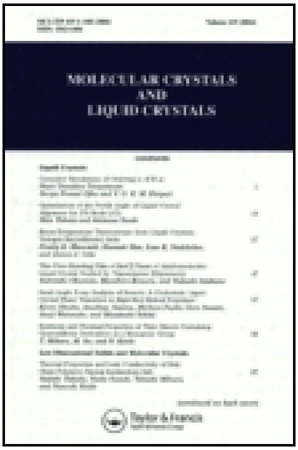


Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

Importance of Semiconductor/ Insulator Interface for Improving Transistor Properties of OFET

Manabu Yoshida [a], Sei Uemura [a], Satoshi Hoshino [a], Takehito Kodzasa [a] & Toshihide Kamata [a]
[a] National Institute of Advanced Industrial Science and Technology, Tsukuba, Ibaraki, Japan

Version of record first published: 31 Jan 2007

To cite this article: Manabu Yoshida, Sei Uemura, Satoshi Hoshino, Takehito Kodzasa & Toshihide Kamata (2006): Importance of Semiconductor/Insulator Interface for Improving Transistor Properties of OFET, Molecular Crystals and Liquid Crystals, 455:1, 327-332

To link to this article: http://dx.doi.org/10.1080/15421400600699038

Mol. Cryst. Liq. Cryst., Vol. 455, pp. 327–332, 2006
Copyright © Taylor & Francis Group, LLC
ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400600699038

Importance of Semiconductor/Insulator Interface for Improving Transistor Properties of OFET

Manabu Yoshida
Sei Uemura
Satoshi Hoshino
Takehito Kodzasa
Toshihide Kamata
National Institute of Advanced Industrial Science and Technology,
Tsukuba, Ibaraki, Japan

In this report, we paid attention to the structural and energetic fluctuations at the semiconductor/insulator interface of field effect transistors. We intended to change these factors independently, and then succeeded in determining the effectiveness of each factor on the charge transport.

Keywords: amorphous thin films; control of interface structure and morphology; organic semiconductors based on conjugated molecules; semiconductor/insulator interfaces

INTRODUCTION

Matching between active materials and insulator materials is the most important issue for improving properties of field effect transistors (FETs), because charge carriers flow through the conductive channel formed at the active layer/insulator layer interface [1]. However, the interface charge transport is generally pretty different from the bulk charge transport [2]. Bulk charge transport in the hopping conduction system has been intensively discussed in the xerographic-photoreceptor field [3]. H. Bässler *et al.* have suggested the disorder model for explaining the charge transport in disorder

Address correspondence to Manabu Yoshida, National Institute of Advanced Industrial Science and Technology, Higashi 1-1-1, Tsukuba, Ibaraki 305-8565, Japan. E-mail: yoshida-manabu@aist.go.jp

systems such as molecularly dispersed polymers and molecular glasses [4]. J. Veres *et al.* have reported that the disorder model would be also applied to the charge transport at an interface between an active and insulator layer in FETs in the same manner [5]. However, they have not discussed about structural fluctuations of the semiconductor/insulator interface. In this study, we focused on two physical factors, namely, an energetic factor and a structural factor. We intended to change each physical factor independently at the insulator/semiconductor interface, and observed how the changes of each physical factor affect the charge transport at the interface.

EXPERIMENTAL

Typical FET devices used in this study were fabricated as following procedure. Heavily doped Si with thermally grown SiO_2 (300 nm) was employed as a substrate and a gate electrode. For the purpose of controlling and parameterizing interfacial conditions, a thin layer was inserted between the active layer and the insulator layer shown in Figure 1(a) as the insertion layer. The synthesized capacitance of the SiO_2 and insertion layers was measured by the vibrating capacitor method. For controlling structural factor, the polystylene sphere layer or the SAM layer composed of silane coupling agents with two different chain lengths (chlorotriethylsilane and n-octadecyldimethylchlorosilane) were employed as an insertion layer. In this case, RMS roughness of the insertion layer surface measured by using Atomic Force Microscope (AFM: SPI3800N + HV probe station, Seiko Instruments Inc.) represents a degree of structural factor changes. For controlling energetic factor, various concentrations of o-nitroaniline (ONA with a dipole moment of 5.05D) dispersed PS films were employed as an insertion layer. After fabricating these insertion layers, an active layer (100 nm) was deposited onto the insertion layer. As an active material for FET, N,N′-diphenyl-N,N′-di(m-tolyl)-benzidine (TPD : purity > 98%) powder was purchased from Tokyo Kasei Kogyo CO. LTD. Followed by this process, gold drain-source electrodes were deposited on the TPD thin film surface by using thermal evaporation method at a pressure of ca. 10^{-6} Torr (deposition rate $= 0.1 \sim 0.2$ nm/s). The channel length (L) and width (W) of the drain-source electrode set were 20 μm and 5 mm, respectively. Electrical measurements were carried out by using a cryogenic probing station (NAGASE & CO., LTD. BCT43MRF) with semiconductor parametric analyzer (Keithley 4200).

