by air-brushing CNT suspensions in chloroform, DMF and SDS solutions respectively, in which the chloroform suspension gave the best results. Whena dense CNT layer was deposited, it was difficult to get a clear electrode edge because the randomly entangled CNT have a tendency to prevent photo resist lift-off. Figure 2(b) shows the AFM image of CNT electrodes based on metal of 5 μm channel length. As shown in Figure 2 (b) CNT passed cross the electrode edge, but it is small enoughto be neglected compared with the whole channel length, 5 μm. TFT structures were fabricated by combining pentacen single crystals and the CNTelectrodes. Pressure was applied to enhance the contact between pentacene and CNT like in our previous works5. We measured field effect characteristics of 5, 30, 50 μm channel lengths CNT electrodes and metal electrodes, respectively, at room temperature after checking negligible the gate leakage current less than 10-11.

3. Results and Discussions

For the most devices I-V curves show a linear region and a saturation region asshown in Figure 3 (a), but for 5 μm channel length devices the short channel effect [7] was also observed. The field effect parameters such as the field effect mobility (μlinear, μsat), the subthreshold slop (S), the threshold voltage (Vth), and the on-off ratio (Ion/Ioff), were calculated from the data of gate sweep graphs following the equations inreference [3]. All parameters are summarized in the Table 1. The field effect mobilityof the best device amounts to 0.94 cm2/Vs for linear region and 0.68 cm2/Vs for saturation region, respectively and other parameters show mostly good numerical values. It is also interesting that the smaller ratio of channel width to channel length gives the better results. Comparing parameters of CNT electrodes to those of metallic electrodes, it is difficult to assert that CNT electrodes made the performance of TFTenhance because some parameters (S, Ion/Ioff) become better but others (μlinear, μsat) not. However, it is worth to notice that CNT electrodes made definitely improved some of the TFT performances in spite of the fact that the surface of the electrodes had become quite rough, as shown in Figure 2 (b). It is expected that if we can make the surface of CNT film electrodes flat, the performance of TFT will improve much more. There is another problem to solve. Because pentacene single crystal might have an isotropic properties, simple comparison is meaningless. First of all we should find the direction which shows the best results for both CNT and metallic electrodes, and then the comparison will become meaningful. In our future work, we will concentrate on uniform surfaces of CNT layers and on the anisotropy of organic single crystals.

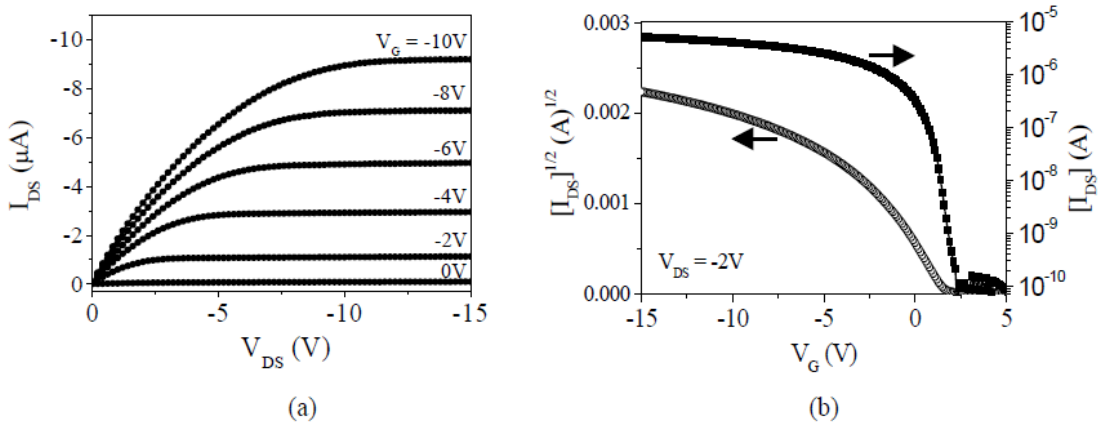

Figure 3. I-V characteristics at VG = 0, -2, -4, -6, -8 and -10V (a) gate voltage dependence of |IDS1/2|and log|IDS| (b) for CNT electrode TFT with 30 μm channel length.

Table 1. Feld effect parameters where W/L is the ratio of channel width to channel length

Electrode type	W/L	μ_{linear} (cm^2/Vs)	μ_{sat} (cm^2/Vs)	S (V/decade)	V_{th} (V)	I_{on}/I_{off}
AuPd 5μm	200	0.77	·	0.9	1.0	3.4×10^2
AuPd 30μm	30	0.65	0.43	1.0	1.2	4.1×10^2
AuPd 50μm	20	0.94	0.68	0.6	1.5	7.3×10^2
CNT 5μm	200	0.65	·	0.3	1.6	3.4×10^3
CNT 30μm	15	0.86	0.54	0.4	1.5	1.7×10^4
CNT 50μm	20	0.52	0.34	0.7	2.3	2.2×10^2

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