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Effects of Deposition Pressure on the Characteristics of Organic Thin-Film Transistors Fabricated with Film Profile Engineering

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Abstract

In this work, we examine the feasibility of a new film profile engineering (FPE) concept in the fabrication of organic thin-film transistors (OTFTs) with submicron channel length. The FPE scheme utilizes a suspended bridge and specific deposition tools to deposit thin films with desirable profiles. In order to form a continuous pentacene channel under the bridge, the background N_2 pressure of thermal evaporator is essential and must be sufficiently high. The results show that, by setting the N_2 pressure at 3 mtorr, functional operations of OTFTs can be obtained.

1. Introduction

OTFTs have attracted considerable attention because of their potential on electronic devices and displays, such as switching devices for AMFPDs, low-end smart cards, and electronic identification tags [1]-[4]. To improve the performance of devices such as on-current and operation speed, down scaling of the channel length is desired. Recently we've reported a new concept dubbed film profile engineering (FPE) for device fabrication. In the proposed scheme the film profiles of gate oxide, channel, and source/drain (S/D) contact layers can be tailored independently and specifically. This concept has been demonstrated with the fabrication of ZnO TFTs [5]. In this study, we further examine the feasibility of this idea in the fabrication of organic TFTs with a pentacene channel and show that the background N_2 pressure plays a key role for the successful operation of the fabricated devices.

2. Device fabrication

The process flow for fabricating the pentacene TFTs is shown in Fig. 1(a). The n-type Si wafer is used as the back gate. First, a 400nm-thick sacrificial oxide and a 200nm-thick poly-Si were sequentially deposited on the Si substrate by LPCVD. The poly-Si was patterned by an I-line stepper to define the S/D regions of the device, flowed by the stripping off of the sacrificial oxide to free the suspended the poly-Si bridge. Next, a nominally 50nm-thick oxide was deposited as the gate dielectric by PECVD under a pressure of 500 mtorr. Afterwards the pentacene channel was deposited by thermal evaporator with nominal thickness of 150 nm. Before the deposition the evaporator was filled with pure N_2 gas at atmosphere and we adjusted the base pressure of the chamber by pumping down to a specific value. In this work, the N_2 was pumped to 3 mtorr or $5x10^{-6}$ torr in order to verify the impact of the pressure. Finally, a 100nm-thick Au layer was deposited by evaporation at 5×10^{-6} torr in the same chamber to form S/D metal pads.

3. Results and discussion

Fig. 2(a) shows the transfer characteristics of the fabricated OTFTs. The two devices compared in this figure are with the pentacene channel deposited at background N_2 pressures of 3 mtorr and $5x10^{-6}$ torr, respectively. From this figure it is clearly seen that the value of the background N_2 pressure is the key for the successful operation of the devices with on/off current ratio $>10^6$, saturation field-effect mobility of 0.02 $cm^2V^{-1}s^{-1}$, and sub-threshold swing of 371 mV/dec. In contrast, the other one deposited with an ultra-low pressure of 5×10^{-6} torr fails to show switching behavior and the drain current is solely contributed by the gate leakage. In Fig. 2(b), the output characteristics of the functional device are shown.

To explain the above observations, we depict the schematic diagrams shown in Figs. 3(a) and (b) to describe the scattering mechanisms during the evaporation of pentacene channel at the relatively low and high deposition pressures, respectively in the thermal evaporator. In Fig. 3(a), the ultra-low pressure ensures a long mean free path so that the vaporized pentacene species transporting from the heated source to the substrate essentially encounter no scattering. As a result, the deposited species are shadowed by the suspended bridge and the resultant pentacene channel is disconnected. In Fig. 3(b), for the case with the deposition pressure increases to 3 mtorr, the density of nitrogen molecules in the air rises accordingly. Scattering rate of the evaporated pentacene species is thus greatly enhanced. The portion of the scattered species into the region underneath the bridge allows the formation of a continuous petancene channel between the source and drain regions, as illustrated in Fig. 3(b).

To understand more about the effects of the dimension of the suspended bridge on the device characteristics, we've also characterized devices of various L with the pentacene channel deposited at 3 mtorr. For devices with L of 0.6 μm or shorter, successful switching operation is obtained. The remaining devices with L of 0.8 μm or longer show no turn-on behaviors. The observed trend indicates that a sufficiently long bridge would effectively prohibit the collided pentacene species from diffusing into the regions beneath the bridge for forming a continuous channel film. The structure-dependent device characteristics highlight the important role of the length of the suspended bridge in the fabrication of FPE OTFTs.

