

Performance Improvement of Organic Thin Film Transistors with Self-Assembled Monolayer Formed by ALD

Hyunsuck Kim, Jaehoon Park, Kang Wook Bong, Jong Mook Kang, Hye Min Kim, and Jong Sun Choi

Dept. of Electrical, Information & Control Engineering, Hongik University, Seoul, 121-791, KOREA

Phone: +82-2-320-1488, E-mail: shine3770@hotmail.com

Abstract

In this study, the effects of SAMs on the performance of OTFTs have been investigated. ALD technique was applied for the deposition of SAMs, which is an ultra-thin film deposition technique based on sequences of self-limiting surface reactions enabling thickness control on atomic scale. According to our investigation results, it is observed that the surface properties of the gate insulator was changed by SAMs, which allow pentacene molecules to be deposited in the upright direction on the gate insulator and hence the performance of OTFTs could be improved. These results will be discussed

1. Introduction

Semiconducting π -conjugated materials have received considerable attention as active components in electronic devices such as light emitting diodes, photovoltaic cells, field effect transistors, and their integrated organic devices[1]. Organic materials can offer substantial advantages in terms of the processing simplicity and competitive cost[2,3].

The performance of these organic devices has significantly improved during the past two years, especially the organic thin film transistors (OTFTs) performance[1]. The optimized OTFTs show the electrical characteristics similar to those obtained with amorphous silicon devices. It has been reported that pentacene(C₂₂H₁₄) shows the most pronounced properties for p-channel conduction, among many organic semiconductors. For this reason, the pentacene was usually employed as the active layer of OTFTs[4]. On the other hands, the use of polymer gate dielectric materials, such as poly(4-vinylphenol) and poly(methyl- methacrylate), have been reported for the OTFTs, recently[5].

One of critical factors for high performance of OTFTs is the characteristics of the pentacene-gate dielectric interface[6]. Pentacene exhibits a strong

tendency to form highly ordered film depending on the growth and substrate surface condition[7]. It is known that vertical alignment of pentacene molecules to the gate insulator surface provides a strong π - π^* overlap and increases the electrical conductivity in the direction of perpendicular to the long-axis. The hydrophilic surface polarity of PVP layer(a gate insulator) can deteriorate the upright growth of pentacene molecules to the substrate. Therefore, in order to align pentacene molecules upright onto the gate insulator surface with high order, certain surface treatments, such as rubbing, photo-align, self-assembled monolayers (SAMs), are necessary and it have been reported that those treatments enhance the performance of OTFTs[7,8].

ALD is a vapor phase thin film growth technique allowing atomic-scale thickness control. The technique is based on a sequence of two self-limiting reactions between gas phase precursor molecules and a solid surface. During the reaction sequence, only one reactant is present in the reaction zone at a time. This procedure prevents unwanted gas phase reactions in contrast to chemical vapor deposition. Because only a finite number of reactive sites exist on the surface, reactions with these surface species are inherently selflimiting. Dense and pinhole-free films are produced when these two reactions are allowed to go to completion. Furthermore, since gas phase reactants are utilized, ALD does not require line-of-sight. Conformal coatings can be applied to very high aspect ratio geometries and porous structures.[9]

In this work, in order to change the polarity of insulator surface self-assembled monolayers (SAMs) were deposited onto PVP layer prior to the deposition of pentacene. Conventional processes for SAMs, dipping in SAMs solution, have some problem associated with processing complexity, uniformity, reproducibility and possibility to harm to polymeric gate insulator. In this study we attempt to form SAMs

onto PVP layer via gas-phase using atomic layer deposition (ALD) method. The properties of pentacene thin film and characteristics of OTFTs are presented.

