Growth of Pentacene Film on Rough Surface with Conic-Nanostructures and Thin-Film Transistor Performance

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Abstract

We report the effects of conic- nanostructures on the growth of pentacene film. The pentacene film deposited on the rough surface with conic-nanostructures maintained the thin-film phase without its degradation up to *003* direction, compared to that without nanostructures, indicating that conic-nanostructures are conducive to the upright growth of pentacene molecules to the substrate. Furthermore, pentacene thin-film transistor (TFT), introduced these structures into the interface between the pentacene layer and gate insulator, achieved a pronounced improvement in the field-effect mobility by about three times. These results clearly demonstrate that conic-nanostructures can contribute to the ordered growth of pentacene molecules for high-performance OTFTs.

1. Introduction

Organic thin-film transistors (OTFTs) have received much interest due to their advantages such as simple process, flexibility, and printable characteristics [1,2]. Extensive research effort on OTFTs have dramatically improved their performances and the achieved hole mobilities are almost comparable or even surpassing to those of TFTs with hydrogenated amorphous silicon (a-Si:H) [3]. Major influences on the mobility have been the purification, deposition conditions of the organic semiconductor and the properties of the dielectric surface. Variations in the surface chemistry cause large changes in the mobility of OTFTs. In addition, several publications mention a reduction in the mobility owing to an increased surface roughness [4,5]. However, there are still many challenges to improve the performances of OTFTs by modifying the interfacial characteristics between the organic semiconductor layer and the gate insulator. Recently, it has been reported that the growth of organic active materials and device performances were improved by introducing structured morphologies on the surface of gate insulator [6,7], which suggests that the patterned structures, in spite of its rough surface, on the gate insulator can contribute to the growth and the charge transport of the organic semiconductor.

In this work, we have fabricated the conic-nanostructures on the gate insulator and investigated the growth of pentacene molecules on the rough surface with conic-nanostructures, combining with the performance of pentacene-based TFTs. These results are presented.

2. Experimental Details

Pentacene-based organic TFTs with the cross-linked poly(4-vinylphenol) (cPVP) insulator were fabricated. For the fabrication of conic-nanostructures, the H1 solution, in which polyurethane was dissolved into acetone solvent, was spin-coated onto the cPVP-coated substrate, followed by thermal curing at 100°C for 1 h. Fig. 1 (a) shows the atomic force microscopy (AFM) image of the fabricated conic-nanostructures. Its height was estimated to be 30-40 nm. And pentacene (TCI, used without further purification) was thermally evaporated through the shadow mask, up to a thickness of 90 nm. Top-contact/bottom-gate OTFTs were constructed by depositing 50-nm-thick Au source/drain electrodes, where the channel length (L) and width (W) were 50 μm and 300 μm, respectively.

3. Results and Discussion

Fig. 1 (b) and (c) show the AFM images of the pentacene films on the substrates with and without conic-nanostructures, respectively. It is observed that the pentacene film deposited on the rough surface incorporated with conic-nanostructures has a different crystallinity, with smaller grains than the film on the bare cPVP. This result indicates that the growth of pentacene molecules is strongly affected by the conic-nanostructures.

The crystallinity of pentacene film was studied by X-ray diffraction (XRD) (DMAX 2500, Rigaku) with monochromatic Cu Kα (λ = 1.54 Å). From the results, we analyzed the thin-film phase characteristics of the pentacene films according to the interface conditions as shown in Fig. 2. For the pentacene film deposited onto the rough surface with conic-nanostructures, the thin-film phase is well maintained without significant degradation up to *003* direction. This result is of great interest because the rough surface of gate insulator generally deteriorates the ordered growth of pentacene molecules [8]. However, the rough conic-nanostructures fabricated in this study facilitated the upright growth of pentacene molecules to the substrate, which indicates that the morphological modification of the gate insulator surface can open up promising directions for the crystalline growth of organic semiconductors. Systematic studies on the interaction between the conic-nanostructures and pentacene molecules are under investigations.