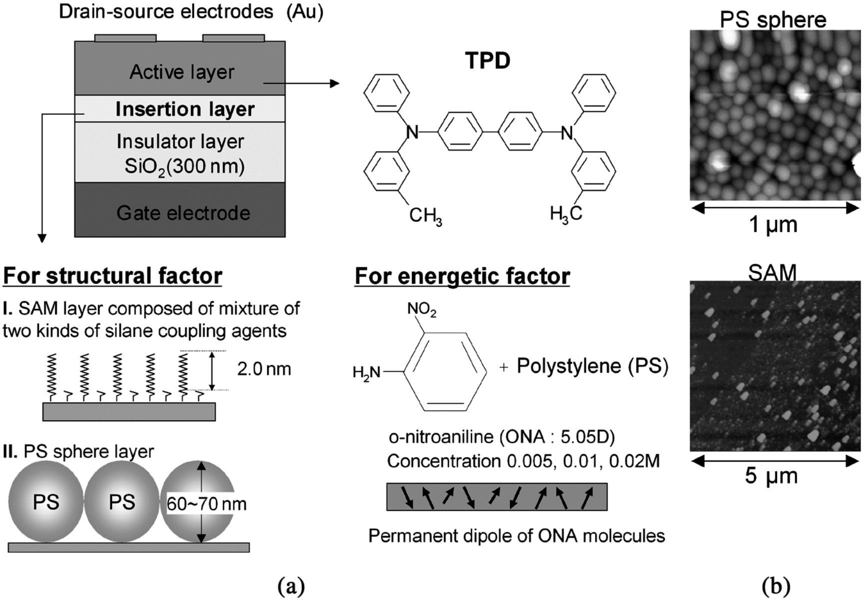


FIGURE 1 (a) Schematic illustration of FET structure used in this study. The insertion layer is employed for controlling interfacial conditions. The contents of the insertion layers for controlling the structural factor and the energetic factor are also shown. (b) Topographical images measured using AFM. The left image shows the surface condition of PS sphere layer, the right image shows the surface condition of SAM layer composed of mixture of two kinds of silane coupling agent with different chain length (the difference is about 2.0 nm). RMS roughness values are 25.6 nm for the left image and 2.0 nm for the right image, respectively.

RESULTS AND DISCUSSION

Figure 1(b) shows topographical images measured using the AFM. RMS roughness values are 25.6 nm for the left image 2.0 nm and for the right image, respectively. The RMS roughness value of the SAM layer is well corresponding to the chain-length difference of two silane coupling agents. The RMS roughness value (25.6 nm) of the PS sphere layer is also corresponding to the average radius of PS spheres (ca. 30 nm). In this case, the threshold voltage (V_{th}) changes by the insertions of the PS sphere layer or the SAM layer were very little. This result means that any energetic changes did not occur at the interfaces. On the other hand, a critical μ_{FET} change is observed at RMS roughness of ca. 2.0 nm originated from the insertion of the

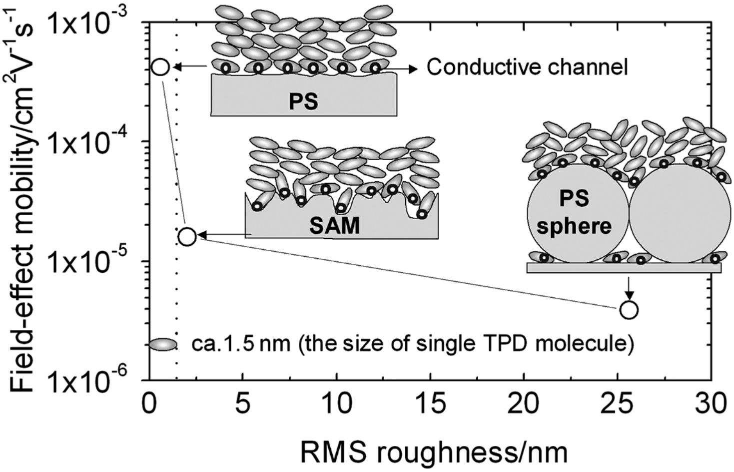


FIGURE 2 The relation between RMS roughness and μ_{FET} for various insertion materials.

SAM layer (Fig. 2). According to this result and the fact that the size of TPD molecule is about 1.0–1.5 nm, it is concluded that the thickness of conductive channel is close to single-molecular size and that single-molecular level roughness at the interface strongly inhibits the charge transport.

