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Pentacene thickness dependence of FET properties in bottom contact structure; Estimation of the effective channel thickness

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1. INTRODUCTION

Thin Film Transistors (TFTs) and light emitting diodes (LED) using organic materials as the active material have made impressive progress over the last ten years in a number of applications including large area flat panel displays, radio frequency identification tag, and smart card [1,2]. Pentacene is one of the most promising materials used for organic TFTs, and much experimental effort such as modification of the film quality has been made to successfully improve the device performance [3]. Along with these efforts, many analytical studies have been devoted to understand the device operation. For example, the effect of pentacene film thickness on the performance of the field effect transistor (FET) is analyzed based on the capacitance-voltage (C-V) characteristics of the FET structure. As a result, it has been recognized that the channel formation process of organic FET (OFET) device is quite different from that of so-called silicon FET. In order to utilize organic devices efficiently, we need to understand such difference based on the difference in physics between inorganic and organic semiconductors. In this presentation, we discuss our pentacene FET operation, keeping in mind the difference between organic and inorganic semiconductors. Pentacene used for the fabrication of FET has large energy gap and are usually used without doping. Consequently, the charge carriers forming the conducting channel are mainly injected ones from the contact. From this background, Maxwell-Wagner model employed in analyzing double-layer dielectrics system is helpful to investigate the channel formation process in OFET [4]. In this presentation, thickness dependence of the FET characteristics (C-V and I-V characteristics) is discussed with consideration of the channel formation. In particular, thickness dependence measurement gives us some hints to treat the organic layer in the device physics. Actually, thickness dependence of drain current showed that the channel is confined within a region of approximately 30 nm from the semiconductor surface.

2. EXPERIMENT

For the OFET measurement, the device characteristics (I-V and C-V) were measured using bottom contact structure with inter-digit Au electrode. The FET characteristics were measured using source-meters (Keithley 2400). Channel length and width of this FET are 50 μm and 11 cm, respectively. In this measurement, to avoid the influence of a laboratory ambience, all measurement was performed in the evaporation chamber without breaking of vacuum (*in-situ* measurement). Before the deposition of pentacene, some Au substrates were specially treated by UV/ozone for 30 min. UV/ozone treatment of the substrate was given in UV/ozone treatment chamber. The chamber was filled with oxygen gas, and then UV-light was irradiated by a low-pressure mercury lump. Pentacene molecule was purchased from Sigma-Aldrich and used without further purification. During deposition of pentacene, pressure and deposition rate were kept less than 10^{-6} Torr and 0.5 Å/sec, respectively, and the temperature of the substrate is about 25 ^{o}C.

3. RESULTS AND DISCUSSIONS

Figure 1 shows the typical Id-Vd characteristics of a pentacene FET using (a) UV/ozone treated and (b) untreated substrate with a thickness of pentacene layer was about 100 nm. As shown in the figure, FET using untreated substrate shows p-channel enhancement FET behavior, but no field-effect at low gate voltage region less than –30 V. On the other hand, interestingly, significant drain current was observed at zero gate bias for the FET using UV/ozone treated substrate. According to the transfer characteristics ($(Id)^{1/2}$-Vg) of these FETs, the field effect mobility increased with a UV/ozone treatment.

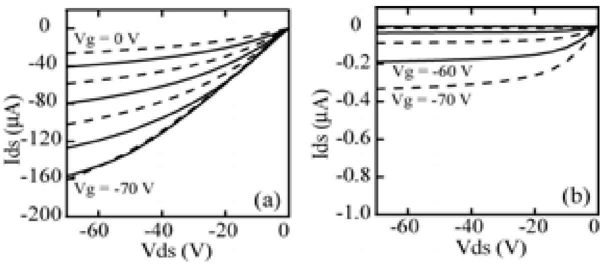

Fig. 1 Id-Vd characteristics of a pentacene FET using (a) UV/ozone treated and (b) untreated substrate (d=100 nm).

Figure 2 shows the current-voltage (C-V) characteristics of the pentacene FET using (a) UV/ozone treated and (b) untreated substrate. As shown in figure, capacitance increased with the bias voltage. Interestingly, only a small change was observed for untreated FET, whereas drastic change was observed for UV/ozone treated FET. These behaviors qualitatively coincide with the FET characteristics, i.e., no field-effect at low gate voltage region less than –30 V, because the capacitance increase corresponds to the accumulation of carriers at the interfacial region of pentacene/metal interface.

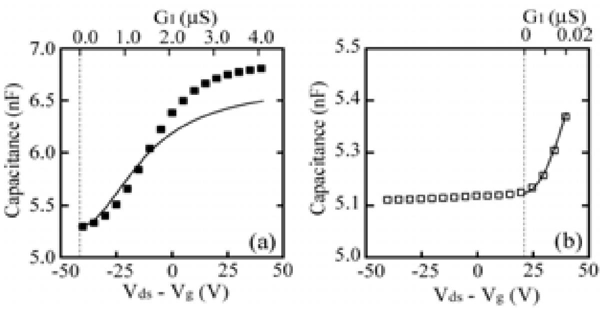

Fig. 2 C-V characteristics of a pentacene FET using (a) UV/ozone treated and (b) untreated substrate (d=100 nm).

In order to discuss the operation of OFET devices, it is important to estimate the charge induced at the channel region. From the view point of Maxwell-Wagner capacitor, charge induced at the interface between two insulating materials is expressed as,

$$Q = \frac{G_1 G_2}{G_1 + G_2}\left(\frac{C_1}{G_1} - \frac{C_2}{G_2}\right) V_g$$

where C and G express the capacitance and conductance of each insulator, respectively. In our previous paper [4], change of the channel conductance was successfully explained using this Maxwell-Wagner model, assuming the difference in the conductance corresponding to the carrier injection for the FETs.

Figure 3 shows the thickness dependence of the drain current of a pentacene FET using (a) UV/ozone treated and (b) untreated substrate. For the UV/ozone treated substrate, drain current saturated at approximately 30 nm indicating that the channel is confined within this region. This indicates that the channel region of pentacene should be treated as a semiconductor. On the other hand, drain current monotonously increase with the film thickness and no saturation was observed for

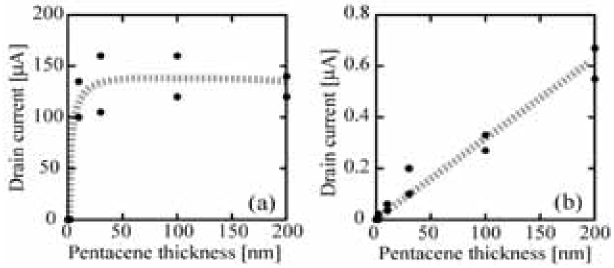

Fig. 3 Thickness dependence of the drain current of a pentacene FET using (a) UV/ozone treated and (b) untreated substrate.

untreated substrate. Within the approximation of Maxwell-Wagner model, thickness of the accumulated layer (semiconductor layer) is considered to be zero. Thus, according to the thickness dependence measurement, it is required to improve this model taking into account the finite thickness of the charge accumulation layer. In this presentation, with consideration of these, our experimental results on FET characteristics will be discussed.

References

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