2. Results

For the OTFT fabrication, an 1000-Å-thick Al gate electrode was thermally evaporated on a glass substrate using the first shadow mask. A 4500-Å-thick gate insulator was formed by spin-coating followed by baking at 60 °C for 10 min and consecutively at 100 °C for 20 min in a vacuum dry oven. The octyltrichlorosilane SAM was deposited by ALD method at 170 °C under a pressure of 0.1 Torr. Pentacene as an organic semiconductor was thermally evaporated through the second mask onto an insulator-coated substrate at a rate of 0.5 Å/s and its thickness was about 600 Å. Subsequently, a 400-Å-thick Au layer was thermally evaporated through the third mask for the source and drain contacts. All the deposition processes were carried out at a base pressure of about 1.6×10^{-6} Torr. The channel length and width of top-contact OTFTs are 90 μm and 300 μm, respectively. The molecular structure and the cross section of the fabricated OTFT are shown in Figure 1.

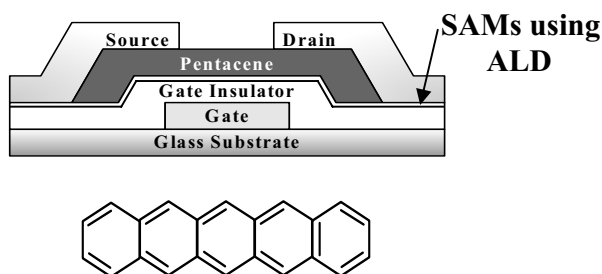


Figure 1, The schematic structures of the fabricated OTFT and pentacene molecule

The change of the surface polarity was confirmed by contact angle analysis as shown in figure 2. In order to calculate the surface polarity and the surface energy water and diiodomethane were used. It is observed that SAMs modify the surface polarity of PVP more hydrophobic and the surface energy is decreased by SAMs. It means that the factor deteriorating the upright growth of pentacene molecules can be eliminated. Measured contact angles and computed surface properties are listed in Table 1

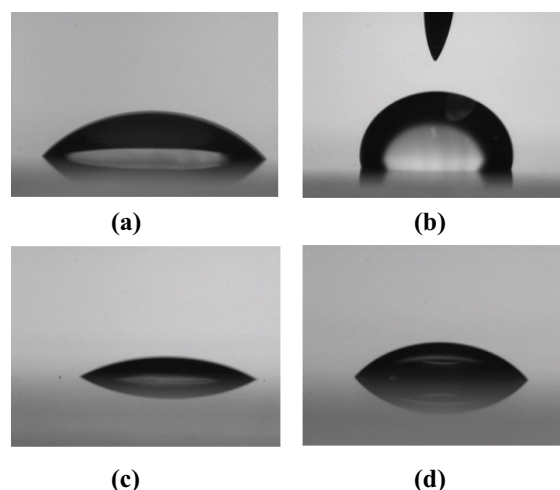


Figure 2. (a) water contact angle of bare PVP, (b) water contact angle of SAMs on PVP, (c) diiodomethane contact angle of bare PVP and (d) diiodomethane contact angle of SAMs on PVP

Table 1. Contact angle and Surface property

	Contact angle (Water)	Contact Angle (Diiodo-Methane)	Polarity	Surface energy
Bare PVP	58.4	35.2	15.14	50.30
SAMs on PVP	105.3	58.5	0.03	29.93

The surface morphology of pentacene thin film with / without SAMs on PVP is confirmed by atomic force microscopy (AFM) as shown in figure 3. Both pentacene films were thermally evaporated and the thickness of pentacene layer was 30 nm. It is observed that the grain size of pentacene film on SAMs became uniform and decreased. Therefore the average roughness of pentacene film is improved and the crevice between the grains become shallow by depositing SAMs

