Improvement of the Field Effect Mobility by the Nano-scale Structure on Organic Thin Film Transistor

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ABSTRACT

We investigate an effect of nano-scale structures onto an insulating layer in organic thin-film transistor (OTFT). The electrical performance of OTFT could be improved by using source/drain nano-scale structures. The nano-scale structure reduces the contact resistance and thus improves the device performances.

1. INTRODUCTION

Organic thin-film transistors have attracted great interest in the field of organic electronics [1]. In recent decades, the device performances of OTFTs such as field effect mobility, low voltage operation, have shown a remarkable progress. Especially, the field effect mobility is the most important factor dictating the electrical performances of the OTFTs. Recently, it has been reported that the in-plane ordering of the pentacene molecules on a groove-patterned insulator enhances the field effect mobility and gives rise to the mobility anisotropy [2-3]. However, most of studies just focused on the ordering of the organic semiconductor not on the other parameters like how to influence the nano-scale structure on the charge transport across metal-organic interface.

Recently, we reported on the effect of the nano-scale structure on the OTFT performances through the selective nano-scale structure onto the insulating layer, source/drain (S/D) region by decreasing injection barrier height [4]. In this study, we report on the enhanced electrical performance of the OTFTs with forming the nano-scale structure by improving of the electric conductivity. The nano-scale structures, formed in different regions on the insulating layer such as the S/D region and channel region, were prepared by the electron-beam lithography method. In the S/D-region-patterned OTFT, the excellent performances were obtained, which was mainly originated from the enhancement of the carrier injection in the S/D region by the reduction of the contact resistance rather than the carrier flow in the channel region.

2. EXPERIMENT

The schematic structure of top-contact OTFTs with/without nano-scale structures are shown in Figure 1. The devices were built on a glass substrate and gate electrode was thermally evaporated by using an aluminum 70-nm-thick layer on substrate at a basal pressure of about 10^{-6} Torr, a deposition rate of 1.0 Å/s. A polymeric insulator of cross-linked poly (4-vilyphenol) (cPVP), formed from the solution of PVP and poly(melamine -co-formaldehyde) dissolved in propylene glycol mono-methyl ether acetate, was spin-coated on the patterned Al layer and heated at 180 °C for 1 hour in vacuum oven.

For the nano-scale structures onto the gate insulator, the e-beam lithography using ma-N2401 photoresist (Micro Resist Technology, Germany) was carried out with Tescan MIRA-XMH scanning electron microscope equipped with Raith ELPHY Plus beam controller. To investigate an effect of the selective nano-scale structures on the OTFT performances, we prepared three test samples with the line-shaped nano-scale structures at the S/D region, channel region, and a reference sample without line patterns as shown in Fig. 1. The height and the width of the line-shaped nano-scale structures with the period of 1 μm were 100 nm and 200 nm, respectively. A 60-nm-thick pentacene (Tokyo Chemical Industry, Japan) layer was directly thermally evaporated under a basal pressure of about 10^{-6} Torr at a deposition rate of 0.5 Å/s on the insulator. Finally, top-contact S/D electrodes of 50-nm-thick layer were thermally evaporated through a shadow mask with channel length (*L)* of 100 μm and width (*W)* of 300 μm. All the materials used without any further purification.

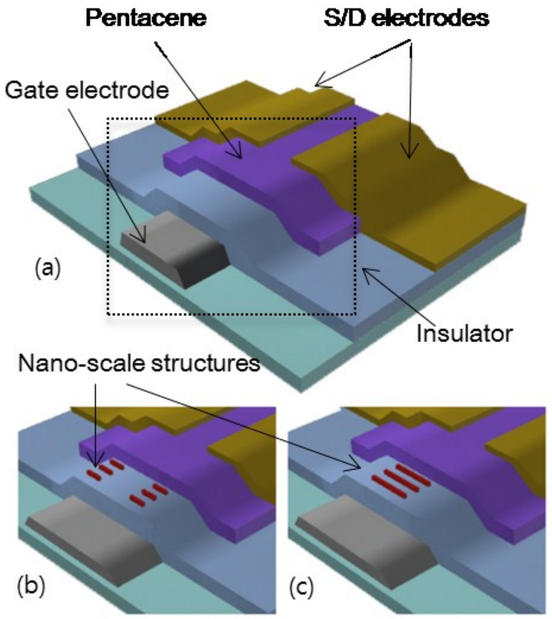


Fig. 1 Schematic diagram of OTFTs with (a) no line patterns and [(b), (c)] nano-scale structures are formed at (b) S/D regions, (c) channel region, respectively

