KLCC 2006, Vol. 1,
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The interfacial anisotropic effect induced on inorganic insulator in organic thin film transistors

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In this paper, we studied interfacial anisotropic effect in pentacene-based organic thin film transistors (OTFTs) on an anisotropic insulator fabricated by obliquely evaporated silicon dioxide. It was observed that the obliquely evaporated gate dielectric layer affected molecular ordering. As the evaporation angle of SiO_2 increased, the anisotropic interaction at the dielectric interface and molecular ordering of evaporated pentacenes increased. We obtained the anisotropic ratio of the field-effect mobility for carriers transported parallel and perpendicular to the evaporation direction was 2.9.

1. Introduction

Organic thin film transistors (OTFTs) are attracting much attention to flexible electronic applications such as flexible display, smart card, and radio frequency identification tag. Recently reported OTFTs demonstrated field effect mobility approached or exceeded the value of hydrogenated amorphous silicon TFTs [1],[2]. So, it is enlarging that expectation for commercial use of OTFTs.

In such a rapid development of OTFT's performances, the results of intensive studies on interfacial properties had an important role. The degree of molecular ordering and crystalline orientation of the organic thin film was proven to be significant factors in determining the performance of OTFTs [3],[4]. In order to enhance molecular ordering and crystalline orientation, there were several efforts to modify interfacial anisotropic properties between the pentacene molecules and the insulator surface. Considering that pentacene is a rigid rodlike molecule similar to the core structure of liquid crystal, it is expected that similar surface-induced order can also be imposed on pentacene [5] such as mechanical rubbing [6], irradiation of polarized UV right [7] on organic insulators.

In this paper, we used the obliquely evaporated silicon dioxide layer as gate insulator in order to align pentacene molecules. As the evaporation angle of SiO_2 increased, the anisotropic interaction at the dielectric interface and molecular ordering of evaporated pentacenes increased. However, in highly obliquely evaporated dielectric surface, it was observed that growth of the pentacene molecules was highly limited due to increased roughness at the interface. The molecular ordering effect and the grain size effect depending on the surface anisotropy and the surface roughness were discussed with the results of the field-induced mobility and the surface morphology.

2. Experimental

Figure 1(a) shows a bottom-gate TFT device with pentacene fabricated on top of anisotropic insulator fabricated by obliquely evaporated SiO_2. The effects of the anisotropic inorganic interface were investigated by oblique evaporation of silicon dioxide with an e-beam evaporator at the angle of 0°, 10°, 20°,and 40° to normal on the thermally grown oxidized surface, as shown Fig 1(b). Then, the 700 Å pentacene film was deposited at a deposition rate of 0.5 Å/s. This film was grown by thermal sublimation at a pressure of 10^{-6} torr and the substrate was held at room temperature during pentacene evaporation. Source and drain contact were formed by evaporation a 400 Å gold layer at a deposition rate of 1 Å/s through a shadow mask.

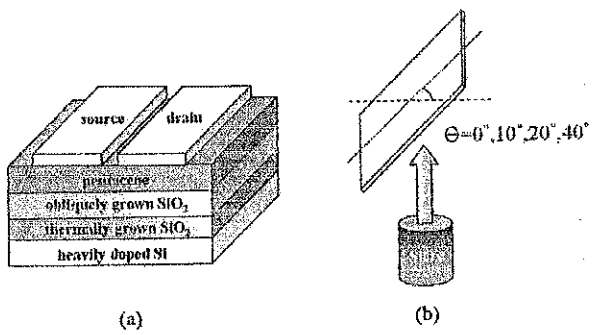

Fig. 1(a) Structure of pentacene-based TFT with an anisotropic inorganic dielectric layer, (b) method of oblique evaporation method.

The channel width and length were 300 μm and 50 μm, respectively. The channels of the transistor were aligned parallel and perpendicular to evaporation direction in order to investigate anisotropic electrical properties, in each condition. The sample which direction of current flow is parallel to direction of the evaporation of SiO_2 is called 'sample A', whereas the sample which direction of current flow is perpendicular to direction of the evaporation of SiO_2 is called 'sample B'. For comparison, conventional OTFT with an isotropic silicon dioxide surface was prepared by thermally grown oxidation with about 1300 Å thick on the heavily doped silicon wafer. The I-V characteristics of the OTFTs were obtained by using a semiconductor test and analyzer in ambient condition. And the carrier mobility of the OTFTs were calculated in the saturation regime by classical theory, which is given

$$I_D = -\frac{1}{2} C_i \mu \frac{W}{L} (V_{GS} - V_{TH})^2$$

for $V_{GS} < V_{TH}$ and $V_{DS} < (V_{GS} - V_{TH})$ (1)

$$C_i = \frac{\varepsilon_0 \cdot \varepsilon_i}{d_i} \quad (2)$$

Where C_i, V_{TH}, and μ are total insulator capacitance, threshold voltage, and carrier mobility, respectively. The surface morphologies of insulator and evaporated pentacene were measured by atomic forced microscope (AFM) in the non-contact mode.

