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Dinaphtho Thieno Thiophene Thin-Film Transistors with Modified Platinum Electrodes in Bottom-Contact Configuration

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1. Introduction

Dinaphtho[2,3-b:2',3'-f]thieno[3,2-b]thiophen (DNTT) and the derivative have attracted much attention as channel materials for organic thin-film transistors (TFTs) because of their high mobility and stability in the air. Since Yamamoto and Takimiya reported DNTT-based TFT [1], many groups have studied TFTs using DNTT and the derivative [2-6]. The field effect mobilities reached to about 8 cm^2/Vs in alkylated DNTT [2] and single-crystal DNTT TFTs [8]. However, such high mobility demonstrated in long-channel transistors having top-contact configuration. On the other hand, bottom-contact configuration is desirable for short-channel transistors and the high frequency operation.

We have demonstrated bottom-contact pentacene TFTs operating at high frequencies above 10 MHz [7]. Gold drain/source electrodes modified with pentafluorobenzenethiol (PFBT) were used to realize the short-channel, high-mobility pentacene TFTs [8]. DNTT have a highest occupied molecular orbital (HOMO) level of -5.44 eV [1], which is lower than -5.1 eV for pentacene. Thus, a high work-function metal such as Pt is suitable for electrodes in DNTT TFTs.

In this work, we report bottom-contact, short-channel DNTT TFTs with modified Pt drain/source electrodes. The performance is compared to those of DNTT TFTs with unmodified Pt and Au electrodes. As a result, the TFTs with modified Pt electrodes have higher mobilities than those of the TFTs with unmodified Pt and Au electrodes.

2. Experimental

Cross-section of the DNTT TFT fabricated in this work is shown in Fig. 1. A silicon substrate with a 35-nm-thick SiO_2 layer was used as a substrate of the DNTT TFT. The SiO_2 has a unit area capacitance of 92.3 nF/cm^2. Drain/source electrodes of Pt/Ti and Au/AuNi were patterned by photolithography and lift-off. The SiO_2 surface was treated with hexamethyldisilazane. For some substrates, the Pt/Ti electrode was modified with PFBT. DNTT was deposited through a metal mask on a substrate heated at 60 °C. The channel width (W) was 1 mm and the channel length (L) was in the range of 2 to 40 μm. The current-voltage characteristic was measured in a dry-nitrogen glove box.

For three electrode types, PFBT-modified Pt/Ti, Pt/Ti and Au/AuNi, the work function of the surface was measured with an atmospheric photoelectron spectrometer.

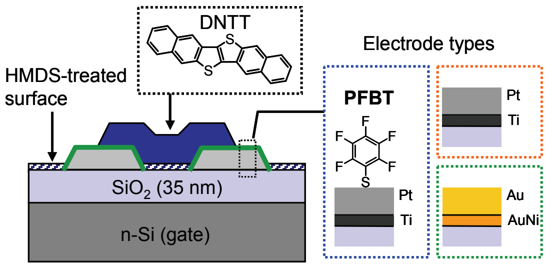

Fig. 1 Schematic illustration of a bottom-contact DNTT TFT.

3. Results

Measured work functions of PFBT-modified Pt/Ti, Pt/Ti and Au/AuNi surfaces were 5.33, 5.02, and 4.82, respectively. Thiol derivative generally react to Au surface, and then a molecule layer forms on the surface. When using thiol derivative with electron-attracting substituents such as nitro group and fluorine atoms, the work function of the modified surface increases by the dipole moment. On the other hand, there have been few reports about reaction of thiol derivative to Pt surface. Although reaction between thiol derivative and Pt surface is unclear, the result in this work indicates that PFBT modification is effective to increase work function of Pt electrode.

Figure 2 shows drain current (I_D) versus gate voltage (V_G) and I_D versus drain voltage (V_D) characteristics of DNTT TFTs with different electrode types of L = 2 μm. The current-voltage characteristic strongly depends on the electrode types. The TFT with the Pt/Ti electrode has higher drain current than that with the Au/AuNi electrode. Furthermore, PFBT modification improves the drain current. The mobility in the saturation regime (μ_{sat}) and threshold voltage (V_T) are 0.32 cm^2/Vs and –2.1 V for PFBT-modified Pt/Ti, 0.14 cm^2/Vs and -2.9 V for Pt/Ti, and 0.048 cm^2/Vs and -3.6 V for Au/AuNi, respectively. The μ_{sat} and V_T values were estimated from the $|I_D|^{1/2}$-V_G characteristic.

