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Bottom-Contact Pentacene Thin-Film Transistors with Threshold Voltages Controlled by Oxygen Plasma Treatment

Hiroki Fujita[1], Yoshinari Kimura[1], Yoshiaki Hattori[1], and Masatoshi Kitamura[1]

[1] Department of Electrical and Electronic Engineering, Graduate School of Engineering, Kobe University
1-1, Rokkodai-cho, Nada, Kobe 657-8501, Japan
Phone: +81-78-803-6072 E-mail: 187t245t@stu.kobe-u.ac.jp

Abstract

Threshold voltage control by oxygen plasma treatment has been applied to bottom-contact pentacene thin-film transistors (TFTs). The threshold voltage in the pentacene TFT shifted to positive gate voltages with the plasma treatment time as well as that in a top-contact TFT. Although the long-time plasma treatment led to increase in the contact resistance, the plasma treatment time for threshold voltage shifts of several voltages had no large influence on the field-effect mobility in the saturation regime.

1. Introduction

Organic thin-film transistors (TFTs) have attracted much attention because of their applications to logic circuits and flat panel displays [1-3]. Threshold voltage control is an important issue for the application of organic TFTs. Some approaches have been attempted for the threshold voltage control [4-7].

We have used oxygen plasma treatment to the gate dielectrics for the control [8-11]. The threshold voltage shifts to positive gate voltage with increase in the treatment time. Thus, the threshold voltages can be controlled by changing the treatment time. Since the fabrication process has an advantage that it does not require additional structures, it is straightforwardly applied to logic circuits. In fact, we demonstrated operation of a ring oscillator consisting of top-contact pentacene TFTs with different threshold voltage [11]. However, the top-contact configuration limited the operational frequency to about 300 Hz because of the long-channel length. It is expected that the threshold voltage control is applied for bottom-contact organic TFTs with short-channel lengths toward demonstration of high-frequency operation.

In this study, we fabricated bottom-contact pentacene TFTs with gate dielectrics treated by oxygen plasma to confirm whether the method of threshold voltage control is applicable to bottom-contact organic TFTs. The current-voltage characteristics and contact resistance were measured to evaluate the method.

2. Experimental

Figure 1 shows the fabrication process for pentacene TFTs investigated in this study. The pentacene TFT was fabricated on a highly-doped Si substrate with a 90-nm-thick thermal oxide layer, which had a unit area capacitance of 36.9 nF/cm^2. The drain/source electrode was patterned by photolithography and lift-off process. The use of AuNi serving as an adhesive layer contributes to suppress contact resistance [12]. The substrate with the patterned electrode was exposed to UV/ozone for t_U = 15 min, to O_2 plasma for a time of t_P, and then to hexamethyldisilazane (HMDS) vapor. After the treatment, the drain/source electrode was modified with pentafluorobenzenethiol (PFBT). Finally, a 45-nm-thick pentacene layer was deposited through a shadow mask to form channel region. The channel width (W) was 1 mm and the channel length (L) was in the range of 4 to 40 µm. The characteristics were measured in a dry-nitrogen-filled glovebox.

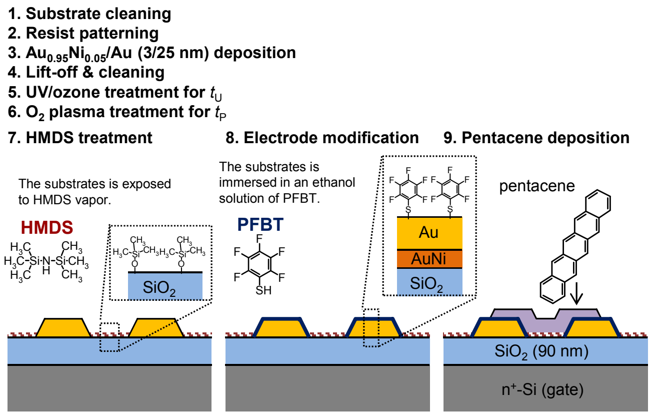

Fig. 1 Fabrication process of pentacene TFTs.

3. Results

Figure 2 shows the drain current (I_D) versus gate voltage (V_G) characteristics of pentacene TFTs with L = 4 µm for different t_P at a drain voltage (V_D) of −20 V. The I_D-V_G curves shifted to positive gate voltage with increase in t_P.