3. Result and Discussion

In order to induce interfacial anisotropy, we fabricated OTFTs with obliquely evaporated SiO_2 at 20° and measured electrical properties. Figure 2(a) shows a plot of the $\sqrt{I_D}$-V_{GS} characteristic for the 'sample A'. When gate voltage increased until -35V, the drain current was measured at -0.24 μA. On the contrary, Figure 2(a) shows a plot for the 'sample B'. And it was obtained three times higher drain current than drain current of 'sample A' at the same gate-source voltage, interestingly. The mobility calculated from the Eq. (1) of the 'sample B' was higher than 'sample A', with values of 5.13 x 10^{-3} cm^2/Vs and 1.49 x 10^{-2} cm^2/Vs, respectively.

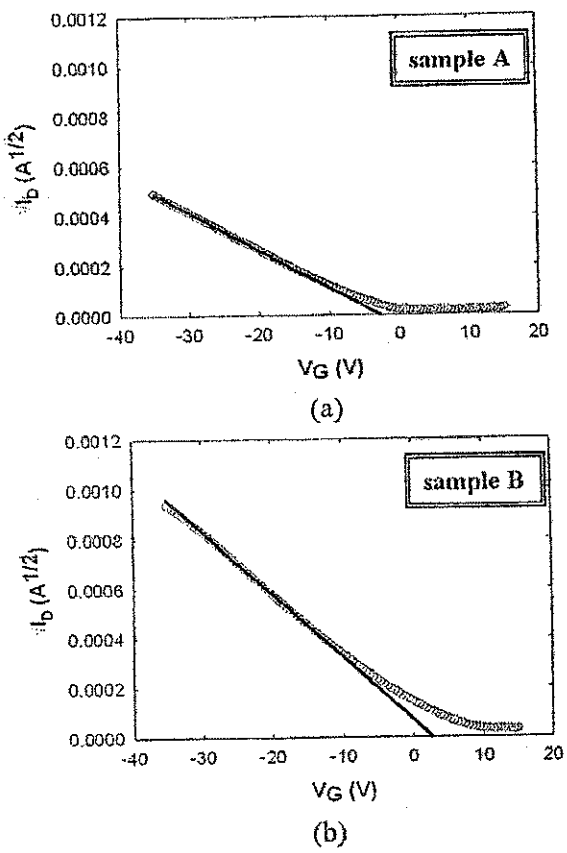

Fig. 2 $\sqrt{I_D}$-V_{GS} characteristics of OTFTs where the oblique incidences of the SiO_2 evaporation at 20° are (a) perpendicular and (b) parallel to the channel direction.

Such mobility difference depending on direction of evaporation was due to anisotropic charge transport induced by interfacial anisotropy. And threshold voltage has no difference in direction of evaporation. It shows that electrical anisotropy is not caused by discrepancy of insulator surface between 'sample A' and 'sample B' samples.

In organic semiconducting material, charges transport by π-π interactions between molecules through the hopping mechanism. During the hopping process, charges propagate along the stacking axis of molecules through their overlapping π-obitals [5]. Accordingly, mobility

difference shows that 'sample A' has more overlapping π-obitals than 'sample B', which means that the anisotropic interface affected molecular ordering of pentacene molecules.

However, when we evaporated SiO_2 at a smaller angle of 10°, there was no electrical anisotropy, as show in Fig. 3. It represents that surface anisotropy which can affect to molecular ordering of pentacene is induced under special condition. Whereas pentacene on SiO_2 obliquely evaporated at 40° has electrical anisotropy but lower mobility than pentacene on obliquely evaporated at 20°.

