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Improvement of Pentacene Organic Thin-Film Transistor Considering Quantum Effect

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1. Introduction

Recently, performance of organic thin-film transistors (OTFTs) has improved and is comparable to amorphous silicon thin-film transistors (TFTs) [1]. Therefore, it is expected that OTFTs can be applied to special applications such as flexible displays and IC tags. And also it is important to improve the driverbility from a viewpoint of current drive of organic light emitting diode (OLED) displays. The characteristics of pentacene OTFT depends on interface properties between the gate insulator and pentacene.

We propose the OTFT with very thin active layer for improvement of carrier mobility. In this OTFT, the triangle potential will be fabricated in pentacene film because of high electric field. It is expected that carrier mobility can be increased by quantum effect.

In this work, the film thickness dependence of film properties and OTFT properties were investigated.

2. Experimental

Si (111) wafer (n-type, 0.2 - 0.4 Ωcm) was cleaned and 100 nm thick SiO_2 film was formed by thermal oxidation at 1000°C for 540 s.

Pentacene OTFT was fabricated on the SiO_2/Si substrates. The thickness of pentacene film was varied from 1 to 50 nm. These thicknesses were measured by quartz crystal unit during deposition. The pentacene films and Au electrodes were deposited by vacuum thermal evaporation and electron beam evaporation, respectively. The sample-holder temperature was RT and base pressure was lower than 2×10^{-4} Pa. The deposition rate and the pentacene thickness were 0.15 nm/s and 50 nm, respectively. The deposition rate and Au thickness were 1 nm/s and 100 nm, respectively. OTFT pattern (L=1 mm and W=10 mm) was fabricated by a metal-shadow mask during pentacene and Au deposition. Electrical characteristics of pentacene OTFT were evaluated at RT in air.

In order to estimate the applied voltage for vertical and lateral direction in active layer of OTFT, the sample for vertical direction evaluation was prepared. In this sample, the pentacene film was deposited on Si substrate (n-type, 0.2 - 0.4 Ωcm). Au electrode ($1 \times 2mm^2$) was formed on pentacene/Si substrate. The electrical property was measured from Au electrode (ground) to Si substrate.

In addition, film properties were measured by atomic force microscope (AFM) and X-ray diffraction (XRD) in the region between source and drain electrodes.

3. Results and discussion

AFM images of pentacene film on SiO_2/Si substrate are shown in Fig. 1. The dendritic grain was observed at pentacene film with 1 nm thickness. As the film thickness increased, edge of grain became to round shape. It is considered that grain growth of pentacene film was influenced by substrate surface. As film thickness increased, grain was cohered because the effect of substrate surface was weak. The grain size was almost constant.

From the XRD patterns, pentacene film was preferentially oriented to (00l) of thin-film phase. In addition, the peak due to (011) was also observed at pentacene film with 50 nm thickness. It is shown that the

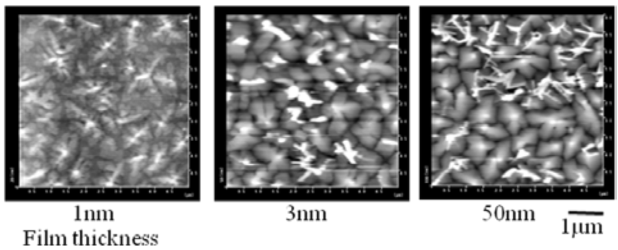

Fig. 1. AFM images of pentacene films with various film thickness.

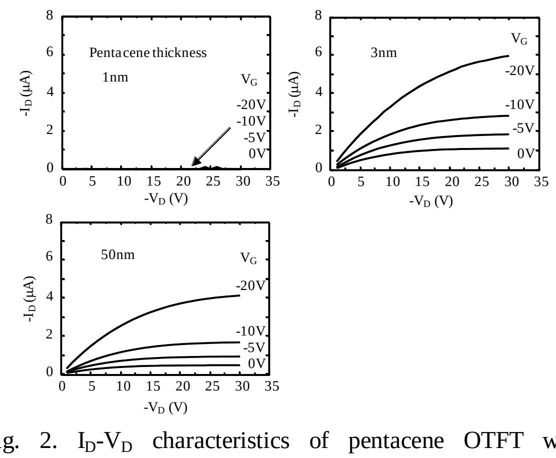

Fig. 2. I_D-V_D characteristics of pentacene OTFT with thickness of 1, 3 and 50 nm.

carrier transported thought standing molecular in channel region.

