Accumulated Carrier Density Dependence of Pentacene TFT Mobility Determined by Split C-V Technique

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1. Introduction
Pentacene has attracted much attention from its high mobility of organic field-effect transistors [1,2]. However, it is rather questionable about the mobility determination method by the conventional I-V characteristics on the basis of analytical FET model. This paper reports the pentacene mobility determined by the split C-V technique for the first time.

2. Experiments and Results

2.1 Sample Fabrication
The top-contact type capacitors and FETs were fabricated as schematically shown in Fig. 1. Each device was fabricated on 31 nm-thick SiO2 thermally grown on n-Si as electrical contacts were thermally evaporated. The a rather wide area capacitor is effectively measured as described below.

2.2 Frequency Dependent C-V Characteristics of Au/Pentacene/SiO2/n-Si/Al Capacitors
Fig. 2 shows C-V characteristics measured for type (a) and (b) capacitors in Fig. 1 as a function of measurement frequency. It is noted that there is a big discrepancy between them in spite of having the same Au electrode area.

In the case of Fig. 1 (a), a rather wide area capacitor is effectively measured as described below.

2.3 Channel Capacitance of Pentacene TFT by a Split C-V Technique
A split C-V technique can be used for extract the surface carrier density [3], by integrating gate-to-channel capacitance, C_{GC} which is defined as C_{GC}=S\frac{dQ_{CH}}{dV_{GS}}. where S is the area of accumulation channel and C_{GC} is determined by measuring the ac current with LCR meter in the configuration described in Fig. 3.

In the pentacene TFT in Fig.1 (c), however, the LCR meter measures the ac current component injecting into the channel in addition to the displacement current involved with Au/pentacene/SiO2/n-Si/Al capacitors at source and drain electrode because of large overlapped areas between gate (n-Si) and source/drain. To evaluate only the channel capacitance, two channel lengths TFTs with the same size Au electrodes were employed. Fig. 4 (a) shows a difference of C-V characteristics between capacitors with L=100 μm and L=200 μm. This result has a also measure-
ment frequency dependence, as shown in Fig.4 (a). With this method, only the channel capacitance accumulated at the pentacene/SiO₂ interface can be evaluated by using the frequency independent capacitance component.

Fig.4. (a) A difference of C-V characteristics between capacitors L=100 µm and L=200 µm for three measurement frequency. (b) The accumulation charge density, Ns, is independent of the measurement frequency below 100 Hz for FETs with channel length shorter than 200 µm.

The surface carrier density, Ns, was accurately evaluated by integrating C-V characteristics of Fig.4(a). 50 Hz was used for evaluating the channel capacitance, because Fig. 4(b) assures that accumulated charges are in proportion to the channel length at 50 Hz. The DC I-V characteristics were also measured as shown in Fig. 5. Since \( V_{DS} = -1 \) V was applied to evaluate the channel conductance, \( N_{CH}(V_{GS}) = \frac{N_{S}(V_{GS}+N_{S})(V_{GS}-V_{DS})}{2} \) was used for evaluating the average carrier density in the channel. Fig.6 shows \( N_{CH} \) at the interface as a function of \( V_{GS} \). By comparing the results of Fig. 5 with those of Fig. 6, the split C-V mobility is obtained.

Fig5. \( I_{DS}-V_{GS} \) characteristics of L=100 µm TFT shown in Fig.1(c). These characteristics exhibit typical performance of pentacene TFTs.

Fig6. \( V_{GS} \) dependence of the average carrier density, \( N_{CH} \). The channel charge density was estimated by integrating C-V curve of 50Hz in Fig.4.

3. Discussion

The mobility determined by the present method is shown as a function of \( V_{GS} \) in Fig. 7, together with experimental points of mobility determined by the conventional FET analytical model both in the linear region and in saturation region. The split C-V mobility can provide an overall bias (\( N_{S} \)) dependence of the mobility. The mobilities in the high carrier density region and in the low carrier density region correspond to those in the linear region and in saturation region, respectively. Although the conventional method cannot provide the accumulated carrier density dependence of the mobility in the channel, the present model can evaluate the overall mobility characteristics as a function of \( V_{GS} \) (or \( N_{GS} \)). It is clearly shown that the mobility increases with the carrier density in the accumulation layer [2]. In particular, near the threshold voltage the mobility is significantly lowered. This might be due to the effective increase of random potential fluctuations at the boundaries of pentacene grains in the channel at low \( Q_{S} \) region. Generally, the conventional mobility determination by the analytical FET model on the top contact pentacene FET will overestimate the mobility value due to the fact that the finite carrier density near \( V_{th} \) is ignored for the carrier density estimation, while the split C-V method accurately counts the carrier number all over the \( N_{S} \) region.

Fig. 7. Three kinds of mobilities as a function of \( V_{GS} \). The Split C-V mobility can provides an overall \( \mu \)-\( V_{GS} \) characteristics.

The method presented in this work will be useful for carrier transport study of organic devices. A concern of this method including the conventional method on the basis of analytical model is the time dependent degradation of FET characteristics. This will be an issue for further study.

4. Conclusion

The pentacene TFT mobility has been accurately determined by the split C-V technique for the first time. The frequency dependence of C-V characteristics should be carefully treated, since pentacene is a highly resistive semiconductor with dielectric properties. With the increase of the carrier density the mobility sharply increases near \( V_{th} \), and gradually increases. The result also verifies that the conventional mobility analysis on the basis of analytical FET model is approximately correct in a limited bias condition. In the low \( N_{S} \) region, the carrier conduction study will be interesting from the viewpoint of the strongly localized carrier transport.

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References