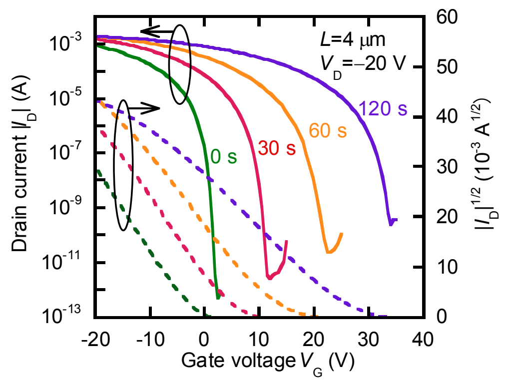

Fig. 2 Transfer characteristics of pentacene TFTs with L = 4 µm for t_P = 0, 30, 60, and 120 s at V_D = −20 V.

Figure 3 shows the threshold voltages (V_{TH}) estimated from the $|I_D|^{1/2}$-V_G characteristics. The relationship between V_{TH} and L for a time of t_P shown in Fig. 3 indicates that the change of L has no large influence on the threshold voltage shift. Thus, we can discuss the change in the threshold voltage on the basis of pentacene TFTs with a certain L. Figure 3(b) shows the V_{TH} versus t_p of bottom-contact pentacene TFTs with L = 4 μm fabricated in this work and of top-contact pentacene TFTs with L = 100 μm reported in Ref. [8]. The V_{TH} linearly increases with t_P for both cases. However, the V_{TH} in this work is more sensitive to t_P as compared to that in previous work. The different procedure of the surface treatment may cause the difference of the sensitivity. Although UV/ozone treatment was performed before O_2 plasma treatment in this study, no UV/ozone treatment was performed in previous work.

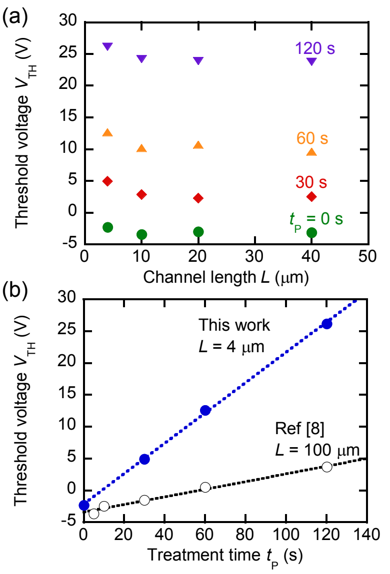

Fig. 3 (a) V_{TH} versus L of pentacene TFTs for different t_P. (b) V_{TH} versus t_P of pentacene TFTs in this work and in previous work.

To investigate the influence of O_2 plasma treatment on the drain/source electrode of the TFT, we estimated the contact resistance (R_C) using transfer line method. The channel-length normalized contact resistance increases with t_P as seen in Fig. 4. This indicates that O_2 plasma treatment causes the increase in contact resistance. The origin of the increase may relate to modification of drain/source electrodes after O_2 plasma treatment. The detail has been under investigation. The importance is whether the increase of the contact resistance leads to degradation of TFT performance.

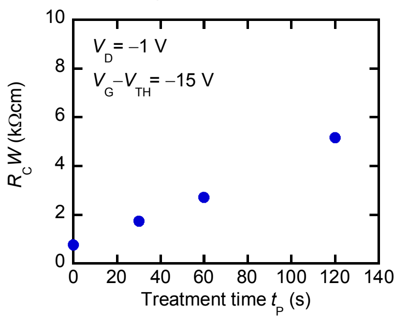

Fig. 4 Dependence of $R_C W$ on t_P for pentacene TFTs.

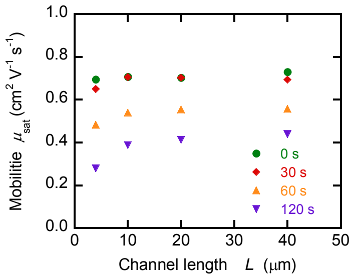

Fig. 5 Channel-length dependence of μ_{sat} in pentacene TFTs.

Figure 5 shows the field-effect mobility in the saturation regime (μ_{sat}) in pentacene TFTs for different t_P. Although the μ_{sat} for t_P = 60 and 120 s is lower than that for t_P = 0, the μ_{sat} values of 0.65-0.71 cm^2 V^{-1} s^{-1} for t_P = 30 s is close to that of 0.70-0.73 cm^2 V^{-1} s^{-1}for t_P = 0. This indicates that short O_2 plasma treatment has no large influence on μ_{sat}. This is probably because the contact resistance for the t_P is significantly low under operation in the saturation regime.

4. Conclusions

In conclusion, we demonstrated threshold voltage control of bottom-contact pentacene TFTs using O_2 plasma treatment. As a result, the plasma treatment time for threshold voltage shifts of several voltages had no large influence on the field-effect mobility in the saturation regime. Thus, the method of threshold voltage control is useful for application of short-channel, bottom-contact organic TFTs to logic circuit operating at a high-frequency.

Acknowledgements

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