

## Modification of Dielectric Surface in Organic Thin-Film Transistor with Organic Molecule

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### Abstract

*We herewith report for the effect of dielectric surface modification on the electrical characteristics of organic thin-film transistors (OTFTs). The kist-jm-1 as an organic molecule for the surface modification is deposited onto the surface of zirconium oxide (ZrO<sub>2</sub>) gate dielectric layer. The OTFTs are elaborated on the flexible plastic substrates through 4-level mask process to yield a simple fabrication process. In this work, we also have examined the dependence of electrical performance on the interface surface state of gate dielectric/pentacene, which may be modified by chemical properties in the gate dielectric surface.*

### 1. Introduction

Organic thin-film transistors (OTFTs) have recently attracted much interest for a number of electronic application areas due to their lower cost, flexible nature and plastic compatibility [1, 2]. As a result, the organic displays with flexible substrate materials become attractive for the future electronic devices such as electronic paper, portable display, smart card, radio frequency identification tag and flexible arrays of plastic microphone [3-5]. The OTFTs also have substantial advantages over inorganic thin film transistors with respect to processing cost, weight, and manipulation, but show comparatively lower electronic response time because of their low charge carrier mobility.

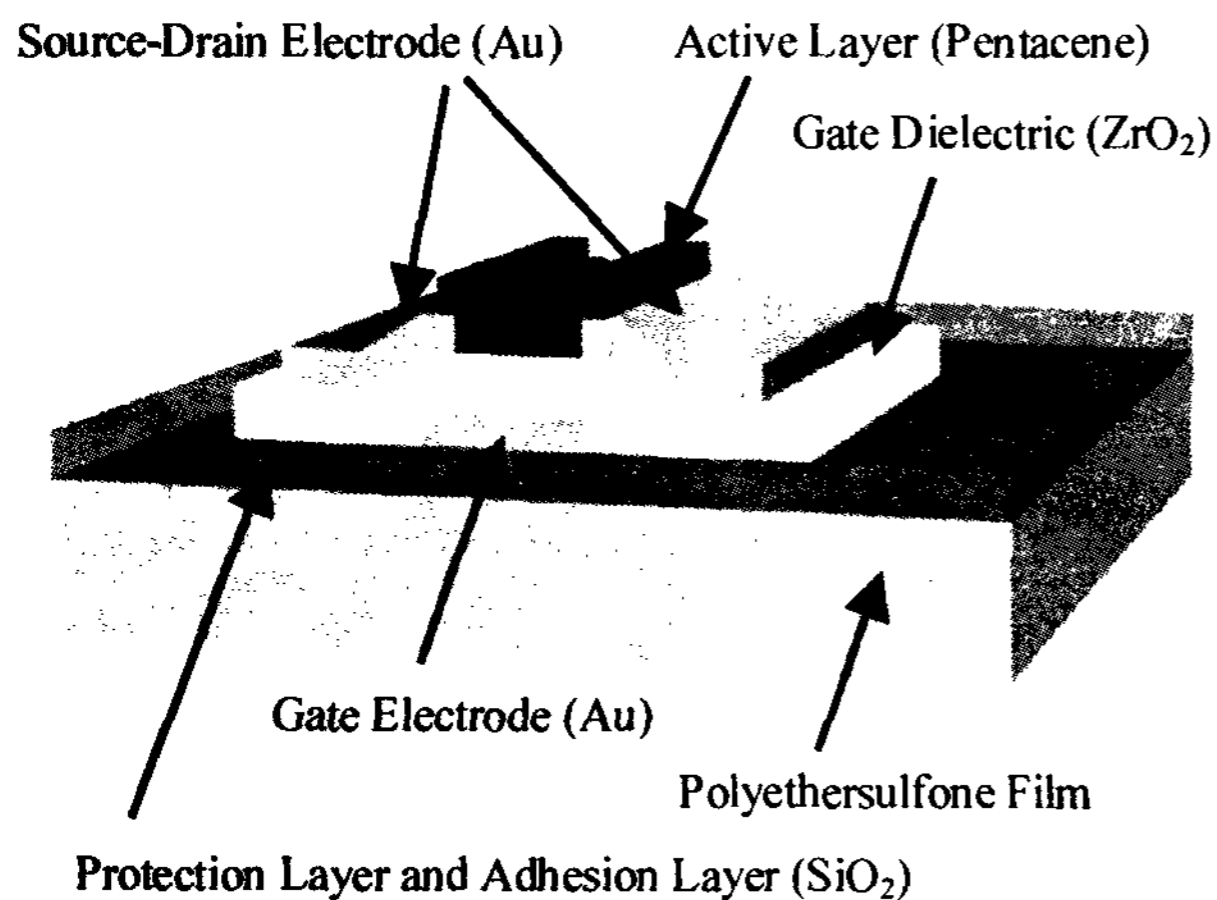
Therefore, as an organic interlayer material for dielectric passivation of OTFT, kist-jm-1 has been applied to improve the field effect mobility of OTFTs in this study. It is found that such a simple surface modification of pentacene TFTs could remarkably enhance the charge carrier mobility through the change of interface surface state and potential barrier height in the dielectric layer.