Figure 3 shows the typical output and transfer characteristics of OTFTs according to the interface conditions. The electrical characteristics for the OTFT with the conic-nanostructures are higher for the device without the nanostructures. Most importantly, the field-effect mobility was significantly improved by using conic-nanostructures. The calculated mobility in the saturation regime was about 2.94 cm^2/Vs for the device with the conic-nanostructures, while that for the device without the nanostructures was about 0.95 cm^2/Vs. We believe that the notable enhancement in the mobility is attributed to the upright growth of pentacene molecules expedited by the conic-nanostructures because the vertical alignment of pentacene molecules to the gate insulator surface provides a strong π-π^* overlap, increasing the electrical conductivity in the channel direction in OTFTs.

4. Summary

In this paper, we have fabricated the conic-nanostructures consisting of polyurethane on the gate insulator, and investigated its effects on the pentacene molecular growth and device performance. The pentacene film deposited on the rough surface incorporated with conic-nanostructure maintained the thin-film phase without significant degradation, indicating that the fabricated conic-nanostructures are conducive to the upright growth of pentacene molecules to the substrate. And also, the OTFT with the conic-nanostructures exhibited improved electrical characteristics. In particular, the enhancement in the mobility was up to three times. Consequently, we suggest that nanostructures formed on the gate insulator can be applied to assist the crystalline growth of organic semiconductor, thereby contributing to improving the performance of OTFTs.

Acknowledgement

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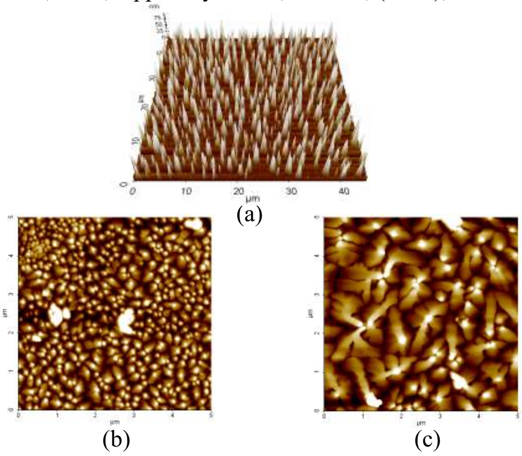

Fig. 1. AFM images of (a) the conic-nanostructures, the pentacene films (b) on the cPVP with conic-nanostructures and (c) on the bare cPVP.

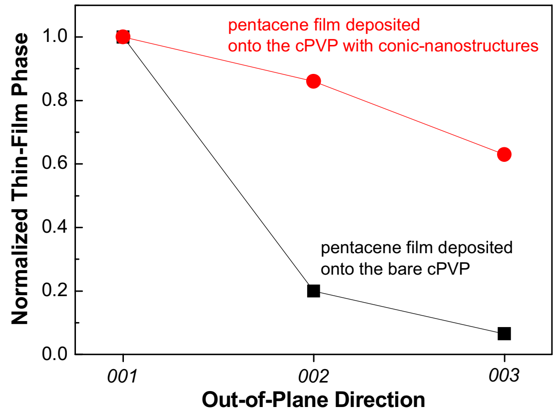

Fig. 2. Normalized thin-film phase characteristics of pentacene films according to different surface conditions.

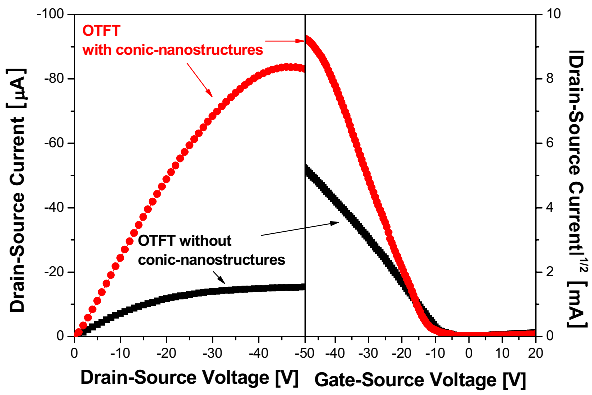

Fig. 3. The electrical characteristics of the fabricated OTFTs with and without conic-nanostructures on the cPVP surface.