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Demonstration of a record high current-gain cutoff frequency(>10 MHz) in organic thin-film transistors

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1. Introduction

Organic based TFTs have attracted much attention because of their potentials to provide large area, flexible, lightweight, and low cost devices. C_{60} is one of the promising materials that exhibit high mobilities. C_{60} TFTs with field-effect mobilities more than 1.0 cm^2/Vs have been demonstrated [1-3]. In many cases, the mobility of an organic transistor decreases with reducing the channel length even if the length is of the order of μm. The behavior is caused by large contact resistance. We have successfully fabricated high mobility C_{60} TFTs with micron order channel length suppressing contact resistance [4]. In addition, we have demonstrated C_{60} TFTs with low threshold voltage using modified drain/source electrodes [5]. The result indicates that the C_{60} TFTs have potential for high frequency operation. In this paper, we report on demonstration of a record high current-gain cutoff frequency (>10 MHz) in organic TFTs. The achievement will open various new potential applications that require high speed performance of organic FETs.

2. Experimental

The cross section of the fabricated C_{60} TFT is shown in Fig. 1. The substrate is a glass substrate. The gate electrode is an AlSi layer and the gate insulator is a 200-nm-thick SiO_2 layer. The SiO_2 layer has a unit area capacitance of 20 nF/cm^2. The drain/source electrodes were patterned by conventional photolithography and lift off. The electrodes consist of a 3-nm-thick $Au_{0.9}Ni_{0.1}$ adhesion layer and 25-nm-thick Au layer. The surfaces of the gate insulator and the drain/source electrodes were treated using hexamethyldisilazane and (dimethylamino)benzenethiol, respectively [5]. Finally, C_{60} was deposited at a substrate temperature of 120 ºC on the channel region through a shadow mask. The channel width is 1 mm and the channel lengths (L) are 2, 4, 6, and 10 μm. A photograph of a C_{60} TFT with L = 2 μm is shown in Fig. 2.

In this study, current gain was obtained from measurement of ac gate current ($i_G(t)$) and drain current ($i_D(t)$). For the measurement, ac voltage biased was applied to a gate electrode using a function generator. The peak-to-peak voltage was set to 2 V. Bias drain voltage (V_D) and gate voltage (V_G) were applied with dc voltage sources; being set to 25 V and 20 V. Current probes were used to measure $i_G(t)$ and $i_D(t)$ without electrical connection. For the measurement, C_{60} TFTs were placed in a dry-nitrogen glovebox.

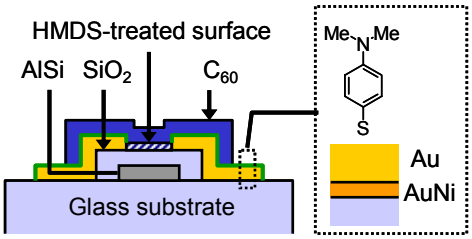

Fig. 1 Cross section of the fabricated C_{60} TFT.

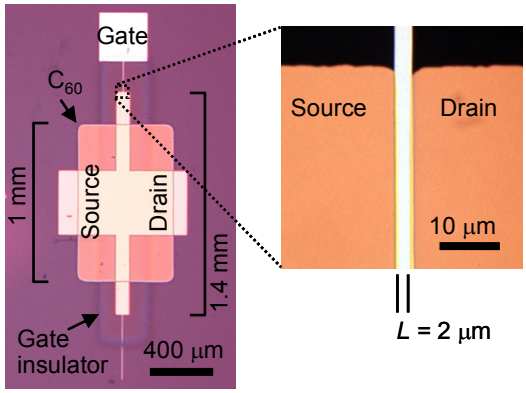

Fig. 2 Photograph of a C_{60} TFT with L = 2 μm.

3. Results

Figure 3 shows saturation mobility (μ_s) and threshold voltage (V_T) for C_{60} TFTs with L = 2-10 μm. The μ_s and V_T are 0.86-1.12 cm^2/Vs and 5.9-8.6 V, respectively. There is no large difference in μ_s.

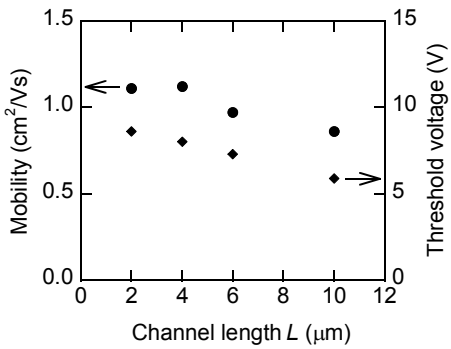

Fig. 3 Saturation mobilities and threshold voltages of C_{60} TFTs with different L.