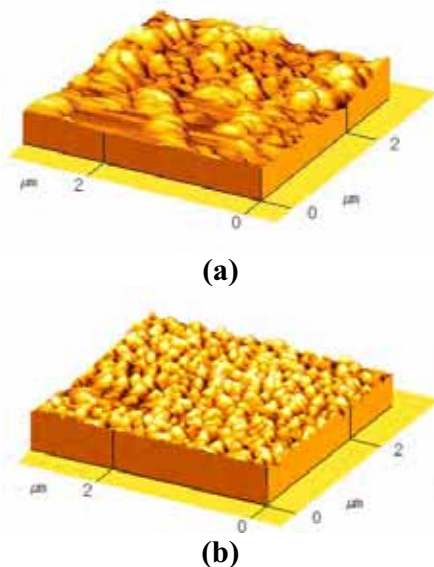


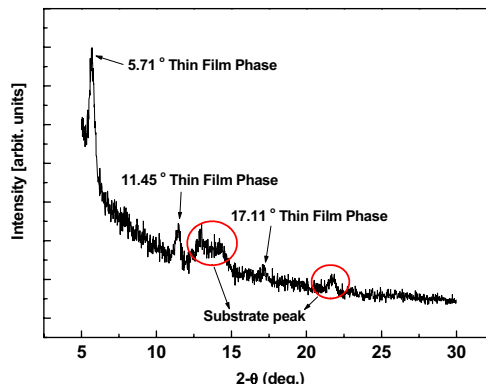
Figure 3, Atomic force microscopy (AFM) images of pentacene film deposited onto (a) as-deposited PVP, (b) SAMs on PVP

According to the AFM images, it is expected that SAMs affect the growth condition of pentacene and the crystallinity of pentacene film is changed. In order to confirm the change of the crystallinity X-ray diffraction (XRD) measurement is performed. Pentacene was thermally evaporated with 30nm-thick onto Si wafer. XRD patterns of pentacene film without and with SAMs are shown in figure 4(a) and 4(b). In both cases no phase other than the thin-film phase[10] are observed. And the pentacene film on SAMs shows the improved molecular ordering.

The output characteristics of the pentacene based TFTs with bare PVP and SAMs on PVP are shown in figure 5(a) and the transfer characteristics of OTFTs are shown in figure 5(b). The open and solid lines represent the characteristics of TFTs with bare PVP and SAMs on PVP, respectively. Detailed device properties of OTFTs are listed in Table 2. The field effect mobilities were extracted using the following equation;

$$I_{DS} = \frac{W}{2L} \mu_{FET} C_i (V_G - V_T)^2$$

(a) Si / PVP / Pentacene



(b) Si / PVP / SAMs / pentacene

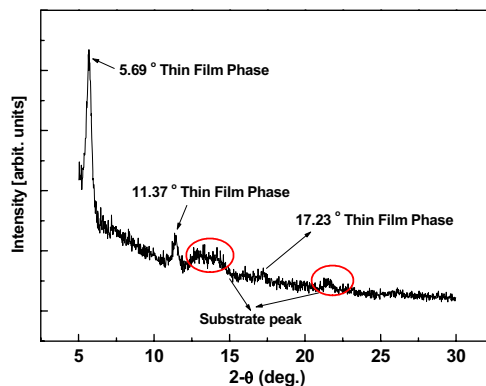
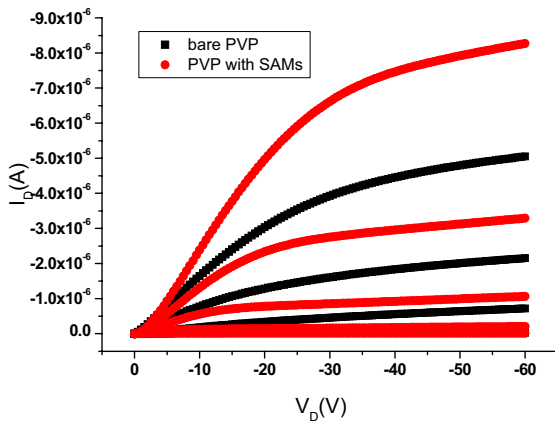
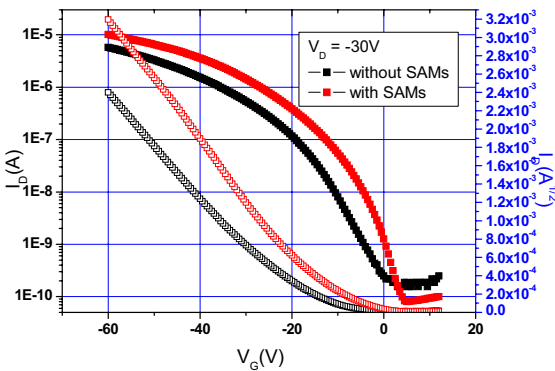


