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Displacement Current and Transfer Curve Simultaneous Measurement in Bottom-Contact Organic Thin-film Transistors

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1. Introduction

Organic thin-film transistors (OTFTs) have a great potential for applications requiring large area, structural flexibility, and low-cost fabrication processes.[1] Many trials have been proposed and demonstrated such as flexible displays, electronic paper, and radio frequency identification tags. One of the issues for the practical use of OTFT, it is essential to understand the OTFT device operation mechanisms, including both charge injection properties and carrier transport properties. Displacement current measurement (DCM) is a direct method of determining carrier injection properties in organic materials.[2-5] We have developed a simultaneous measurement method for displacement current and transfer curve in top-contact OTFTs, which enable us to understand carrier injection properties under OTFT operation.[6,7]

In this paper, we demonstrate charge sheet formation dynamics at the channel during the device operation using the simultaneous measurement method for displacement current and transfer curve in bottom-contact OTFTs.

2. Experiments

The basic set-up of the simultaneous measurement method for displacement current and transfer curve in bottom-contact OTFT is simple and is illustrated in Fig. 1. The gate electrode is connected to the wave generator, which applies triangular wave of V_{GS}. A constant source–drain bias voltage (V_{DS}) is applied, while source current (I_S) and drain current (I_D) are measured. When it is assumed that displacement current at the source (I_{disS}) and drain (I_{disD}) electrodes have the same value, then displacement current (I_{dis}) is expressed as

$$I_{dis} = \frac{dQ(t)}{dt} = I_{disS} + I_{disD} = I_S + I_D, \qquad (1)$$

while channel current (I_{DS}) is given by

$$I_{DS} = \frac{-I_S + I_D}{2}. \qquad (2)$$

We use bottom-contact pentacene OTFTs with a dielectric double layer of SiO_2 and polyimide, and gold electrodes in the experiments. [6,7] Polyimide film was formed onto SiO_2/n+Si substrate using spin-coating method. Au source and drain electrodes were thermally evaporated through a shadow mask, followed by a physical vapor deposition of pentacene thin-film with a shadow mask. The channel length and width were 400 and 1000 μm, respectively. The long channel length allows easier observation of changes in displacement current at the channel. Simultaneous measurements for displacement current and transfer curve took place inside a nitrogen atmosphere at 300 K. I_S and I_D were measured using a digitizing storage oscilloscope (Hioki, 8855) while applying a constant drain bias voltage (V_{DS}) and a triangular-wave gate voltage (V_{GS}) in the bottom-contact pentacene OTFTs. Transfer characteristics and output characteristics were measured with semiconductor parameter analyzer (Agilent 4156C) for comparison.

3. Results and Discussions

Figure 2 shows the typical experimental results of (a) square-root of channel current ($I_{DS}^{1/2}$) – V_{GS} and (b) displacement current (I_{dis}) – V_{GS} characteristics at the V_{DS} of 0 and -20 V. I_{dis} and I_{DS} were calculated from the simultaneously measured I_S and I_D of the first cycle of V_{GS} using eqs. (1) and (2). From Fig. 2 (a), hysteresis was not observed between backward and forward bias sweep, and the field-effect mobility (μ) and the threshold voltage (V_{th})

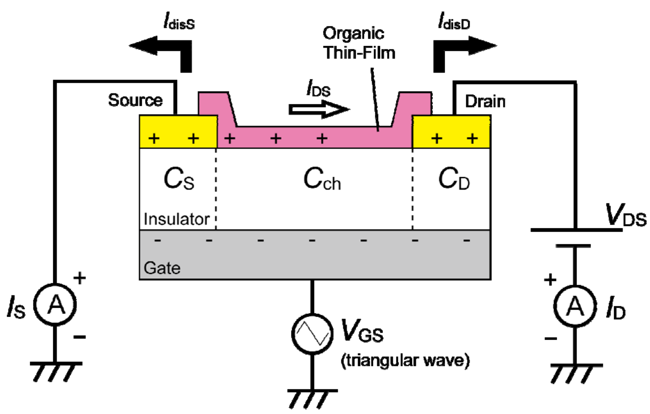

Fig. 1 Schematic diagram of simultaneous measurement method of I_{dis} and I_{DS} in bottom-contact OTFTs. I_S and I_D are simultaneously measured under the applications of a triangular-wave V_{GS} and a constant V_{DS}.