### 2. Experimental

In order to approach simple fabrication process, a four-level mask process without a photolithography for the device patterning is employed to fabricate the flexible OTFTs with a self-aligned bottom-contact electrode structure on the plastic substrate. Pentacene (C<sub>22</sub>H<sub>14</sub>) composed of five benzene rings with a chain-like aromatic molecule was used for an organic active layer [6]. In prior to device processing, a flexible polyethersulfone (PES) substrate was pre-annealed for one hour at 120°C to minimize a shrinkage of polymer substrate during subsequent processing. A 200-nm thick silicon dioxide (SiO<sub>2</sub>) film for the adhesion layer is deposited on the bare plastic substrate by e-beam evaporator. Subsequently, the gold gate electrode was deposited on the flexible substrate using thermal evaporator at a pressure of 2×10<sup>-6</sup> Torr through a shadow mask. On the patterned gate electrode, a 250-nm thick ZrO<sub>2</sub> for gate dielectric layer was deposited by the e-beam at relatively low temperature (<120°C). The ZrO<sub>2</sub> is known as one of the most promising materials due to its high permittivity of 20-25, excellent adhesion and good thermal stability [7, 8]. Following the gate dielectric layer deposition, in order to have a good affinity of organic molecule on the surface of dielectric layer, we modified the surface of ZrO<sub>2</sub> by using combinational self-assembled monolayers (SAMs) of alkyl silanes. The SAMs deposition was performed by soaking a solution of KIST-JM-1/isopropanol (1:20/v:v) for a few minutes under nitrogen atmosphere. For making the OTFTs of the bottom-contact structure, gold source and drain electrodes were deposited through shadow-mask by a thermal evaporator at the vacuum pressure of 2×10<sup>-6</sup> Torr. Then, a 100-nm thick pentacene film was thermally evaporated through shadow-mask at average deposition rate of 0.5 Å/s onto the fixed substrates at 60°C under a pressure of 10<sup>-5</sup> Torr. All the electrical measurements of fabricated devices were performed in a dark room without any considerations to prevent the degradation phenomena of pentacene film.

### 3. Results and Discussion

Fig. 1 (a) presents the structure of bottom-contact electrode device fabricated for organic TFTs and Fig. 1 (b) is the photograph of a fabricated device on the flexible substrate.



