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# Pentacene Thin-Film Transistors with Controlled Threshold Voltages and Their Application to Pseudo CMOS Inverters

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**Abstract**

**Threshold voltage control in pentacene thin-film transistors (TFTs) has been demonstrated by oxygen plasma treatment to the surface of the $SiO_2$ gate dielectric. The threshold voltage linearly shifts with increase in plasma treatment time. Pseudo CMOS inverters consisting of the TFTs with controlled threshold voltages successfully operated at 10 V.**

## 1. Introduction

Organic thin-film transistors (TFTs) have attracted much attention because of their potential for applications such as logic circuits and radio-frequency identification tags. The logic circuits have been demonstrated using pseudo CMOS circuits consisting of organic TFTs [1-5]. Although pseudo CMOS circuits have high power consumption as compared to CMOS circuits, the circuits can be composed only with PMOS or NMOS.

Threshold voltage control is a key issue for applications of organic TFTs to electronic circuits including pseudo CMOS circuits. Some groups have attempted threshold voltage control for organic TFTs using several approaches. However, there is no standard process for threshold voltage control in organic TFTs. It is known that oxygen plasma treatment to gate dielectrics influences the threshold voltages in organic TFTs [6-8].

In this study, we systematically investigated the influence of oxygen plasma treatment to $SiO_2$ surface on characteristics of pentacene TFTs. Relation between plasma treatment time and the threshold voltage is examined. Pseudo CMOS inverters composed with pentacene TFTs having controlled threshold voltage are demonstrated.

## 2. Experimental

Figure 1 shows illustration of fabricated pentacene TFTs and the fabrication process. Pentacene TFTs were fabricated on $n^+$-Si substrate with 90-nm-thick $SiO_2$. The surface of $SiO_2$ was exposed to oxygen plasma. The plasma treatment time ($t_P$) was set to 5 to 120 s. The substrate was immediately treated with hexamethyldisilazane vapor to obtain hydrophobic surface. The 45-nm-thick pentacene was deposited through a shadow mask to form channel region. Then, the TFTs were completed by deposition of Au for drain/source electrodes. The channel width and length were 1 mm and 100 μm, respectively. The transistors characteristics were measured in a dry-nitrogen-filled glovebox.

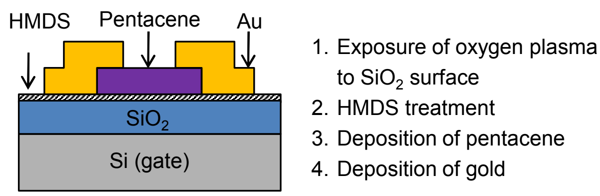


Fig. 1 Illustration of a fabricated pentacene TFT and the fabrication process.

## 3. Transfer Characteristics of TFTs

Figure 2 shows drain current ($I_D$) versus gate voltage ($V_G$) characteristics of the TFTs with different $t_P$. The $I_D$-$V_G$ curves shifted to positive gate voltage with increase in $t_P$. Figure 3 shows the threshold voltages ($V_T$) and the mobilities in the saturation regime ($\mu_{sat}$), which were estimated from the $|I_D|^{1/2}$-$V_G$ characteristics. The $V_T$ values linearly increase with $t_P$. This implies that the oxygen plasma treatment generates negative charges on the $SiO_2$ surface. On the other hand, the $\mu_{sat}$ values range from 0.63 to 0.82 $cm^2/Vs$, and the plasma treatment provides no large influence on the $\mu_{sat}$. These results indicate that threshold voltages are controlled by oxygen plasma without changes in mobility.

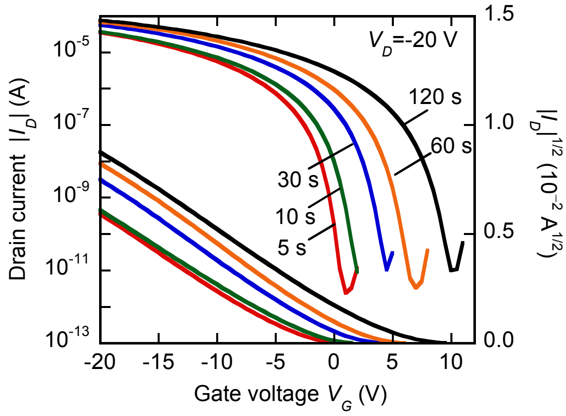


Fig. 2 Transfer characteristics of pentacene TFTs wiht different plasma-treatment time.