Figure 4 shows waveforms of $i_G(t)$ and $i_D(t)$ obtained at frequencies (f) of 1 MHz and 10 MH for a C_{60} TFT with L = 2 μm. Peak-to-peak drain currents (I_{out}) at f = 1 MHz and 10 MHz are 237 and 276 μA, respectively. The difference is small. The peak-to-peak current was consistent to the static characteristic. On the other hand, peak-to-peak gate currents (I_{in}) at f = 1 MHz and 10 MHz are 12.6 and 137 μA, respectively. The gate current at 10 MHz is about ten times as large as that at 1 MHz. Since gate current passes through gate capacitance, the frequency dependence of the ac gate current is reasonable.

From the frequency dependence of the I_{out}, experimental gate capacitances are calculated to be 0.95 pF for L = 2 μm. Subtracting intrinsic gate capacitances from the values, we estimate parasitic capacitances to be 0.55 pF. The parasitic capacitance corresponds to overlap lengths between gate and drain/source electrodes of 2.0 μm. The estimated overlap length is consistent with the designed gate width.

Figure 5 shows current gain of a C_{60} TFT with L = 2 μm. The gain is proportional to f. The unit gain is obtained at f = 20 MHz.

Measured cutoff frequencies of C_{60} TFTs with different L are shown in Fig. 6. The dotted line shows f_T estimated from

$$f_T = \frac{\mu_{sat}(V_G - V_T)}{2\pi L^2} \times \frac{1}{(1 + C_p / C_i WL)} \quad (1)$$

where C_i and C_p are unit area gate capacitance and parasitic capacitance. The measured f_T is consistent with the estimated f_T.

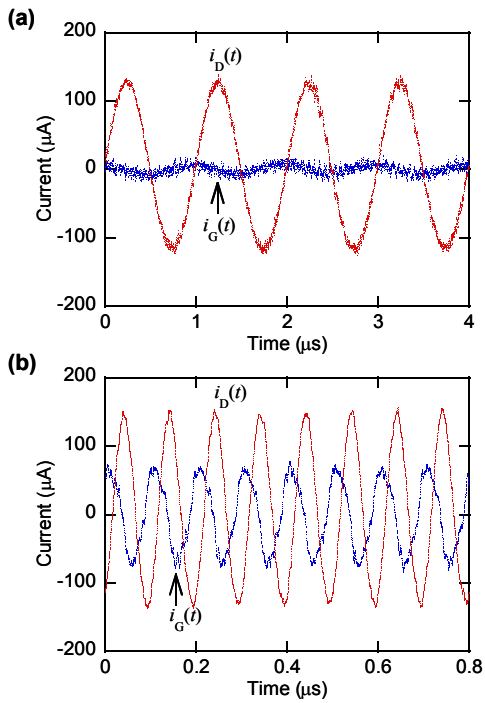

Fig. 4 Waveforms of $i_G(t)$ and $i_D(t)$ obtained at 1 MHz and 10 MH for a C_{60} TFT with L = 2 μm.

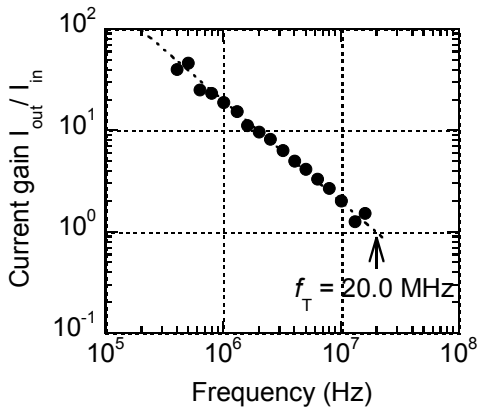

Fig. 5 Current gain of a C_{60} TFT with L = 2 μm.

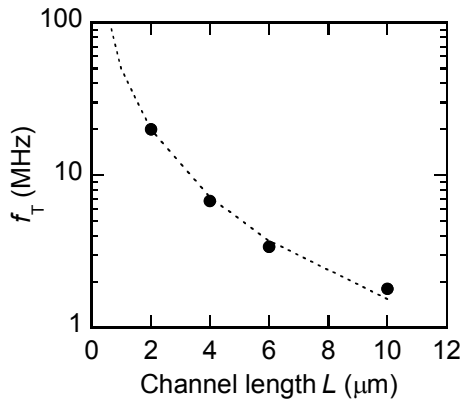

Fig. 6 Cutoff frequencies measured for C_{60} TFTs (closed circles) and estimated from the equation (dotted line).

4. Conclusions

In summary we measured current-gain cutoff frequencies f_T of C_{60} TFTs with different channel lengths. The f_T increased with reducing L. The maximum f_T of 20 MHz was obtained from the TFT with L = 2 μm. The achievement will open various new potential applications that require high speed performance of organic FETs.

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