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Carrier injection and accumulation of pentacene field effect transistor with P(VDF-TeFE) gate insulator

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1. Introduction

Recently, the performance of organic field-effect transistor (OFETs) has been remarkably improved. And many important aspects of OFETs' operation have been revealed owing to many experimental and theoretical efforts. For example, it was found that carriers injected from the source electrode significantly contribute to the formation of OFETs' channel [1-3], and OFET functions as an injection-type element. However, there are still many issues to be solved for use, theoretically and experimentally. Control of threshold voltage is one of key issues. As an important step, we need to clarify the mechanism of charge accumulation at the OFETs' channel. In our previous study, we focused on spontaneous polarization in gate insulator, and showed that the amount of accumulated charges at the OFETs' channel was modulated by the spontaneous polarization; that is, the threshold voltage of pentacene FET was found to be changed by turn over of spontaneous polarization in ferroelectric gate insulator. However it is still not clear the relationship between carrier injection from the source electrode to pentacene and the change of accumulated charges generated by the spontaneous polarization [4-5]. In the present study, using OFETs with Au and Al source and drain electrodes, we examined the characteristics of pentacene FET with ferroelectric gate insulator in terms of carrier injection.

2. Experiment

Figure 1 shows the structure of pentacene FET with ferroelectric gate insulator used in this study. The Al-gate electrode was prepared on the glass substrate with thermal evaporation. The gate insulator was copolymer of vinylidene fluoride and tetrafluoroethylene, i.e., P(VDF-TeFE). P(VDF-TeFE) films were spin coated on the gate electrode with a thick ness of 400 nm, using a 10 %

methylethylketone solution. The spontaneous polarization of the P(VDF-TeFE) film was about $P_0 = 22.4 \text{ mC/m}^2$ [6]. The pentacene films were deposited with a thickness of 100 nm by means of vacuum evaporation. The source and drain electrodes were Au or Al electrodes deposited using thermal evaporation.

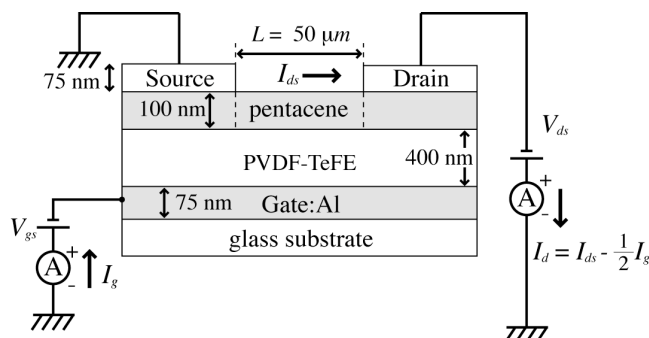


Fig. 1: The structure of pentacene FET with ferroelectric gate insulator

3. Results and Discussion

Figure 2 shows the $I_{gs} - V_{gs}$ characteristics of samples with Au electrodes and with Al electrodes, which were obtained using a ramp voltage of 0.1 Hz. One peak (peak A) appeared in the region $V_{gs} < 0$. The voltage V_a , giving the peak A, for the sample with Au electrodes corresponded to a voltage calculated as $E_c d_i$, where E_c is coercive field and d_i is the thickness of P(VDF-TeFE). This result indicates that the origin of the peak was turn over of spontaneous polarization P_0 . Also the result indicates that pentacene was conductive and the voltage across the P(VDF-TeFE) was V_a when the turn over was generated, i.e. the turn over of P_0 was generated while injected carriers were fully accumulated at the channel. This situation reasonably happens when hole injection from the Au

electrodes is smooth. On the other hand, the voltage V_a , giving peak A of the sample with Al electrodes, is greater than $E_c d$, indicating that the voltage across the P(VDF-TeFE) films was $E_c d$, but the voltage across the pentacene films was $V_a - E_c d$, not zero, when the turn over was generated. In other words, the turn over of P_0 triggers the hole injection. To further clarify the mechanism of the turn over and its related phenomena for OFETs with Au and Al electrodes, we examined the relationship between V_a and the frequency of ramp voltage. Figure 3 shows the results. For the samples with Au electrodes, V_a did not depend on the frequency of the ramp voltage. This result indicated that the hole injection from the Au-electrode was quiet smooth, and the pentacene was conductive. On the other hand, for the sample with Al electrode, the V_a depended on the frequency of the ramp voltage. That result indicated that the amount of accumulated charge in the channel changed because the hole injection from Al electrode was not so smooth, and the amount of accumulated charge decreased with increase of the frequency.

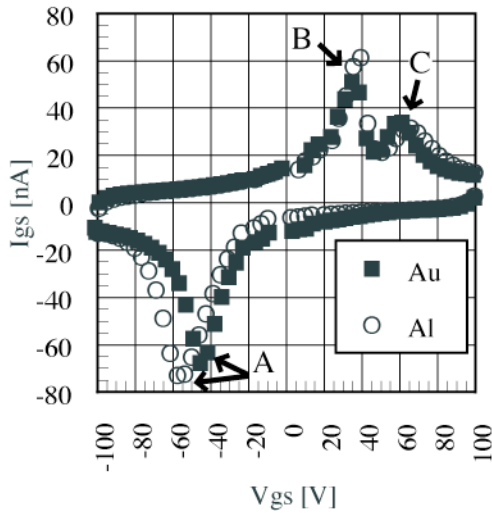


Fig. 2: $I_g - V_{gs}$ characteristics of pentacene FET with ferroelectric gate insulator at $V_{ds} = 0$ V

Two peaks (peaks B and C) appeared in the region $V_{gs} > 0$. Note that the origin of the peaks was tentatively identified in our previous study [5]. The C -V characteristics with $V_{ds} = 0$ V revealed that the capacitance decreased in the region where peak B appeared. This result indicated that the peak B was due to the release of accumulated holes from the pentacene. On the other hand, peak C was due to the turn-over of spontaneous polarization. Interestingly, the absolute value of voltage giving peak C is greater than that giving peak A. In the region of $V_{gs} > 0$, charges were not

accumulated in the pentacene film, and the pentacene and P(VDF-TeFE) films functioned like ideal dielectrics. Hence, a voltage applied to P(VDF-TeFE) film was approximately given as $(C_s / (C_s + C_f)) V_{gs}$. That is, an external voltage greater than V_a was needed to generate the turn over of the spontaneous polarization. As has been discussed here, the origins of peaks A and B have no relation with carrier injection from the source and drain electrodes. Hence it is reasonable to conclude that there is no difference between the samples with Au and Al electrodes in the generation of the peaks B and C.

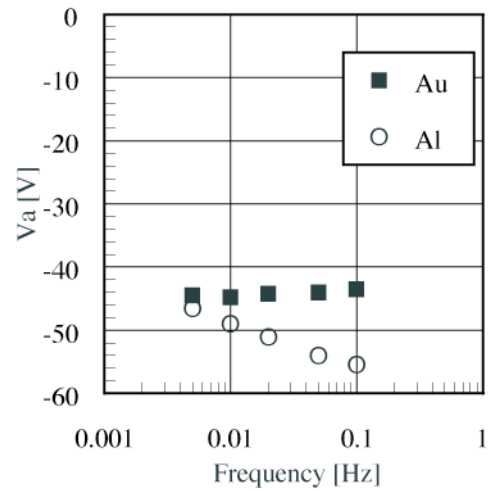


Fig.3: Dependence of voltage generating the turn over of spontaneous polarization on the frequency of applied ramp voltage

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