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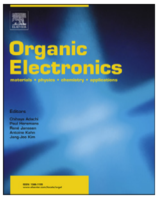

Current saturation effect for pentacene-based static induction transistor under negative drain-source and gate voltages

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ABSTRACT

Usually, the drain-source current (I_{DS}) increases with positive drain-source voltage (V_{DS}) for pentacene-based organic static induction transistor (OSIT) ITO(Source)/Pentacene/Al(Gate)/Pentacene/Au(Drain) and it shows an inherent rectifying property under negative gate voltages (V_G), i.e. the slope of I_{DS} vs. V_{DS} curve increases with V_{DS} but without any current saturation effect. In this paper, we investigated the electrical characteristics of pentacene-based OSIT ITO/Pentacene(80 nm)/Al(15 nm)/Pentacene(80 nm)/Au under negative V_{DS} and V_G, and found that I_{DS} changed from rectifying property to saturation effect when the magnitude of negative V_{DS} was increased from 0 V to −6 V under negative V_G, and the turn-on voltage (V_{ON}) moved to larger negative voltages when the magnitude of negative V_G increased and the movement step of V_{ON} gets smaller after keeping the device for a long time, and the possible mechanisms for such a kind of current modulation were discussed.

1. Introduction

Due to the obvious advantages of organic semiconductors (OSCs) such as low cost, light weight, large area, easy processing and flexibility, organic field-effect transistors (OFETs) have been intensively studied as potential alternatives to conventional inorganic FETs for optoelectronics. Many efforts have been devoted to improve the device performance of OFETs [1–5] for its extensive applications in the optoelectronic integrated circuits by varying the device configuration, controlling the molecular orientation, modifying the interfaces at functional layers and electrodes, preparing new organic materials and exploring new preparation technology. Among them, it has become an effective approach to reduce the channel length by changing the device configuration [1,6–9] from common planar-type to vertical-type, and it determines the device performance directly. In the vertical configuration such as the organic static induction transistors (OSITs) [10–15], the channel length of the OSIT is defined by the thickness between the source electrode and the drain electrode, and it reduces down to nanometers, which could cause a high current output at low applied voltages without any high-resolution patterning, enabling high-speed and high-power operation [16,17]. Usually, the p-type OSITs operate as typical SITs without saturation [10] under negative gate voltages (V_G), i.e. the output characteristics of OSITs [9] usually show an inherent rectifying property, in other words, the slope of drain-source current (I_{DS}) vs. drain-source voltage (V_{DS}) increases with increasing positive V_{DS} but without any current saturation effect, and it is different from the common saturation curves for the conventional metal-oxide-semiconductor FETs (MOSFETs) [18].

In this paper, we studied the electrical characteristics of p-type pentacene-based OSIT ITO/Pentacene(80 nm)/Al(15 nm)/Pentacene(80 nm)/Al under negative both V_{DS} and V_G, and found that the I_{DS} changes from rectifying property to saturation effect under negative V_G by increasing the magnitude of V_{DS} from 0 V to −6 V, and the turn-on voltage (V_{ON}) moved to larger negative voltages when the magnitude of negative V_G increased and the movement step of V_G gets smaller after keeping the device for an enough time, and the possible mechanisms for such kind of current modulation were discussed.

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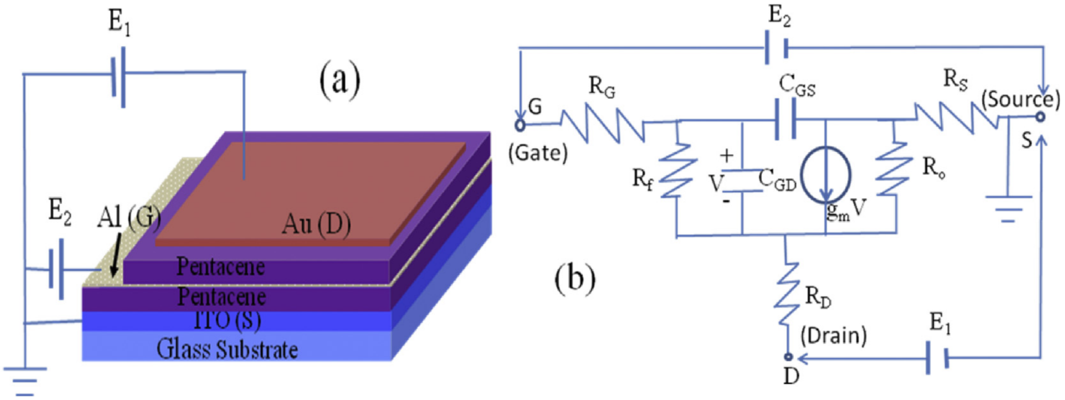

Fig. 1. (a) The configuration of pentacene-based OSIT and the circuits for its characterization. (b) The equivalent circuit of the pentacene-based OSIT.

