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Evaluation of Pentacene Thin Films Fabricated on Sio_2 Surface Modified by Phenyl-Radical

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We fabricated pentacene OTFTs with chemically modified SiO_2 surface by phenyltrichlorosilane (PTS), and studied the molecular ordering of the pentacene films and electrical characteristics of the OTFTs. The molecular ordering of the pentacene thin film was improved by PTS treatment. We also fabricated organic thin film transistors with phenyltrichlorosilane treatment. The carrier mobility of the transistor with PTS treatment was $3.7 \times 10^{-2} cm^2/Vs$, it was larger than that of the transistor without PTS treatment ($2.0 \times 10^{-2} cm^2/Vs$). We believe that this improvement of the μ value was due to improvement of the molecular ordering by PTS treatment.

Keywords: OTFT; pentacene; phenyl-radical; Phenyltrichlorosilane

1. INTRODUCTION

Pentacene is an attractive candidate for organic thin film transistors (OTFTs) because pentacene OTFTs have relatively high carrier mobility [1–4]. Carrier mobility is very sensitive to the morphology of organic films [5]; therefore, to further improve their performance a greater understanding and control of the molecular ordering and roughness of organic films is required. The morphology of organic thin films fabricated by thermal evaporation is controlled by the surface chemistry of the gate insulators [6,7]. A self-assembled monolayer (SAM) modification changes the surface chemistry of a gate insulator

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surface from hydrophilic to hydrophobic, leading to an improvement in the molecular ordering of the pentacene thin films [7–9].

In this study we fabricated pentacene OTFTs with chemically modified SiO_2 surface by phenyltrichlorosilane (PTS), and studied the molecular ordering of the pentacene films and electrical characteristics of the OTFTs. We expect that the PTS surface have phenyl-radical and thus more smooth interface structure transition between pentacene can be possible.

2. EXPERIMENTAL

We modified SiO_2 surface by PTS based on the method introduced on reference 10). Heavily n-doped Si substrates with a thermally oxidized SiO_2 dielectric layer 300 nm thick were immersed in a 0.5 mM toluene solution of PTS for 10 min in a N_2 atmosphere to form a SAM on the SiO_2 surface. PTS was purchased from Shin-Etsu Chemical Co., Ltd. Then, the substrates were rinsed with toluene, and heated at 100°C for 5 min on a hot-plate in a N_2 atmosphere to remove residual solvent. Figure 1 is a schematic illustration of the top-contact OTFT device we fabricated in this work. Pentacene was purchased from Wako Pure Chemical Industries, Ltd. and was used without further purification. For 120 min, pentacene was thermally evaporated in a vacuum onto a substrate modified by PTS, up to a thickness of approximately 45 nm. Au was also thermally evaporated in a vacuum through a shadow mask to define the source and drain contacts. The channel length and width were 50 μm and 2 mm, respectively. To clarify the effect of PTS, we also fabricated an OTFT under the same conditions but without PTS treatment. We estimated the carrier mobility and threshold voltage of the OTFTs. We also studied the molecular ordering of the pentacene thin films by atomic force microscopy (AFM) and X-ray diffraction (XRD).

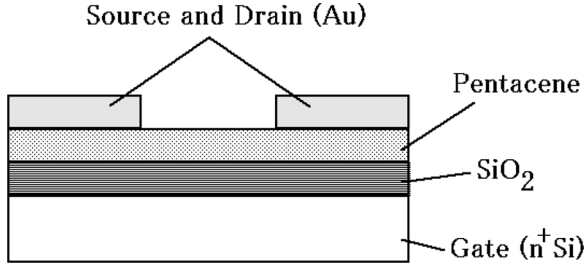

FIGURE 1 Schematic illustlation of the top-contact OTFT device.

3. RESULT AND DISCUSSIONS

Figure 2 shows AFM images for the 10 nm-thick pentacene films with and without PTS treatment. In both films we observed pentacene islands. There is no difference in size and shape of the pentacene islands between both films. However, we can see a difference in the size of the pentacene grain when the thicknes of the pentacene films are 45 nm, as shown in Figure 3. The pentacene film without PTS treatment is composed of slightly small grain compared with the pentacene film with PTS treatment, but significant change of the grain size was not observed.

Figure 4 shows XRD patterns for the pentacene films with and without PTS treatment. The thickness of the films was 45 nm. The XRD peaks correspond to the Miller indices (001), (002), (003), and (004), respectively. In both films, a thin film phase was observed [11,12]. We can see the obvious difference between with and without PTS treatment although it was hard to see the obvious difference in AFM. It is notable that the intensity ratio in the XRD signal of the pentacene film with PTS treatment is two-times larger than that of the film without PTS treatment. The results of AFM and XRD demonstrate that the PTS treatment improved the molecular ordering of individual grains, but it hardly effect the grain size of pentacene.

Figure 5 shows the drain current vs. source/drain voltage (I_D-V_{DS}) characteristics of the OTFTs measured in air. The devices have typical

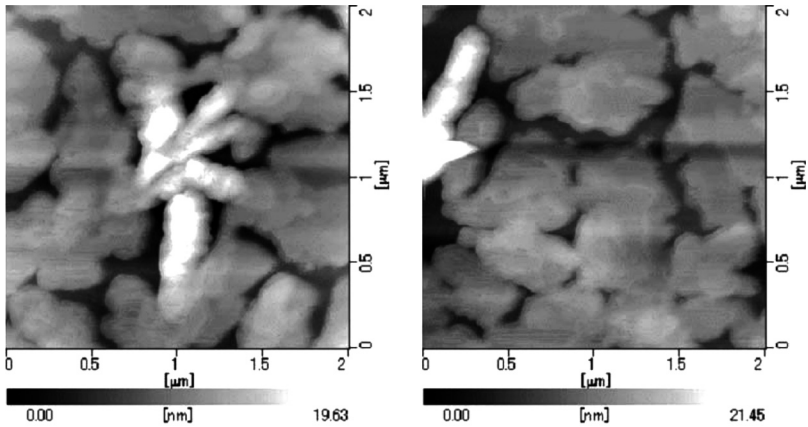

FIGURE 2 AFM images of the pentacene films (10 nm) (a) with and (b) without PTS treatment.

