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Contact-correlated Bias Stress Instability in Pentacene Thin Film Transistors

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1. Introduction

The bias stress (BS) effect and the large contact resistance (R_C) are two remaining problems to be solved for practical applications of organic thin film transistors (OTFTs). The former is the feature of drain current (I_D) change with prolonged operation time, which has a great influence on the operation stability of OTFTs. The latter can greatly limit the device performance, especially for short-channel OTFTs. Although extensive studies on the BS effect and on R_C in OTFTs have been reported, there is a lack of investigation probing the relation between the BS effect and R_C. We report the observation in pentacene TFTs that R_C is changing during the BS measurements, and the effect of the R_C change (ΔR_C) on the I_D decay can even exceed that of the channel resistance (R_{ch}) change (ΔR_{ch}) arising from the threshold voltage (V_T) shift (ΔV_T). The OTFTs with different contacts show very similar channel properties including R_{ch} and ΔR_{ch}, whereas the copper (Cu) contact has much smaller R_C and ΔR_C than the corresponding gold (Au) contact. The results suggest that the BS effect in pentacene OTFTs may result from the hole trapping into the deep trap states in both the contact and channel regions.

2. Experimental

The pentacene OTFTs were fabricated on heavily-doped silicon substrates with 200 nm silicon dioxide (SiO_2) layers. After cleaning, the substrates were coated with a self assembling monolayer of β-phenethyltrichlorosilane (β-PTS). The pentacene thin films with 40 nm thickness were subsequently deposited in high vacuum, where the deposition rate was kept at 0.1 Å/s. Finally, seven transistors having an identical channel width (W = 750 μm) and varied channel lengths (L = 50–350 μm with 50 μm interval) [1], were defined by the deposition of Cu or Au top electrodes. Note that all the processes except the final metal deposition were performed at the same time. The BS measurements (in dark, room temperature) were carried out in a high vacuum probe system, employing a sequence of (1) initial transfer characteristics scan (V_{DS} = –1 V, t = 0 s), where V_{DS} is the drain bias and t is the time, (2) continuous I_D measurement at ON state for 1000 seconds, and (3) final transfer characteristics scan (V_{DS} = –1 V, t = 1000 s). The different channels in Fig. 1(a) were measured one by one, with a recovery time (V_{GS} = V_{DS} = 0 V) of over two hours after each BS measurement, where V_{GS} is the gate bias. The examples of the normalized I_D decay for the OTFTs with different contacts are shown in Fig. 1, the Cu OTFTs show higher stability than the Au ones.

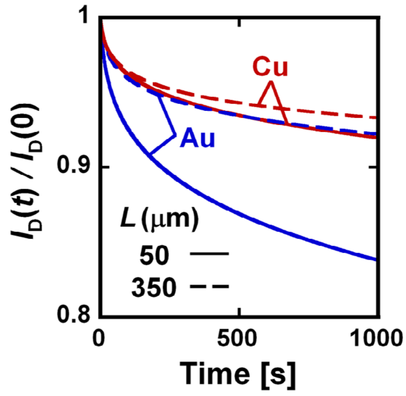

Fig. 1 Normalized drain current decay of Cu and Au OTFTs with 50 or 350 μm channel length.

3. Results and Discussion

In the contact region, R_C is precisely obtained at each time point using the transfer line method (TLM) [1]. Figure 2 shows the initial (t = 0 s) and stressed (t = 1000 s) R_C for the Cu and Au contacts, and it is apparent that R_C is increasing during the BS measurements.

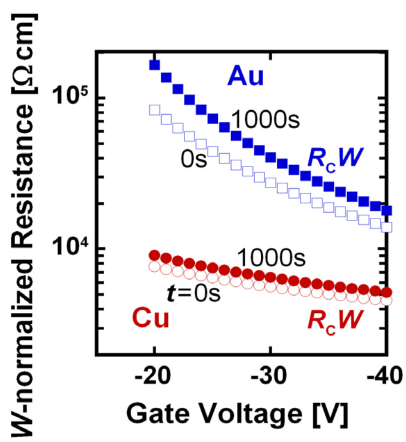

Fig. 2 Normalized contact resistance of Cu and Au contacts at initial state and after 1000s bias stress.

In the channel region, V_T can be considered as a measurement of the surface density of deeply trapped charges [2]. The time dependence of contact-corrected ΔV_T of a Cu TFT is shown in Fig. 3(a), and the corresponding Au TFT shows the very similar dependence and magnitude of ΔV_T. The appearance of the logarithm relation implies ΔV_T becomes slower and slower with time, it may be due to a growing potential barrier for the deep charge trapping [2]. On the other hand, ΔV_T increases with stressing V_{GS}, as shown in Fig. 3(b). This feature can be explained with higher charge density leading to faster deep trapping.

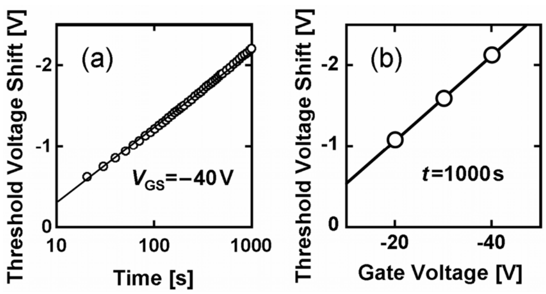

Fig. 3 Time dependence (a) and stressing gate bias dependence (b) of threshold voltage shift under bias stress.

Therefore, I_D in the linear regime can be described as Eq. (1).

$$I_D(t) = \frac{V_{\mathrm{DS}}}{\dfrac{L}{WC_i\left[V_{\mathrm{GS}} - V_{T0} - \Delta V_T(t)\right]\mu_{\mathrm{ch}}} + R_{C0} + \Delta R_C(t)} \tag{1}$$

where L, W, C_i, μ_{ch}, V_{T0} and R_{C0} are the channel length, the channel width, the capacitance per unit area of the insulating layer, the channel mobility, the initial V_T and R_C, respectively. That is, the I_D decay under BS results from the combination of the contact resistance change and the threshold voltage shift in the channel.

4. Conclusions

Bias stress instability in pentacene thin film transistors was observed to be correlated not only to the channel, but also to the metal/organic contact. The BS effect is a total effect of ΔV_T in the channel region and ΔR_C in the contact region. The results suggest that the time-dependent charge trapping into the deep trap states in both the contact and channel regions is responsible for the BS effect in organic thin film transistors.

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References

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