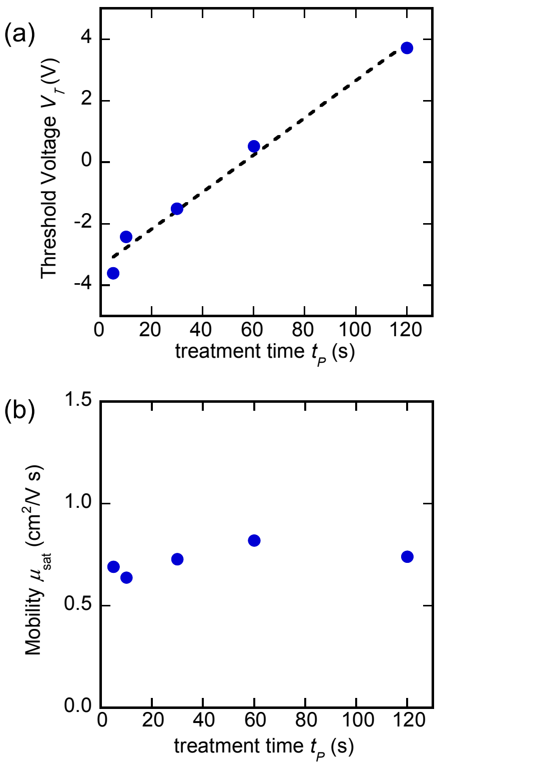


Fig. 3 Dependence of (a) threshold voltages and (b) mobilities in the saturation regime of pentacene TFTs on plasma treatment time.

## 4. Characteristics of Pseudo CMOS Inverters

Pseudo CMOS inverters were composed as an application of the pentacene TFTs with controlled threshold voltages. Figure 4 shows the circuits and output-input characteristics of the pseudo CMOS inverters. We composed the inverters electrically-connecting two pentacene TFTs on different substrates. The threshold voltages of the TFTs and the measured switching voltages ($V_S$) of the inverters are summarized in Table I. The switching voltage is defined as an input voltage ($V_{IN}$) at which an output voltage ($V_{OUT}$) equals a half of a supply voltage ($V_{DD}$). Inverters INV1 and INV2 have switching voltages of 7.8 and 5.0 V, respectively. When the mobility of PMOS1 equals the mobility of PMOS2, the switching voltage is written as

$$V_S = V_{DD} + V_{T1} - V_{T2}. \quad (1)$$

For INV1 and INV2, the $V_S$ values are calculated as 7.8 and 5.0 V from eq. (1), respectively. The calculated values are just the same as measured values in Table I. On the other hand, inverter INV3 does not work as an inverter. The $V_S$ value for INV3 is calculated as 0.0 V from eq. (1). Thus, the measured characteristic of INV3 is consequent.

## 5. Conclusions

In conclusion, we demonstrated the threshold voltage control in the pentacene TFTs by oxygen plasma treatment to the $SiO_2$ gate dielectric. The threshold voltage linearly shifts to positive voltage with increase in plasma treatment time without change of the mobility. Pseudo CMOS inverters consisting of pentacene TFTs with different threshold voltages operated according to the threshold voltages. As a result, the inverters consisting of TFTs with suitable threshold voltages normally operated as an inverter.

Table I Threshold voltages of pentacene TFTs used for pseudo CMOS inverters and switching voltages of the inverters

| Inverter name | Threshold voltage of PMOS1 $V_{T1}$ (V) | Threshold voltage of PMOS2 $V_{T2}$ (V) | Switching voltage $V_S$ (V) |
|---|---|---|---|
| INV1 | -0.7 | 1.5 | 7.8 |
| INV2 | -1.6 | 3.4 | 5.0 |
| INV3 | -4.2 | 5.8 | - |

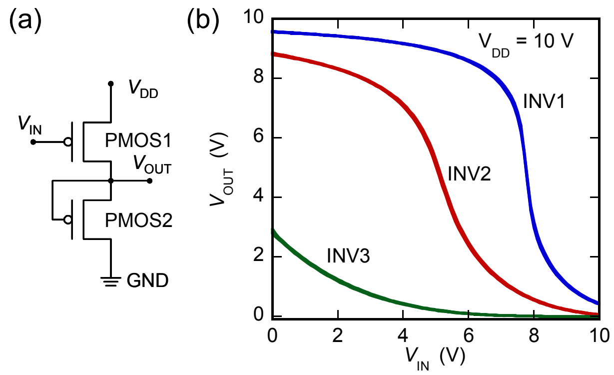


Fig. 4 (a) Circuit of pseudo CMOS inverter and (b) output-input characteristics of inverters composed with pentacene TFTs with different threshold voltages.

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