Figure 4, X-ray diffraction spectrums of pentacene film

It is likely that the improvement of drive current of TFTs with SAMs on PVP originated from the change of molecular ordering in the pentacene film. However, when SAMs is deposited on PVP the permittivity is slightly decreased due to the reduction of surface polarity. In the result threshold voltage of the device with SAMs is slightly deteriorated



(a)



(b)

Figure 5. The electrical characteristics of OTFTs

Table 2. Properties of the fabricated OTFTs with different gate insulators

	Threshold Voltage	Subthreshold Slope	On/Off Current Ratio	Field-Effect Mobility
Bare PVP	- 18 V	6.4 V/decade	$\sim 10^4$	0.12 cm^2/Vs
SAMs on PVP	- 12 V	3.3 V/decade	$\sim 10^5$	0.25 cm^2/Vs

3. Conclusion

The pentacene TFTs with SAMs on PVP gate insulators have been investigated. The properties of pentacene films grown on dielectric layers are closely related with the characteristics of the interface condition between pentacene and gate dielectric. The hydrophilic surface polarity of PVP layer can deteriorate the upright growth of pentacene molecules onto the insulator surface. Octyltrichlorosilane SAMs deposited on PVP via gas- phase modify the surface polarity more hydrophobic and that changes affect the growth of pentacene film. As a result, the morphology and crystallinity of pentacene film are improved by depositing SAMs. And most characteristic parameters of OTFTs such as on/off current ratio and carrier mobility are improved.

4. Acknowledgements

This work was supported from Information Display R&D Center, one of the 21st Century Frontier R&D Program funded by the MOCIE of Korea.

5. References

- [1] L. A. Majewski, R. Schroeder, M. Grell, P. A. Glarvey and M. L. Turner, *J. Appl. Phys.*, 96, 5781, (2004)
- [2] A. R. Brown, C. P. Jarrett, D. M. de Leeuw, and M. Matters, *Synthetic Metals*, p.37 (1997)
- [3] G. Velu, C. Legarand, O. Tharaud, A. Chapoton, D. Remiens, and G Horowitz, *Appl. Phys. Lett.*, 79, 659, (2001)
- [4] J. H. Lee, C. H. Kang, J. S. Choi, D. M. Song, D. M. Shin, S. D. Lee, *IMID 02*, 575, (2002)
- [5] Sei Uemura, Manabu Yoshida, Satoshi Hoshino, Takehito Kodazasa, Toshihide Kamata, *Thin Solid Films* 378-381,(2003)
- [6] S. I. Kang, J. H. Park, J. H. Lee, J. S. Choi, *SID '04*, 252, (2004)
- [7] D. Knipp, R. A. Street, A. Völkel, and J. Ho, *J. Appl. Phys.* 93, 347,(2003)
- [8] A. Salleo, M. L. Chabinyc, M. S. Yang, and R. A. Street, *Appl. Phys. Lett.*, 81, 4383,(2002)
- [9] C. F. Herrmann, F. H. Fabreguette, D. S. Finch, R. Geiss, S. M. George. *Appl. Phys. Lett.* 87, 123110 (2005)
- [10] J. Puigdollers, C. Voz, A. Orpella, I. Martin, M. Vetter, R. Alcubilla, *Thin Solid Films*, 427, 367,(2003)