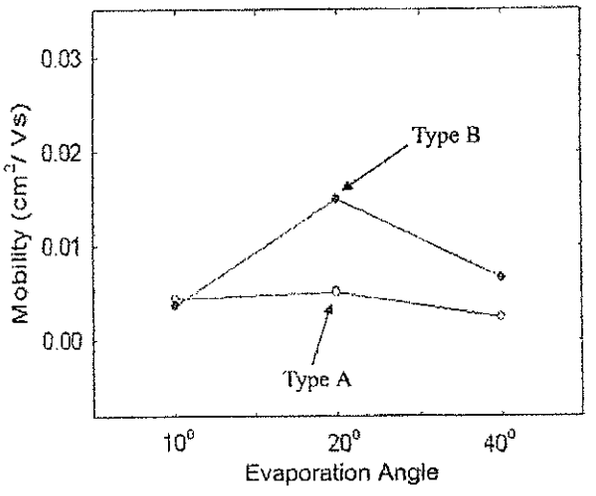

Fig. 3. Variation of field effect mobilities of pentacene on obliquely evaporated SiO_2 at various angle.

In order to find out the reason of decrease mobility in spite of existence of surface anisotropy, we measured morphology of surface with AFM. Figure 4 is AFM images of the topology of obliquely evaporated SiO_2, before pentacene evaporated.

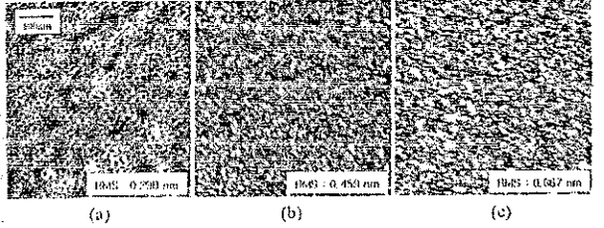

Fig. 4. AFM images of surface of obliquely evaporated SiO_2 at (a) 0°, (b) 10°, and (c) 40°.

The RMS values of obliquely evaporated SiO_2 at 0°,10°, and 40° are 0.298 nm, 0.459 nm, and 0.667 nm, respectively. It shows that steep evaporation angle induces much roughness of surface. Rough surface of insulator leads reduction of diffusion length and energy barrier for nucleation cause to decrease grain size. Small grain size causes a significant decrease of mobility because grain boundaries can act as trap sites in charge transport and limit the carrier mobility [3],[8]. Accordingly, though OTFT fabricated by obliquely evaporated SiO_2 at steep angle has high electrical anisotropy, the field-effect mobility is decreased by grain boundary effect.

An increase of interfacial anisotropy by the oblique evaporation is interact with an augmentation of surface roughness. Therefore, to obtain high field effect mobility and electrical anisotropy, it is required to optimize evaporate condition such as evaporate angle and deposition rate.

4. Conclusion

We studied the enhancement of molecular ordering and crystal orientation through obliquely evaporated SiO_2 as gate insulator. The sample which evaporated at 20° has much high mobility than samples which evaporated at other degrees and anisotropy ratio between perpendicular and parallel direction was 2.9. However, as evaporation angle is steeper, grain boundary effect induced by surface roughness is more increased. The carrier mobility and electric anisotropy decreased, again. The interfacial anisotropy effect and grain boundary effect in oblique evaporation interacted each other. We believe that further optimization of oblique evaporation in OTFTs would result in more anisotropic electric property and more high field effect mobility.

Acknowledgement

This research was supported by a grant (F0004052) from Information Display R&D Center, one of the 21st century Frontier R&D programs funded by the Ministry of Commerce, Industry and Energy of the Korean government.

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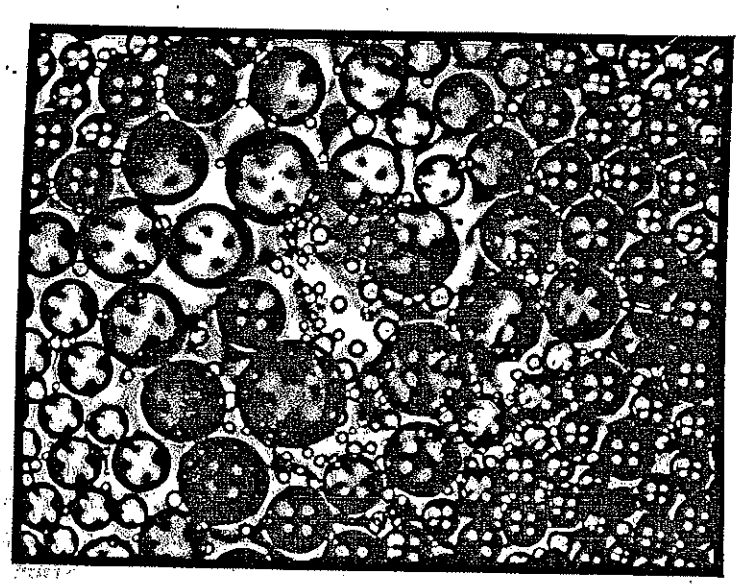

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