Study on the characteristics of the organic thin-film transistors according to the gate electrode surface treatments

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Abstract

In this report, the effects of chemical surface treatments of ITO gate electrodes of OTFTs have been studied by using acid and base solutions. As a result, it is observed that the threshold voltage of OTFTs could be influenced and modified by the surface treatments. The device with an ITO gate electrode surface-treated by a base solution shows the lowest threshold voltage of -7.66 V, while the threshold voltages are about -13.51 V and -15.3 V for the devices without a surface treatment and with the acid solution treatment, respectively. It is thought that the work function of ITO electrode surface might be affected by the surface treatments, thereby influencing the threshold voltage.

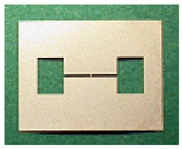
1. Introduction

Organic thin-film transistors (OTFTs) are considered to be of great importance in the area of flexible, large-area, and low-cost applications [1, 2]. At the early stage of research for OTFTs, many groups had made OTFTs with inorganic insulators, such as SiO_2, SiN_x, and so on. But recently, inorganic insulators are being replaced by polymeric materials due to some problems associated with manufacturing complexity and compatibility with plastic substrate, and processing cost. However, the operating voltage of OTFTs is quite high for the practical use. The key to low voltage operation is the reduction of threshold voltage [3]. This transistor parameter could be controlled by the workfunction of gate electrode. However, different values of workfunction of ITO thin film have been reported in the literature, ranging from 4.1 to 5.5 eV [4, 5, 6]. This discrepancy is well known for many metal oxide semiconductors and it has been documented that the workfunction is extremely sensitive to the state of surface [7], and other surface treatments such as plasma treatments [8] of grafting of molecules [9, 10] induce important changes in the workfunction. In this work, the effect of the acid and base surface treatments of the gate electrode on the OTFT characteristics, which can be utilized for controlling of the gate electrode workfunction.

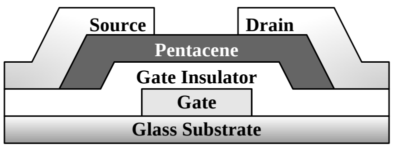
2. Experimental

The samples of 100-nm-thick ITO film on the glass substrate with a resistivity of 20 Ω/□ were supplied by LG.PHILIPS LCD. The samples were cleaned by an ultrasonic bath in acetone, iso-propyl alcohol, and distilled water in sequence. After drying under a dry nitrogen flow, the ITO samples were baked in a vacuum dry oven at 180 ℃ for 20 min.

For the surface treatment on ITO, an ITO-coated glass substrate was dipped in phosphoric acid solution for the acidic treatment or in tetrabutylammonium hydroxide solution for the base treatment. After the base treatment, followed by rinsing with ultra-pure water, and then dried at 175 ℃ for 40 s for cleaning remnant. And 4800 Å-thick cross-linked PVP as gate insulator was formed by spin-coating and baked at 175 ℃ for 1 hr. in a vacuum dry oven. Pentacene thin film as an active layer was thermally evaporated through the shadow mask onto the insulator at a rate of 0.5 Å/s and it thickness was about 60 nm. Subsequently, a 40 nm-thick Au layer as source/drain electrodes were thermally evaporated through the electro-plating mask as shown in figure 1(a). All deposition processes were carried out at a pressure of about 1×10^{-6} Torr. All the fabricated OTFTs have the top-contact structure, where the channel length (L) and width (W) are 90 µm and 200µm, respectively. The cross-section of fabricated OTFTs was shown in figure 1(b).



(a)

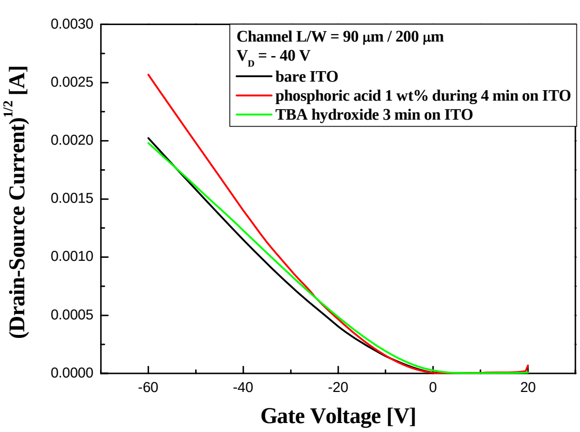


(b)

