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Charge Trapping Barrier and the Effect of Surface Treatment in Pentacene Thin Film Transistors

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1. Introduction

The current instability of organic thin film transistors (OTFTs), which is measured as the current degradation under a fixed gate-voltage (V_g), is one of the most important factors for practical application in such devices as flexible displays and low cost radio frequency identification (RFID) tags. Since the current instability in OTFTs is considered to originate from the trapping of charge carriers at the semiconductor/insulator interface, current instability has been investigated in devices with different gate insulator surfaces or materials.^[1] However, the mechanism for current instability has not yet been completely clarified.

In this study, the current transition of the top-contact pentacene OTFTs with the application of pulse or step V_g was measured in order to clarify the mechanism for current stability (Fig. 1 (a)). The factor for the current stability was discussed by measuring the devices with different gate insulator surface treatments and pentacene grain sizes at various temperatures. The energy parameters of the charge trapping process and the effect of semiconductor/insulator interface are discussed.

2. Results and discussion

The measured current transition under pulsed V_g was shown in Fig. 1 (b). There are two component of current decay: charge accumulation into the channel, and current decay due to charge trapping. The former component has been reported to be modeled by distributed constant circuit,^[2] where the time constant can be calculated by $\tau = CR \sim 10^{-5}$ s (C : gate capacitance, R : channel resistance). In this

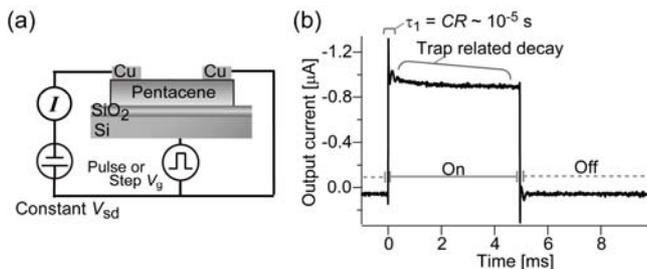


Fig. 1 (a) Schematic of the measurement setup for the time dependent current analysis. (b) Current transition of pentacene OTFT with the application of V_g pulse of 1 kHz (20 V).

study we paid attention to the latter component. The energy parameters of charge trapping were analyzed by the measurement varying V_g and temperature systematically. V_g was changed from the transistor off-state ($V_g = 0$ V) to the on-state ($V_g = -10$ to -40 V) at $t = 0$, and this condition was maintained for 2 s, while the source drain voltage (V_{sd}) was kept constant ($V_{sd} = -1$ V). The interval between the measurements was more than 1 min for initialization.

The current decay of OTFTs fabricated under different conditions was measured (gray solid lines in Fig. 2). A clear difference was observed between the devices with and without the β -PhTS treatment. The hydrophobication of the SiO_2 surface by β -PhTS causes the OTFTs to be more stable. On the other hand, there was little difference in current instability between the devices with different deposition rates and grain sizes of pentacene. The importance of the insulator surface condition for the stability of OTFTs has been previously indicated.^[1] However, there has been no report of the effect of grain boundaries on the stability of OTFTs, although the grain boundaries are affected by the surface condition. In this study, the grain boundaries were found to have little influence on the stability of OTFTs. These results indicate that traps related to the instability of the OTFTs are not located at the grain boundaries of pentacene, but are located at the interface between the insulator and organic semiconductor layers.

The current decay in this experiment exhibited typical

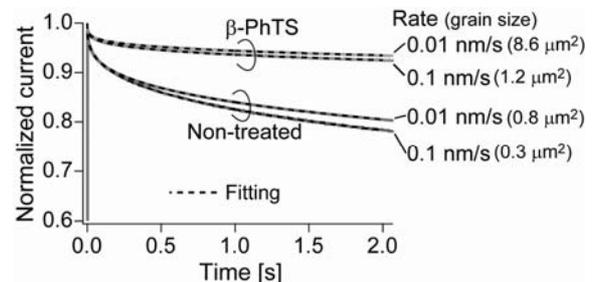


Fig. 2 Gray solid lines indicate experimental results of the time dependent I_{sd} decay under step V_g (-40 V) and at constant V_{sd} ($= -1$ V) for the OTFTs fabricated under four different conditions (substrate treatment and deposition rate). Typical grain sizes of pentacene thin films are also shown. Dashed lines indicate fitting to the experimental data using the stretched exponential function.