I_D-V_D characteristic is shown in Fig. 2. The OTFT with 1 nm thickness did not show the transistor characteristic. It is considered that the crystal grain did not link other grains because the Ra roughness was as same as film thickness.

Next, the applied voltage for vertical and lateral direction in active layer of OTFT was estimated from I_D-V_D characteristic and IV characteristic of vertical direction (Fig. 3). The lateral and vertical voltage for on and off state are summarized in Table 1. In this case, V_D was 20 V. For off state, V_D was almost applied to lateral direction. For on state, the voltage of vertical direction was slightly increased compared with off state. However,

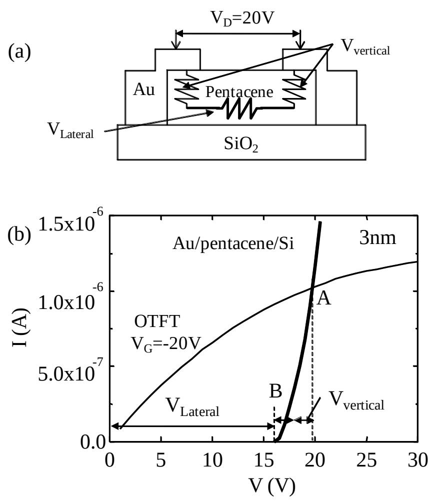

Fig. 3. Estimation model of applied voltage for vertical and lateral direction (a) and IV characteristics of OTFT and evaluation sample for vertical direction transport for 3 nm thickness.

Table 1. Lateral and vertical voltage for on and off states.

State	On (V_G=-20V)		Off (V_G=20V)	
Direction	$V_{Lateral}$	$V_{Vertical}$	$V_{Lateral}$	$V_{Vertical}$
3 nm	16V	2V	19.8V	0.1V
50 nm	13V	3.5V	19.9V	0.05V

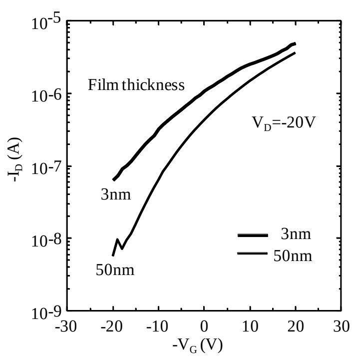

Fig. 4. I_D-V_G characteristics of the pentacene OTFTs with thickness of 3 and 50 nm. The V_D was -20 V.

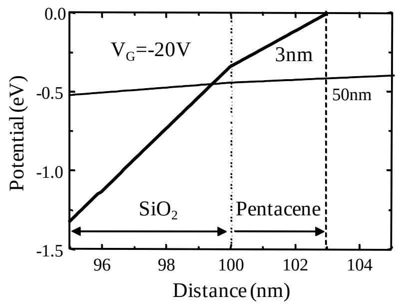

Fig.5. Potential distribution at interface between pentacene film and SiO_2 film at V_G=-20V (on state).

V_D was almost applied to lateral direction at both conditions. It is considered that I_D was defined by carrier transport to lateral direction in channel at interface between pentacene and SiO_2 film.

The I_D-V_G characteristics of the pentacene OTFTs with thickness of 3 and 50 nm are shown in Fig. 4. The I_D was increased with decreasing film thickness. To clear the thickness dependence of I_D, the potential distribution and quantum level at interface of pentacene and SiO_2 film was estimated at V_G=-20V. The potential distribution of pentacene film thickness of 3 and 50 nm is shown in Fig. 5. The dielecrtric constant and effective mass of pentacene film were assumed to 6.7 [2] and 1.55m_o [3], respectively. From these estimation, a triangle potential formed at thickness of 3nm and quantum levels were 0.03 (n=1), 0.11 (n=2) and 0.24 eV (n=3). It is considered that carriers at these levels are located away from the SiO_2/Pentacene interface and therefore the probability of the carrier scattering decreases. This effect increases the carrier mobility. Therefore, I_D of OTFT with 3 nm thickness was high compared with that with 50 nm thickness.

4. Conclusions

Carrier transport in OTFTs was investigated by using pentacene OTFT and sample for vertical transport evaluation with various film thickness from 1 to 50nm. It was found that the drain current was dominated by carrier transport to lateral direction in channel independent of pentacene film thickness. The I_{on} of 3nm OTFT was higher than that of 50 nm OTFT. It is considered that the probability of the carrier scattering decreases for OTFT with 3nm thickness. It is expected that OTFT characteristics was improved by using quantum effect.

References

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