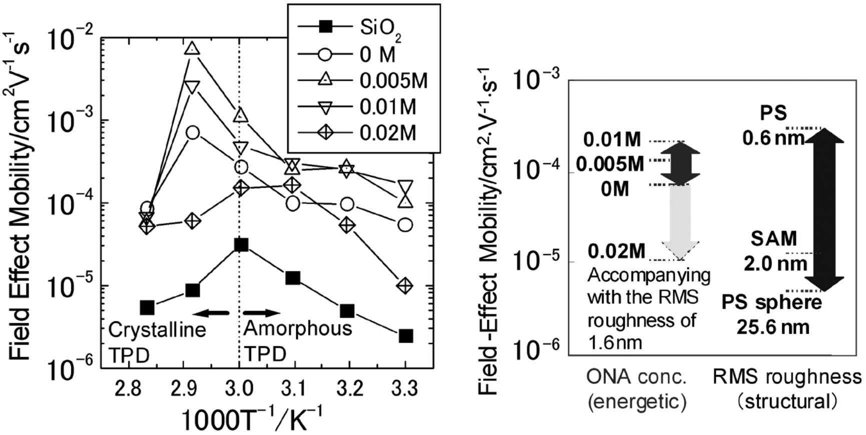
The mobility, activation energy (E_a/eV), and RMS roughness values are shown in Table 1. The E_a values were calculated by using Gill's equation (Eq. (1)) describing the temperature and electric field dependencies of charge carrier mobility in the hopping conduction system [6].

$$\mu = \mu_0 \exp\left(-\frac{E_a}{kT}\right) \exp\left\{\beta F^{1/2}\left(\frac{1}{kT} - \frac{1}{kT_r}\right)\right\} \tag{1}$$

TABLE 1 The Relation Between the ONA Concentration and RMS Roughness, μ_{FET} and E_a

	ONA concentration/M			
	0	0.005	0.01	0.02
Field effect mobility $\mu_{\mathrm{FET}}/\mathrm{cm}^2\cdot\mathrm{V}^{-1}\cdot\mathrm{s}^{-1}$	$5.5\cdot10^{-5}$	$9.8\cdot10^{-5}$	$1.6\cdot10^{-5}$	$9.8\cdot10^{-6}$
Activation energy E_a/eV	0.25	0.4	0.27	1.18
Root mean square (RMS) roughness/nm	0.46	0.4	0.35	1.6

where, μ_0 is the pre-exponential mobility which is related to the glass transition behavior of TPD film, T is the measured temperature, F is the applied electric field, β is the Poole-Frenkel constant, and T_r is a reference temperature which is determined for each hopping system, respectively. E_a was calculated by using the slope of the plots in lower temperature region where the TPD films are in the amorphous phase in Figure 3(a). As shown in Table 1, there is no correlation between the ONA concentration and the E_a values in the ONA concentration region between 0 and 0.01 M. In this region, the change of RMS roughness is also very little. At the concentration of 0.02 M, E_a steeply increases. This increase would be originated from the increase of RMS roughness of the insertion layer surface, resulted from aggregation of ONA molecules. The summary of the mobility change by varying the structural factor (RMS roughness) or the energetic factor (ONA concentration) is shown in Figure 3(b). This figure clearly shows that the structural factor is more effective than the energetic factor on the charge carrier transport at the active layer/insulator layer interface. Especially, the RMS roughness over the single-molecular size drastically decreases the charge carrier mobility.



(a) (b)

FIGURE 3 (a) Temperature dependence of μ_{FET}s for TPD-FETs having ONA dispersed PS insertion layers (ONA concentration: 0–0.02 M). (■) shows μ_{FET} data for TPD-FET without insertion layer, namely, using only SiO_2 layer as an insulator. (b) The mobility change by varying the structural factor (RMS roughness) or the energetic factor (ONA concentration).

CONCLUSION

In this report, we have intended to change the physical fluctuations at the active layer/insulator layer interface of FETs. It has been concluded that the single molecular level structural fluctuations strongly affect on the interfacial charge carrier transport.

REFERENCES

[1] Yoshida, M., Uemura, S., Kodzasa, T., Kamata, T., Matsuzawa, M., & Kawai, T. (2003). *Synth. Met.*, *137*, 967–968.
[2] Tanase, C., Meijer, E. J., Blom, P. W. M., & de Leeuw, D. M. (2003). *Phys. Rev. Lett.*, *91*, 216601-1-216601-4.
[3] Borsenberger, P. M. & Weiss, D. S. (1993). *Organic Photoreceptors for Imaging Systems*, Marcel Dekker: New York.
[4] Bässler, H. (1981). *Phys. Status Solidi (b)*, *107*, 9.
[5] Veres, J., Ogier, S. D., Leeming, S. W., Cupertino, D. C., & Khaffaf, S. M. (2003). *Adv. Funct. Mater.*, *13*, 199–204.
[6] Gill, W. D. (1972). *J. Appl. Phys.*, *43*, 5033.