3. Conclusions

We have developed a method which incorporates FPE concept to fabricate pentacene-based OTFTs with submicron channel length. The deposition of pentacene channel was carried out in a thermal evaporator with an adjustable background N_2 pressure. The results indicate that the background N_2 pressure is essential. For forming a continuous channel under the suspended bridge, the background N_2 pressure must be sufficiently high to enhance the scattering rate of the vaporized pentacene species. Another major parameter is the length of the suspended bridge which must be short enough to enable the formation of a continuous channel.

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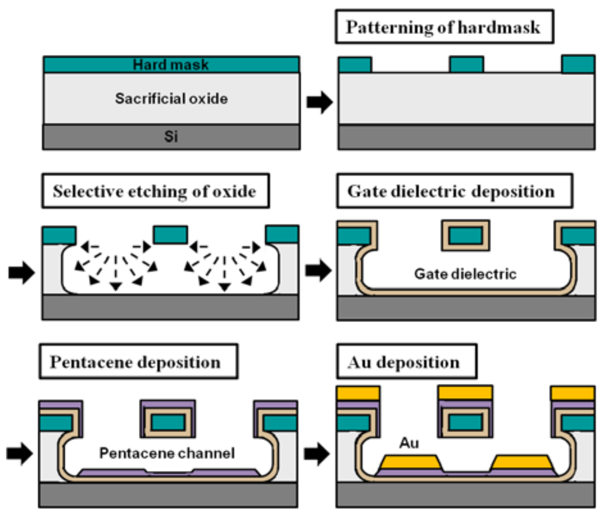

Fig. 1 The process flow for fabricating the organic TFTs with a pentacene channel.

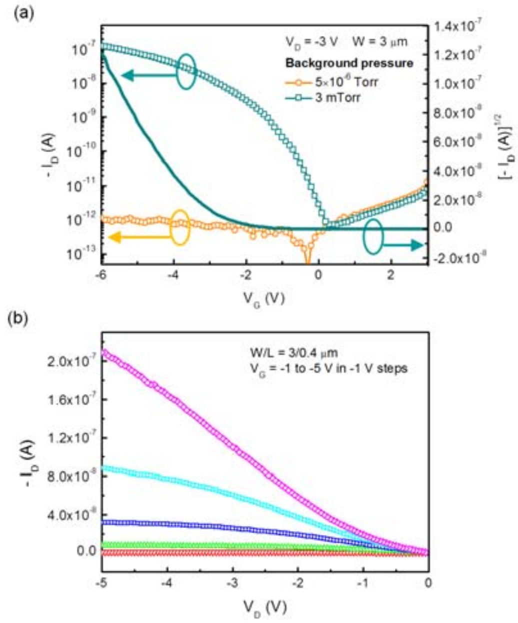

Fig. 2 (a) Transfer characteristics of two fabricated devices with different background N_2 pressures. (b) Output characteristics of the device with background N_2 of 3 mtorr.

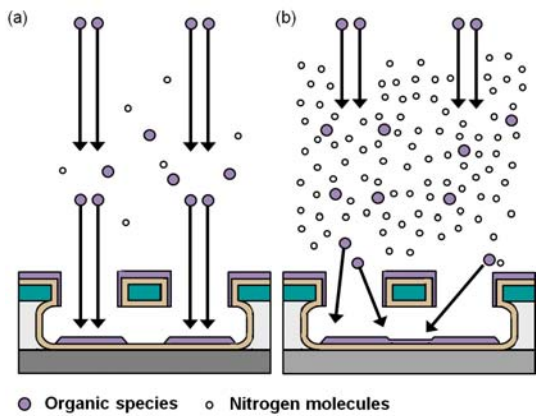

Fig. 3 Schematic diagrams showing the deposition of pentacene channel at (a) low and (b) high background N_2 pressures.

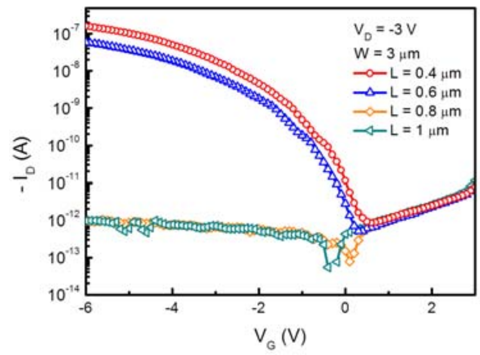

Fig. 4 Transfer characteristics of OTFTs with various channel lengths.