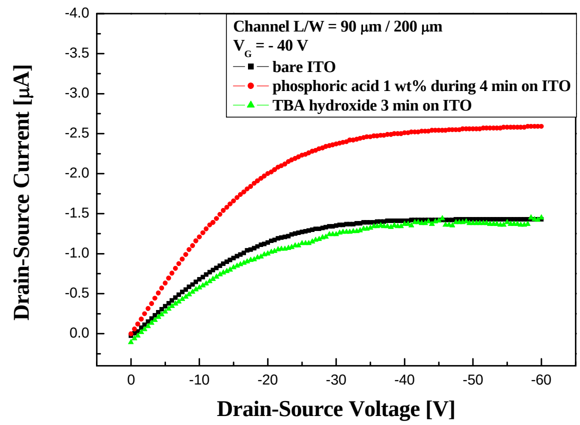
Fig. 1. The schematic of (a) the electro-plating mask and (b) the fabricated OTFT

3. Results and discussion

The dielectric constant of the cross-linked PVP was measured about 4.2. The transfer and output characteristics of OTFTs with and without surface treatments are shown in figure 2. The figure 2(c) shows the gate current configurations of OTFTs with different gate electrode surface treatments. It appeared that the gate current of the device with the acid treated gate is lower than those of the other devices in the large gate voltage region. So the drain current and mobility of the device with the acid treated gate was the largest. It is thought that the strong surface acidity of the treated ITO reduces surface dipole-moments of the insulator and the current to the gate electrode was blocked.



(a)



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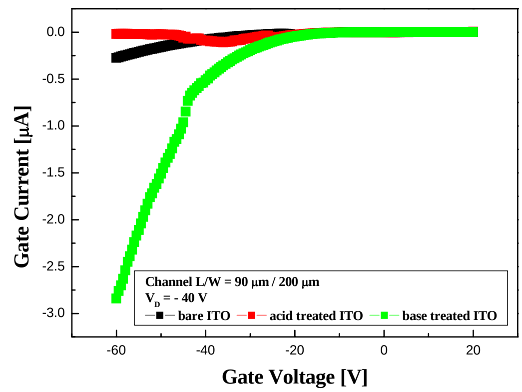

(C)

Fig. 2. (a) Transfer characteristics of root-scale (b) Output characteristics and (c) comparison of gate current.

The important device parameters are listed in Table 1. From the curve of the square root of I_D versus V_G, field effect mobility (μ_{eff}) in the saturation region is estimated using eq. (1):

$$I_{D,sat} = \frac{W \mu_{eff} C_i}{2L} (V_G - V_T)^2 \quad (1)$$

where C_i is the capacitance of gate insulator per unit area, V_T is the threshold voltage of the OTFT. Nüesch *et al.* have reported that the huge shifts in the workfunction are obtained with the ITO surface treatments with bases and acids, which were confirmed with ultraviolet photoelectron spectroscopy (UPS) [11]. These results indicated that the threshold voltage reduction of the OTFT with the base treated ITO gate was caused by change the workfunction of gate electrode.

TABLE 1. Properties of OTFTs with different surface treatments on ITO

	V_T [V]	S.S [V/dec]	on/off ratio	mobility [cm^2/Vs]
Bare	-13.51	1.77	4.93×10^5	0.22
Acid	-15.3	1.23	1.77×10^6	0.39
Base	-7.66	3.29	2.86×10^5	0.16

The threshold voltage can be expressed as the equation (2) for the ideal metal-oxide semiconductor (MOS) structure,

$$V_T = \Phi_{ms} - \frac{Q_i}{C_i} - \frac{Q_d}{C_i} + 2\phi_f \quad (2)$$

where Φ_{ms} is the metal-semiconductor workfunction potential difference, Q_i is total interface charge. The change of the workfunction of the gate electrode surface with the chemical surface treatments must be the decisive factor in the threshold voltage in our study.

For observation of influence on the interface charge, the measurements of bare and base treated devices were carried out on the hot-plate. It was based on a fact that thermal energy affected the interface charge density, not the workfunction of the gate metal. Then we were able to observe that V_T shift variation of bare and base treated devices with the applied temperature is negligible, which, in our study, means that interface charge have little influence on threshold voltage.

Obviously, the important workfunction shifts are not due to a profound modification of the ITO bulk material. However, the observations are consistent with the formation of an adsorbed surface dipole layer. The strong dipole-moment in the insulator was caused by the surface treatments, and then hole accumulation at the pentacene-insulator interface was easily induced, so the threshold voltage was lowered.

4. Summary

We have fabricated the OTFTs with different surface treatments on gate electrode for lowering threshold voltage. The treatment method is very simple as dipping in acid or base solution and the threshold voltage of OTFTs with base treated ITO was lowered to about half of that of OTFTs with the bare ITO. It is expected that the result of this study could be applied to the general practice of controlling OTFT parameters. However, there are still some problems associated with preventing the gate leakage current in the base treated device. Our effort to develop a high-performance treatment method excluding such leakage current is in progress.

5. Acknowledgement

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6. References

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