(a)

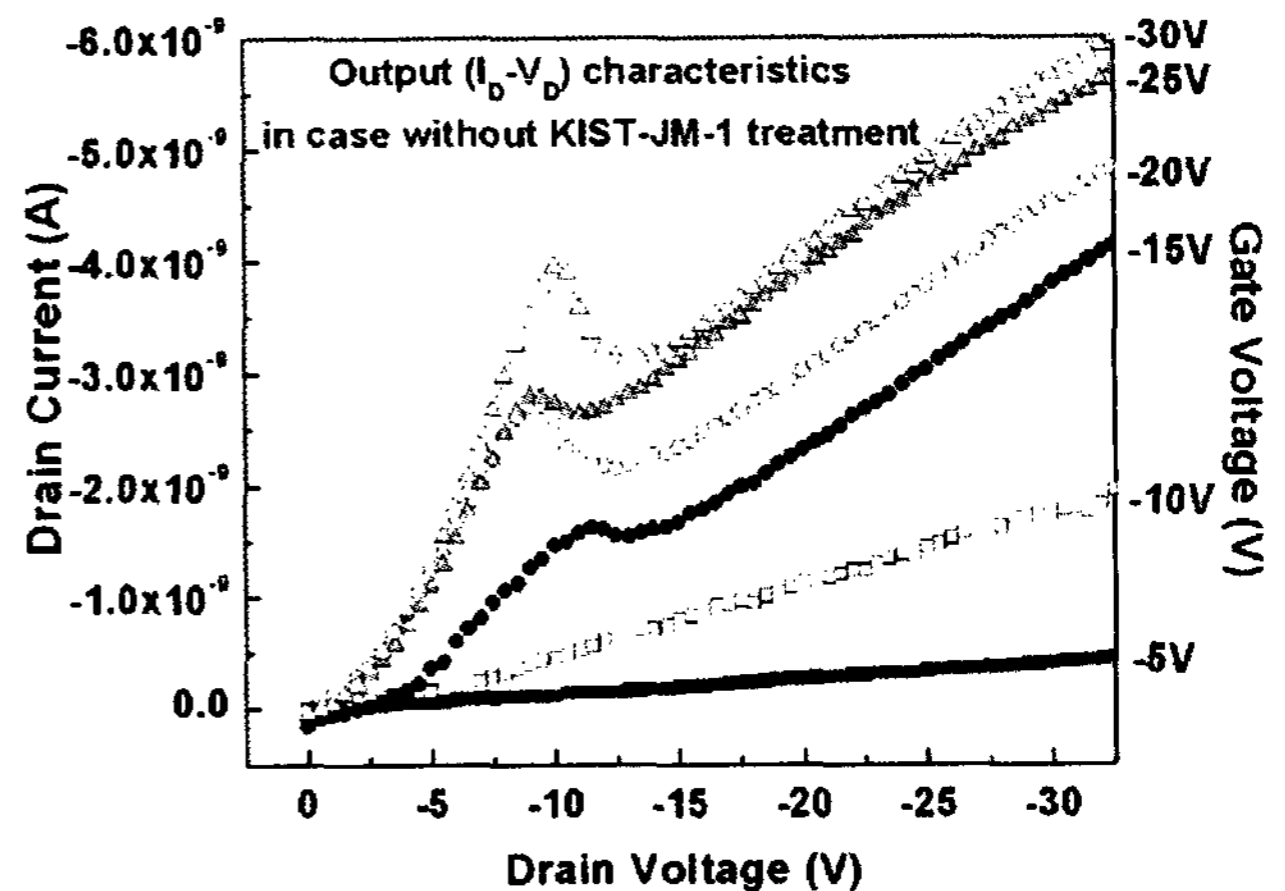


(b)