3. RESULT AND DISCUSSTIONS

Figure 2 shows the surface morphologies of the cPVP and the pentacene layers with the nano-scale structures measured by an atomic force microscope (AFM; XE-100, Park system). As shown in Figure 2(a) and (b), onto the insulator layer with the good fidelity of one-dimensional (1D) line shapes and the smaller grains of the pentacene were observed. It should be noted that the grain size of the pentacene layer does not directly reflect the OTFT device performance [5,6]. The anisotropy of the grains are not observed in the AFM image. As reported previously, the anisotropy of grains was introduced if we control the periodicity and size of nano-grid [2]. And we have reported on the effect of nano-scale structures onto insulating layer by decreasing injection barrier height [4]. However, we now study a certain correlation between the device performances and the contact resistance at the metal-semiconductor interface.

The study of the metal/semiconductor/metal (MSM) structures has provided useful information on the electrical conduction mechanism, transport properties, and the carrier injection properties at the metal-semiconductor interface. Especially, the conduction mechanism in OTFTs can be evaluated from the current density-voltage (J–V) curve of hole-only devices with the MSM structure. The J-V characteristics of bottom-Au/pentacene/top-Au device with and without nano-scale line patterns are shown in Fig. 3. It is clearly seen that the electrical characteristics are improved by introducing the nano-scale structures.

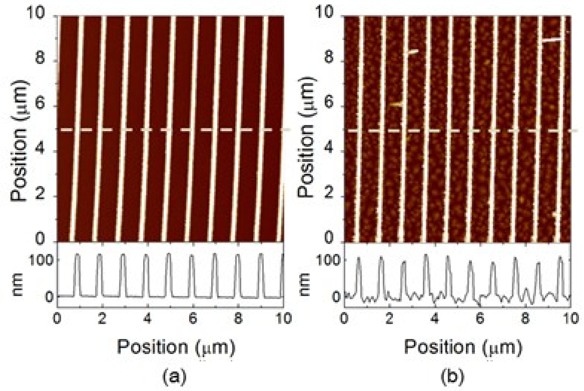


Fig. 2 The AFM images of (a) the line pattern nano-scale structures on cPVP layer (b) the pentacene layer on it with nano-scale structures. The profiles represent the surface morphologies depicted by the dash lines in each AFM image.

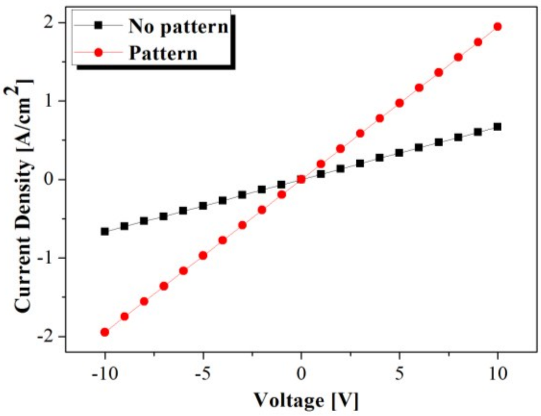
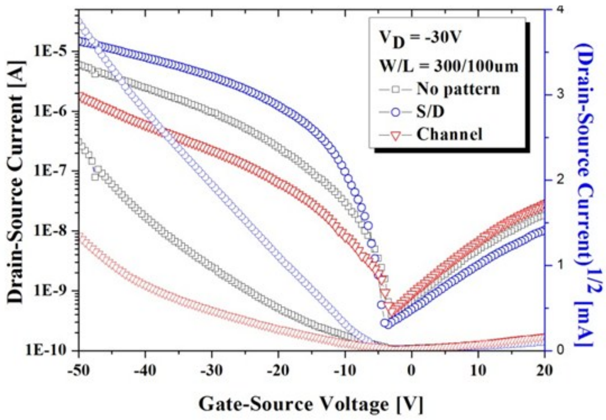


Fig. 3 Current density characteristics on top Au electrode depending on applied voltage for bottom-Au/pentacene/top-Au structure.