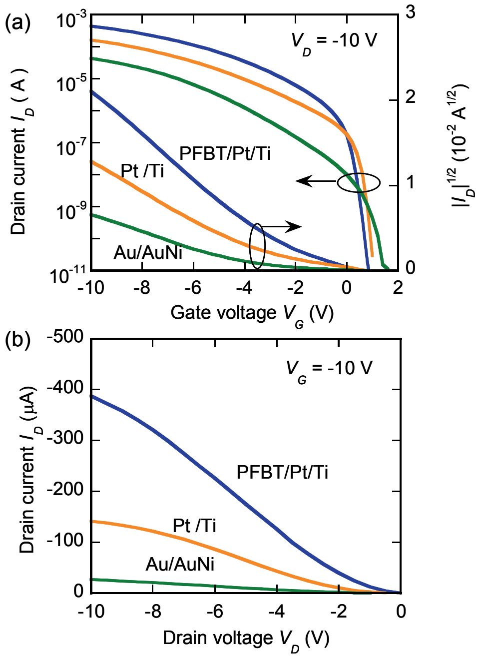

Fig. 2 Current-voltage characteristics of DNTT TFTs with PFBT-modified Pt/Ti, Pt/Ti and Au/AuNi electrodes: (a) $|I_D|$-V_G and $|I_D|^{1/2}$-V_G, and (b) I_D-V_D characteristics.

The channel length dependence of mobilities in the saturation regime is shown in Fig. 3. The TFTs with L = 40 μm have similar mobilities. The mobility decreases by reducing channel length for all electrode types. However, the magnitude of the decrease is significantly affected by the electrode types. Use of PFBT-modified Pt/Ti electrode suppresses the decrease. The difference of the mobility is caused by the contact resistance.

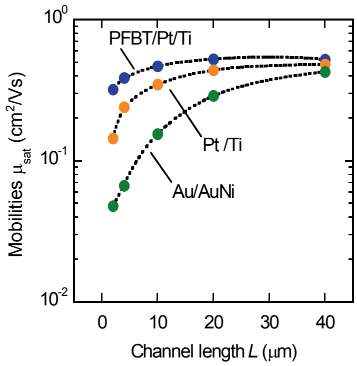

Fig. 3 Channel length dependence of mobilities in the saturation regime of DNTT TFTs with different electrodes.

Figure 4 shows gate-voltage dependence of normalized contact resistance for the DNTT TFTs with different electrode types. The contact resistance (R_C) was calculated from the on resistance in the linear regime of the TFTs with various channel lengths using gated transfer line method. The contact resistance decreases with gate voltage for all electrode types. The normalized contact resistance (R_C W) at V_G–V_T = –8 V are 3.4 kΩ cm for PFBT-modified Pt/Ti, 16 kΩ cm for Pt/Ti, and 160 kΩ cm for Au/AuNi. The difference of R_C values is consistent to difference of the work functions. The low R_C value of PFBT-modified Pt/Ti electrode is mainly due to the high work function.

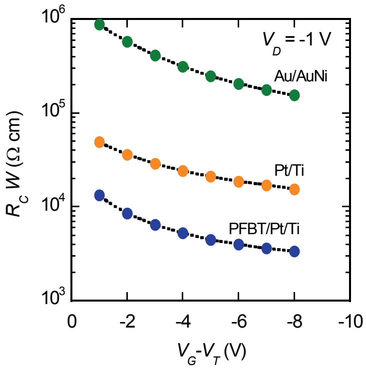

Fig. 4 Normalized contact resistance of DNTT TFTs as a function of gate voltage at V_D = –1 V.

4. Conclusions

We investigated influence of drain/source electrodes on the characteristics of bottom-contact DNTT TFTs. Use of PFBT-modified Pt electrode suppresses the contact resistance and improve the mobility of short channel DNTT TFTs. PFBT-modified Pt electrodes will be useful for p-channel TFT having other organic materials with low HOMO level.

Acknowledgements

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