Effect of Anisotropic Gate Dielectric Layer fabricated by Obliquely Evaporated Silicon Dioxide on Pentacene-Based Field-Effect Transistor

H.-R. Kim, J.-J. Jung, Y.-J. Lee, and J.-H. Kim*

Department of Electronics and Computer Engineering, Hanyang University
17 Heangdang-Dong, Seongdong-Gu, Seoul 133-791, Korea

L.-M. Do

Basic Research Laboratory, Electronic and Telecommunications Research Institute
161 Gajeong-Dong, Yuseong-Gu, Daejeon 305-700, Korea

Abstract

We investigated anisotropic conduction effects of pentacene-based organic thin film transistor on an anisotropic insulator fabricated by obliquely evaporated silicon dioxide. It was observed that the obliquely evaporated gate dielectric layer affected the crystallized grain size as well as the molecular ordering. The mobility of the pentacene film in parallel to the oblique incidence of the e-beam evaporation was about 8 times higher than that in perpendicular one. As the inclination angle of e-beam evaporation was increased, the mobility was decreased due to the decreased grain size induced by increased surface roughness.

1. Introduction

Organic thin film transistors (OTFTs) have drawn much attention for flexible electronics such as smart cards, flexible displays, and several types of low cost and low-end electronics[1]. Recent intensive studies improved the electrical performances of the pentacene-based OTFTs in mobility comparable to that of hydrogenated amorphous silicon transistors[2].

Since the electrical conduction of OTFTs is highly affected by the molecular ordering, crystalline orientation, and the crystallized grain size of the organic semiconductors, there were several efforts to modify interfacial properties between the evaporated pentacene molecules and the insulator surface. In general, highly oriented polymeric layers by mechanical rubbing[3,4] or irradiation of polarized UV light[5,6] were used for the purpose. But, the electrical performances of OTFTs on the organic insulators are not satisfactory yet, comparing with those on the inorganic insulators, especially in terms of leakage current and the driving gate voltage.

In this paper, we investigated anisotropic conduction effects of pentacene-based OTFT on an anisotropic insulator fabricated by obliquely evaporated silicon dioxide. 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 Results and Discussion

Fig. 1 shows our bottom gate transistor structure where an n-type silicon wafer was used as a gate electrode. For comparison, conventional OTFT with an isotropic silicon dioxide surface was prepared by thermally grown oxidization with about 1400 Å thick on the heavily doped silicon wafer. The effects of the anisotropic inorganic interface were investigated by further evaporating silicon dioxide obliquely with an e-beam method on the thermally grown oxidized surface. The thickness of the additional dielectric layer was about 1000 Å. On the inorganic dielectric layer, a pentacene layer was deposited by 300 Å thick with a deposition rate of 0.4 Å/s under the base pressure of 1×10^{-7} Torr. As source and drain contacts, gold was thermally deposited on top of the pentacene film, where the channel length and width were 100 μm and 1 mm, respectively. Two types of samples were prepared, where the channel direction was parallel or perpendicular to the oblique incidence of the e-beam evaporation.

Fig. 2 shows the I_D-V_{DS} characteristics of OTFTs with the anisotropic insulator layer when the inclination angle of the e-beam evaporation was 40° with respect to the channel direction. It was observed that the mobility of the pentacene film in parallel one was higher than that in perpendicular one, with the values of $2.1*10^{-2}$ cm²/V·s and $2.7*10^{-3}$ cm²/V·s, respectively. The induced mobility anisotropy was about 8. Such results mean that the pentacene molecules composed of π-electron conjugated systems are aligned in a direction perpendicular to the evaporation direction of the silicon dioxide, which resulted in the enhanced mobility of Fig. 2 (a) through the increased π-electron orbital overlap. The on/off ratio's were similar in both samples with about 10^4.

However, the mobility was smaller than that of the conventional OTFT, as shown in Fig. 3. The mobility of the pentacene on the thermally grown silicon dioxide was $2.0*10^{-1}$ cm²/V·s. The on/off ratio was also better with the value of about 10^6.