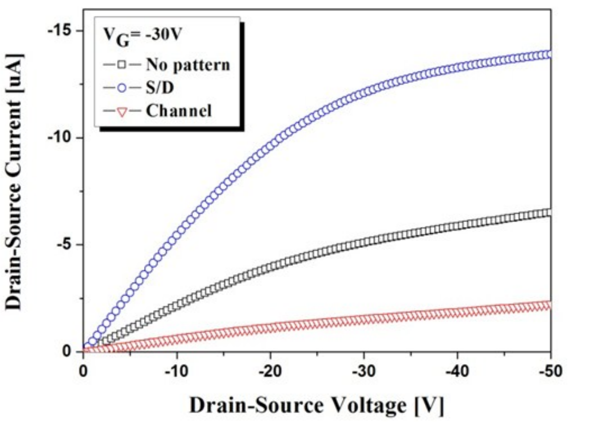
The device with the patterned device showed electrical conductivity value of 2.9 × 10^{-5} S/cm which is larger than that of the no pattern device about three orders. We calculated the electrical conductivity (σ) using eq. (1)

$$\sigma = \frac{L}{R \times S} \tag{1}$$

Here, *R* is the resistance, *S* is the effective area for current flow, and *L* is the thickness of an organic layer [7]. We measured the transfer and output characteristics of OTFTs with/without nano-scale structures at the channel, S/D regions, as shown in Figs. 4(a) and (b). The field-effect mobility μ_{eff} of each transistor was calculated in the saturation regime. The performances of OTFTs are summarized in Table 1, such as field-effect mobility μ_{eff}, threshold voltage V_{th} and on/off current ratio Ion/off of several devices with/without patterns and different regions. The enhancement of μ_{eff} on source/drain nano-scale structured OTFT was clearly observed compared to the device without nano-scale structures. It is thought that the notable enhancement in the μ_{eff} is mainly attributed to the injected carrier on S/D electrodes originated from the reduction of the contact resistance.



(a)



(b)

Fig. 4 Electrical characteristics of OTFTs with/without no line patterns, (a) transfer curves at V_D=-30V, (b) output curves at a V_G=-30V

Table 1. Performances of fabricated OTFTs

Patterned region	μ_{eff} (cm^2/Vs)	V_{th} (V)	$I_{on/off}$
No pattern	0.169	-9.5	1.53×10^4
S/D	0.475	-6.1	5.52×10^4
Channel	0.036	-9.1	5.77×10^3

The μ_{eff} in channel region patterned device decreased seriously compared to the no pattern device. In horizontal direction electric field between the source/drain electrodes induces the current flow in channel region but nano-scale structures work like "valleys" in the channel region [6]. If the holes located in valleys in channel region, horizontal direction electric field cannot affect a charge movement out of the rough valley away from the surface. Therefore, it is thought that OTFT with the nano-scale structure improve the electrical characteristics in Fig 4 and Table 1 might be attributed to improvement of the electric conductivity.

4. CONCLUSIONS

We have investigated the effect of nano-scale structures on OTFTs. We observed that the electrical conductivity could be improved by introducing the nano-scale structures from the current density-voltage (J–V) curve of holes only devices with the MSM structure. For the OTFTs, pentacene films grown on source/drain patterned region showed improved electrical characteristics especially μ_{eff} of no patterned OTFT device. It is thought that the improved device performance was attributed to the improvement of the electric conductivity by increasing the carrier injection in vertical direction electric field.

5. Acknowledgement

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