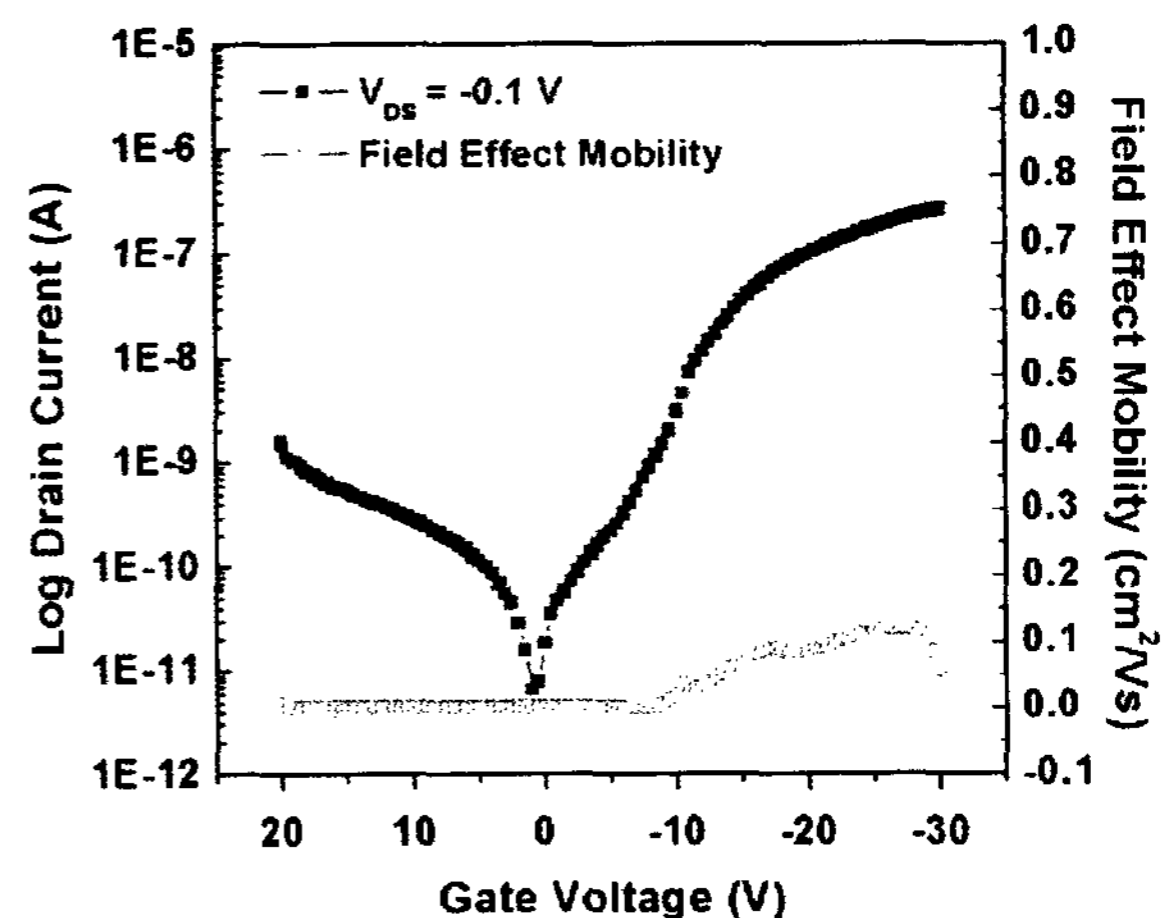
**Fig 1.** Structure of the fabricated pentacene TFTs. (a) Schematic 3-D structure of the bottom-contact electrode device and (b) Photograph of the pentacene TFTs on the flexible PES substrate (W/L=5)

Fig. 2 shows electrical characteristics of the organic pentacene TFTs with a channel width of  $1000\mu\text{m}$  and length of  $200\mu\text{m}$  in the absence of the kist-jm-1 treatment. The kink phenomena shown in Fig. 2 (a) drain current – drain voltage ( $I_D$ - $V_D$ ) characteristics are attributable to the increased surface

potential barrier height between a pentacene organic layer and a gate dielectric layer, resulting in the serious device degradation. Fig. 2 (b) drain current – gate voltage ( $I_D$ - $V_G$ ) curve illustrates the electrical characteristics such as on/off current ratio of  $10^4$  and the field effect mobility of  $0.12\text{cm}^2/\text{Vs}$  at the drain voltage of  $-0.1\text{V}$ .