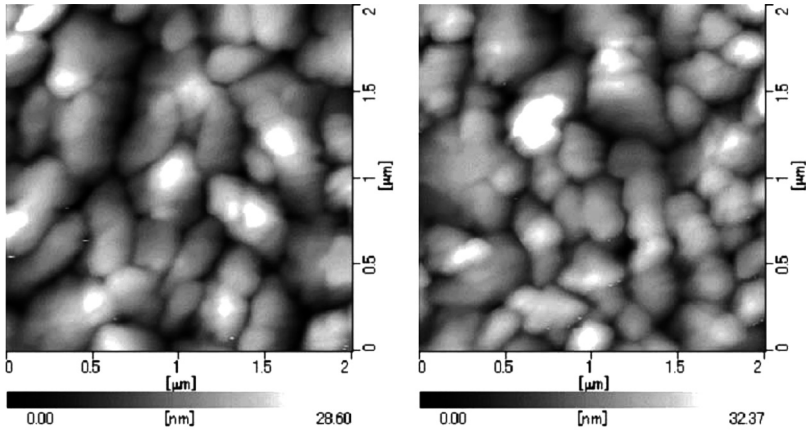

FIGURE 3 AFM images of the pentacene films (45 nm) (a) with and (b) without PTS treatment.

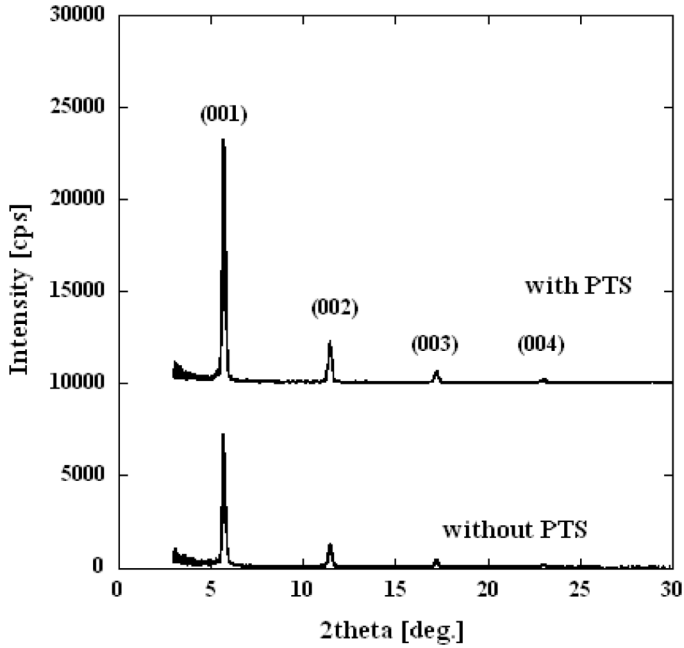

FIGURE 4 XRD patterns of the pentacene films with and without PTS treatment.

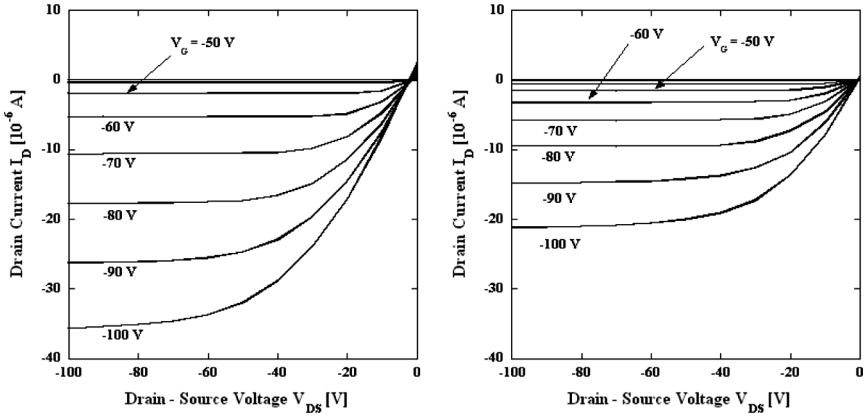

FIGURE 5 I_D-V_{DS} characteristic of the OTFTs (a) with and (b) without PTS treatment measured in air.

p-channel field effect transistor (FET) characteristics. From these curves, we estimated the threshold voltage, V_{th}, and carrier mobility, μ, of these OTFTs. The V_{th} and the μ were estimated to be -34 V and $3.7 \times 10^{-2}\,cm^2/Vs$ for the PTS treated film, and -31 V and $2.0 \times 10^{-2}\,cm^2/Vs$ for the untreated film. The μ value of the OTFT with PTS treatment was about two-times larger than that of the OTFT without PTS treatment. We believe that this improvement of the μ value was due to improvement of the molecular ordering by PTS treatment.

4. CONCLUSION

We fabricated a pentacene/PTS/SiO_2 structure OTFT. The carrier mobility, μ, of the film was approximately twice that of an OTFT similarly prepared but without PTS treatment. We believe that this improvement of the μ value was due to improvement of the molecular ordering of individual grains by PTS treatment. From these results, we conclude that the PTS is one of the effective SAM materials to improve the performance of the pentacene OTFTs.

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