2. Experiments

The configuration diagram of pentacene-based OSIT ITO/Pentacene/Al/Pentacene/Au is shown in Fig. 1(a), as well as the circuits for its characterization. Firstly, patterned ITO/glass substrates (from ShenZhen Nanbo Group) with the transmissivity of more than 85% in the visible region and the roughness of ~1 nm were cleaned in ultrasonic bath firstly and then by ozone treatment. The first and the second 80 nm pentacene (Sigma–Aldrich, 99% in purity) layers were thermally evaporated in a vacuum of 2×10^{-4} Pa at an evaporating rate of 0.01–0.03 nm/s, and 15 nm (or 50 nm) aluminum layer and 50 nm gold layer were fabricated as gate electrode and drain electrode, respectively. The effective area of the pentacene-based OSIT is about 2×2 mm^2. Both the output characteristics and transfer characteristics of the devices were recorded by a semiconductor characterization system (Keithley 4200-SCS). All the measurements were done in ambient air at room temperature.

3. Results and discussion

Fig. 2 shows the output characteristics and transfer characteristics of the as-prepared pentacene-based OSIT ITO(Source)/Pentacene(80 nm)/Al(15 nm, Gate)/Pentacene(80 nm)/Au(Drain) (Device **A**) under negative V_G. From its output characteristics as shown in Fig. 2(a), one can see that the magnitude of I_{DS} increases with varying V_G from 0 V to −3 V at V_{DS} = 0 V. Under higher magnitudes of negative V_G, the rectifying phenomenon gets more obviously after a turn-on voltage (V_{ON}), meanwhile such a V_{ON} moves to a larger magnitude of negative voltage by increasing the magnitude of the negative V_{DS}, as shown by the inset in Fig. 2(a). From here one can clearly see that the drain current will saturate by further increasing the magnitude of negative V_{DS}, and the increasing trend is very different from that under $V_{DS} > V_{ON}$, meaning that it is only the rectifying characteristics under $V_{DS} > V_{ON}$ but it shows the typical saturation curve under $V_{DS} < V_{ON}$. Fig. 2(b) shows the transfer characteristics of the OSIT at $V_{DS} = -3$ V and it is similar to the transfer characteristics of lateral FET. From here, one could obtain the threshold voltage (V_{th}) of −1.0 V by the intercept of the $|I_{DS}|^{1/2}$-V_G plot and its “on/off” current ratio (I_{on}/I_{off}) is ~10^3.

Actually, similar to vertical organic triodes (VOTs) which were firstly reported by Yang et al. [19] and C_{60}-based VOTs reported by Fischer et al. [20] and permeable metal-base transistor (PMBT) reported by Fujimoto et al. [15], such a kind of so-called OSIT ITO/pentacene/Al/pentacene/Au was ever reported [21] and it was found that the slope of the I_{DS}–V_{DS} curve increases with positive V_{DS} and no current saturation were observed, only showing the typical I–V curves for inorganic SITs [22,23].

In fact, the device operation mechanism is governed by many structural and physical factors and it depends on the processing details of devices. In order to explore the underneath transport mechanism of our pentacene-based OSITs, we measured the surface roughness of the 80 nm pentacene layer evaporated on ITO and the 15 nm Al layer on 80 nm pentacene, and the AFM images are shown in Fig. 3. From here, one can see that the roughness of the

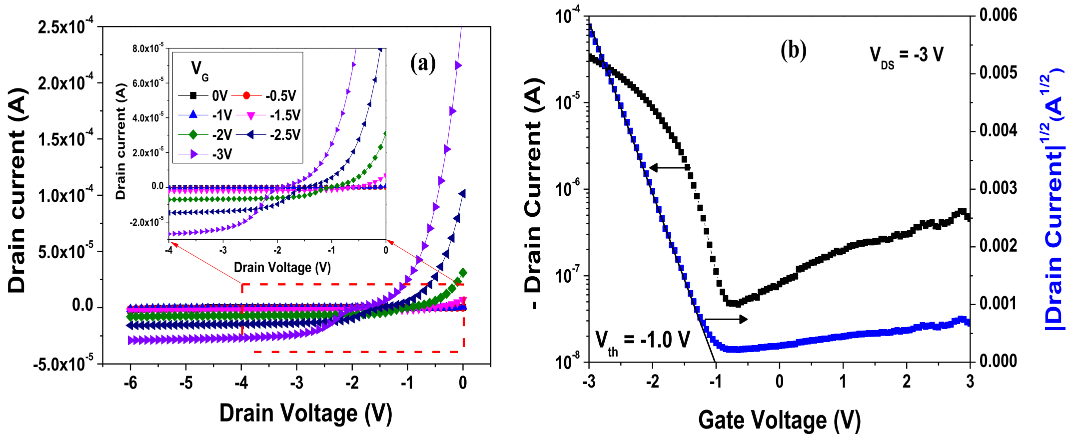

Fig. 2. (**a**) Output characteristics and (**b**) transfer characteristics of the as-prepared pentacene-based OSIT ITO(Source)/Pentacene(80 nm)/Al(Gate, 15 nm)/Pentacene (80 nm)/Au(Drain) at $V_{DS} = -3$ V. The inset in Fig. 2 (**a**) shows the part of I_{DS} for V_{DS} ranging from −4 V to 0 V.