were evaluated as 0.011 cm^2/Vs, and 7.1 V at V_{DS} of -20 V. It should be noted that μ and V_{th} obtained by the semiconductor parameter analyzer were identical with those obtained by our simultaneous measurements. In Fig. 2 (b), the voltage where the displacement current at the source electrode starts to increase was defined as the carrier injection voltage at the source electrode (V_{inj}), since pentacene thin-film acts as p-type semiconductor, carrier should be injected to pentacene thin-film/gate insulator interface below V_{inj}.[6] V_{inj} was found out to be independent of V_{DS} and evaluated as 8.5 V. In the backward bias sweep in Fig. 2 (b), displacement current increased and experienced a short peak around 3.6 and 1.8 V for V_{DS} of 0 and -20 V, respectively. In the case of V_{DS} of -20 V, decrease of I_{dis} was observed at $-13 < V_{GS} < 1.8$ V, then increased again to reach the I_{dis} value of $V_{DS} = 0$ V.

From these characteristics of I_{dis}, charge sheet formation dynamics at the channel in backward bias sweep of $V_{DS} = -20$ V can be classified into four regions as shown in Fig. 2 (b). In region I (8.5 V < V_{GS} < 20 V) the transistor was off-state. In region II (1.8 V < V_{GS} < 8.5 V), charge injection occurred and channel current started to flow at V_{th} of 7.1 V. In region III (-13 V < V_{GS} < 1.8 V), the decrease of I_{dis} can be explained by considering the pinch-off. Since -20 V of V_{DS} was applied, OTFT operates in saturated mode when V_{GS} is small. In the region III, the carrier density along the channel decreases toward the drain electrode and becomes zero at pinch-off in the end of the drain channel when saturation occurs, which leads to small value of I_{dis}. In region IV (-20 V < V_{GS} < -13 V), OTFT operates in linear region and pinch-off disappears, which corresponds to increase in I_{dis}.

4. Conclusions

We have demonstrated the carrier density dynamics at the channel from the saturation to linear region through a simultaneous measurement method for displacement current and transfer curve in bottom-contact pentacene thin-film transistors. For the development of organic thin-film transistors, our simultaneous measurement method for displacement current and transfer curve proved to be a simple and powerful technique to understand carrier density dynamics and carrier transport properties.

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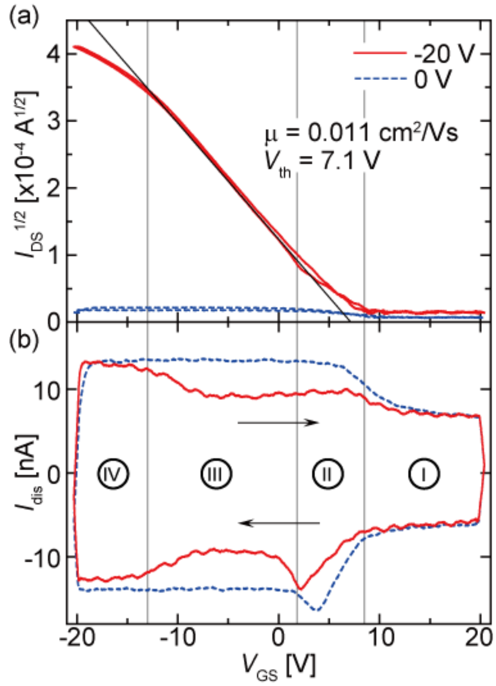

Fig. 2 Experimental results of (a) square-root of channel current ($I_{DS}^{1/2}$) – V_{GS} and (b) displacement current (I_{dis}) – V_{GS} characteristics at the V_{DS} of 0 and -20 V using the simultaneous measurements system.

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