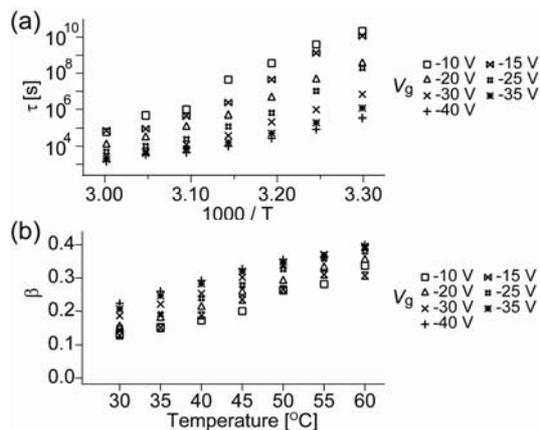


Fig. 3 (a) Arrhenius plot of the time constant τ . (b) Temperature dependence of β .

features of bias stress instability, which can be fitted by a stretched exponential function (dashed lines in Fig. 2).

$$I = I_0 \exp\left\{-\left(t/\tau\right)^\beta\right\} \quad (1)$$

where I_0 is the initial current at time $t = 0$, τ is the time constant, and β is a factor for the stretched exponential. The τ (10^2 - 10^{10} s) is longer than the time domain of this experiment (10^{-3} - 10^0 s) by several orders of magnitude. The small values of β (~ 0.1 - 0.4) result in the quick decay of the current, even if the time is much shorter than τ . The temperature dependence of τ and β (Figs. 3(a) and (b)) agrees with the conventional model of bias stress instability for thin film transistors.^[3] That is, the τ follows an Arrhenius-type temperature dependence, and β increases linearly with temperature.

$$\tau = \tau_0 \exp(E_\tau / k_B T) \quad (2)$$

$$\beta = T/T_0 - \beta_0 \quad (3)$$

E_τ and T_0 are related to the energy parameters of the charge trapping process, although the physical meaning of β_0 is still not clarified. The activation energy, $E_a (= \beta E_\tau)$, and the width of the energy distribution, $k_B T_0$, were extracted from the experimental results (Figs. 4(a) and (b)). The charge trapping mechanism is discussed below, with respect to the temperature dependence analysis.

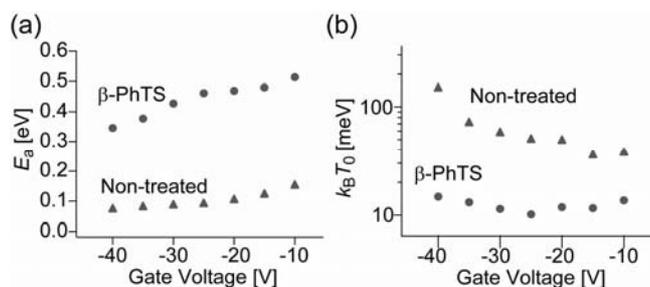


Fig. 4 (a) Effective trapping barrier ($E_a = \beta E_\tau$) extracted from the experimental results (Fig. 3(a)). (b) Energy parameters, $k_B T_0$, determined from the experimental results (Fig. 3(b)).

Two different models have been proposed to explain the mechanism of the current instability, both of which result in the same stretched exponential function. One model is an exponential energy distribution of trap states and the other is an exponential distribution of trapping barriers. The latter model was also proposed for amorphous Si thin film transistors, and was thought to be an effect of Si dangling bonds. In this study, the higher E_a in the β -PhTS-treated device than that in the non-treated device results in more stable operation. This result supports the latter model, where E_a and $k_B T_0$ correspond to the effective energy barrier height and barrier distribution, respectively. Therefore, the energy barrier height variation of the trap site should be considered.

The effective activation energy E_a of the β -PhTS treated device is several times higher than that of the non-treated device. The width of the barrier energy distribution, $k_B T_0$, of the β -PhTS treated device is smaller than that of the non-treated device. The density of barrier heights was shifted to the higher energy region and was less distributed when the surface was treated with β -PhTS. As a result, charge trapping is suppressed and the device becomes more stable. The importance of the insulator surface for the stability of OTFTs was clarified from the analysis of trapping barrier energies.

3. Conclusions

The current instability of pentacene OTFTs was studied. The charge trapping energy was quantitatively analyzed from the results of temperature dependent current decay. The model of energetically distributed trapping barriers was determined as being applicable to the current instability of OTFTs. The barrier energy distribution depends on the treatment of the insulator surface, whereas, it has small dependence on the pentacene film morphology. The average barrier height was increased and less distributed when the substrate was treated by β -PhTS, which suppresses charge trapping.

References

- [1] D. Kumai, M. Yahiro, Y. Inoue, and S. Tokito, Appl. Phys. Lett. **90**, 133511 (2007).
- [2] T. Miyadera, M. Nakayama, and K. Saiki, Appl. Phys. Lett. **89**, 172117, (2006).
- [3] S. G. H. Mathijssen, G. J. Mathijssen, M. Colle, H. Gomes, E. C. P. Smits, B. de Boer, I. McCulloch, P. A. Bobbert, and D. M. de Leeuw, Adv. Mat. **19**, 2785 (2007).