Above results can be explained by considering the grain boundary effects including the molecular ordering effects on the OTFT performances. As shown in Fig. 4, the surface roughness of the dielectric layer fabricated by oblique evaporation was higher than that of the thermally grown one. Thus, the pentacene grains can not be grown in a larger size, which resulted in the reduced mobility of the OTFTs with the aligned molecular ordering. Figs. 5 (a) and (b) show the AFM images of the pentacene surface on the thermally grown isotropic silicon dioxide layer and the obliquely evaporated anisotropic silicon dioxide layer, respectively.

3. Summary

In this paper, we investigated the electrical performances of the pentacene-based OTFT on the obliquely evaporated silicon dioxide surface. On our anisotropic interface, the molecular ordering effects of the pentacene molecules could be obviously obtained. However, since the surface roughness and resultant grain boundary were also increased as the inclination angle of the evaporation increased, it is assumed that the optimization of the fabrication process has to be required.

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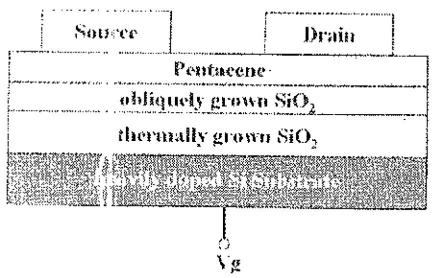

Fig. 1. Structure of pentacene-based TFT with an anisotropic inorganic dielectric layer.

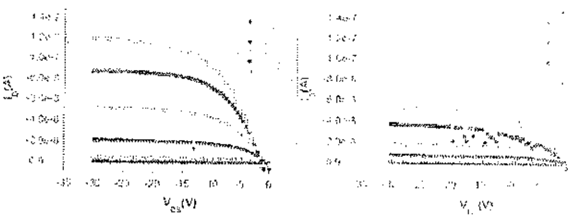

Fig. 2. $I_D - V_{DS}$ characteristics of OTFTs where the oblique incidences of the silicon dioxide evaporation are (a) parallel and (b) perpendicular to the channel direction.

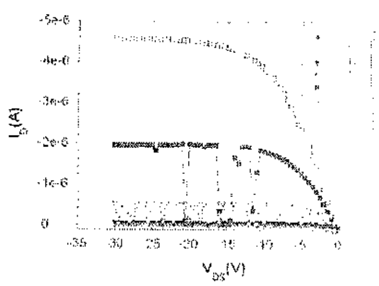

Fig. 3. $I_D - V_{DS}$ characteristics of OTFTs with thermally grown silicon dioxide layer.

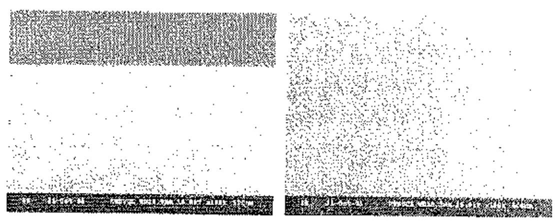

Fig. 4. (a) Cross section and (b) surface SEM images of the obliquely evaporated silicon dioxide dielectric layer.

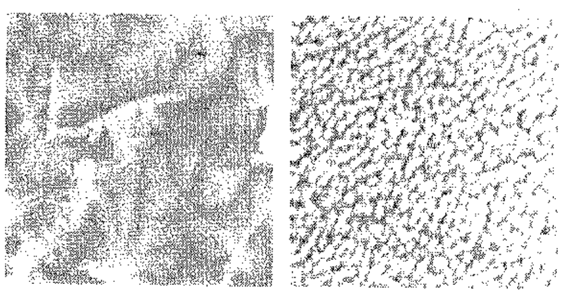

Fig. 5. AFM images of the pentacene surface on (a) the thermally grown isotropic silicon dioxide layer and (b) the obliquely evaporated anisotropic silicon dioxide layer. .

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