(a)



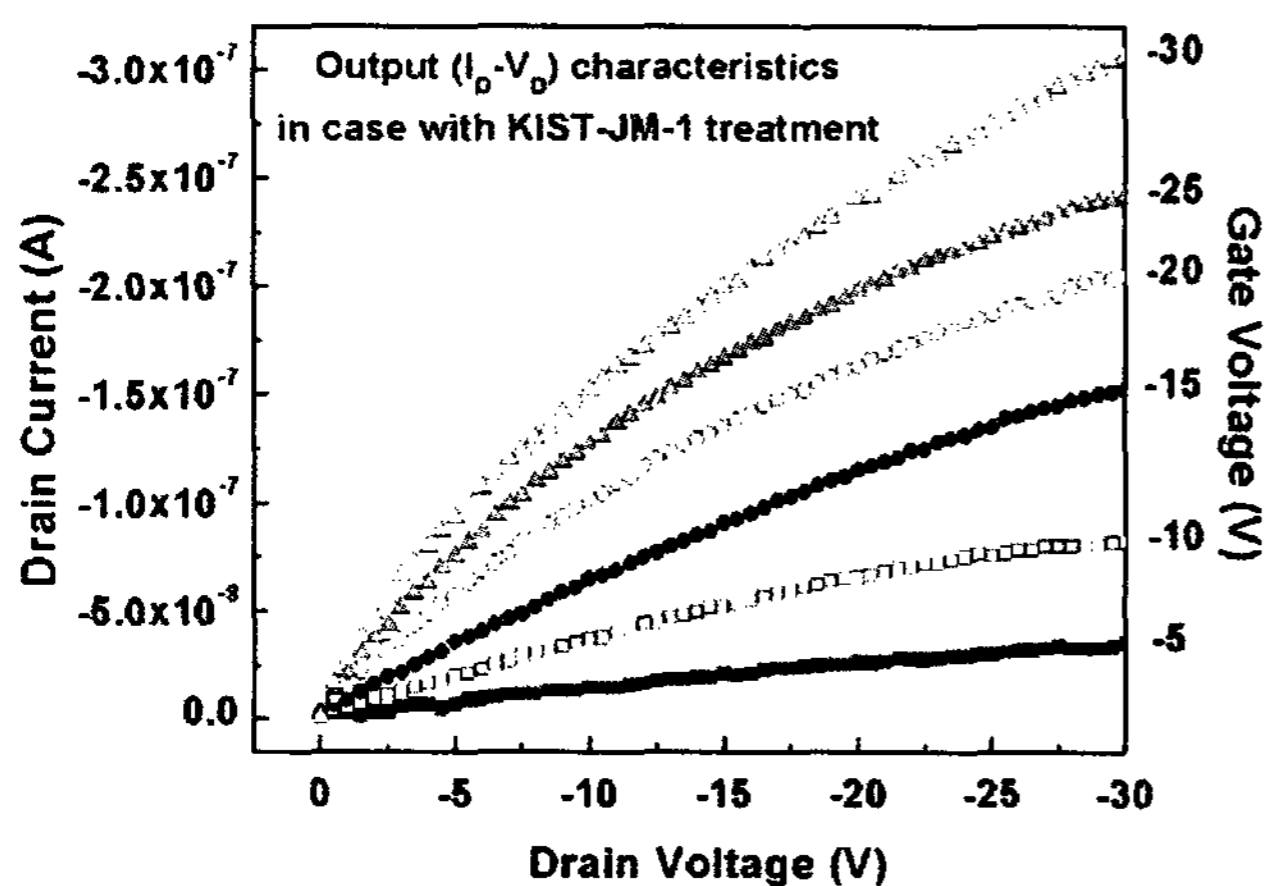
(b)

**Fig 2.** (a) Electrical characteristics of drain current ( $I_D$ ) vs drain voltage ( $V_D$ ) at various gate voltages ( $V_G$ ) obtained from the pentacene TFT prepared in the absence of KIST-JM-1 treatment of the gate dielectrics. (b) Electrical characteristics of  $I_D$  vs  $V_G$  and field effect mobility at drain voltages ( $V_D$ ) of  $0.1\text{V}$  obtained from the pentacene TFT prepared in the absence of KIST-JM-1 treatment of the gate dielectrics.

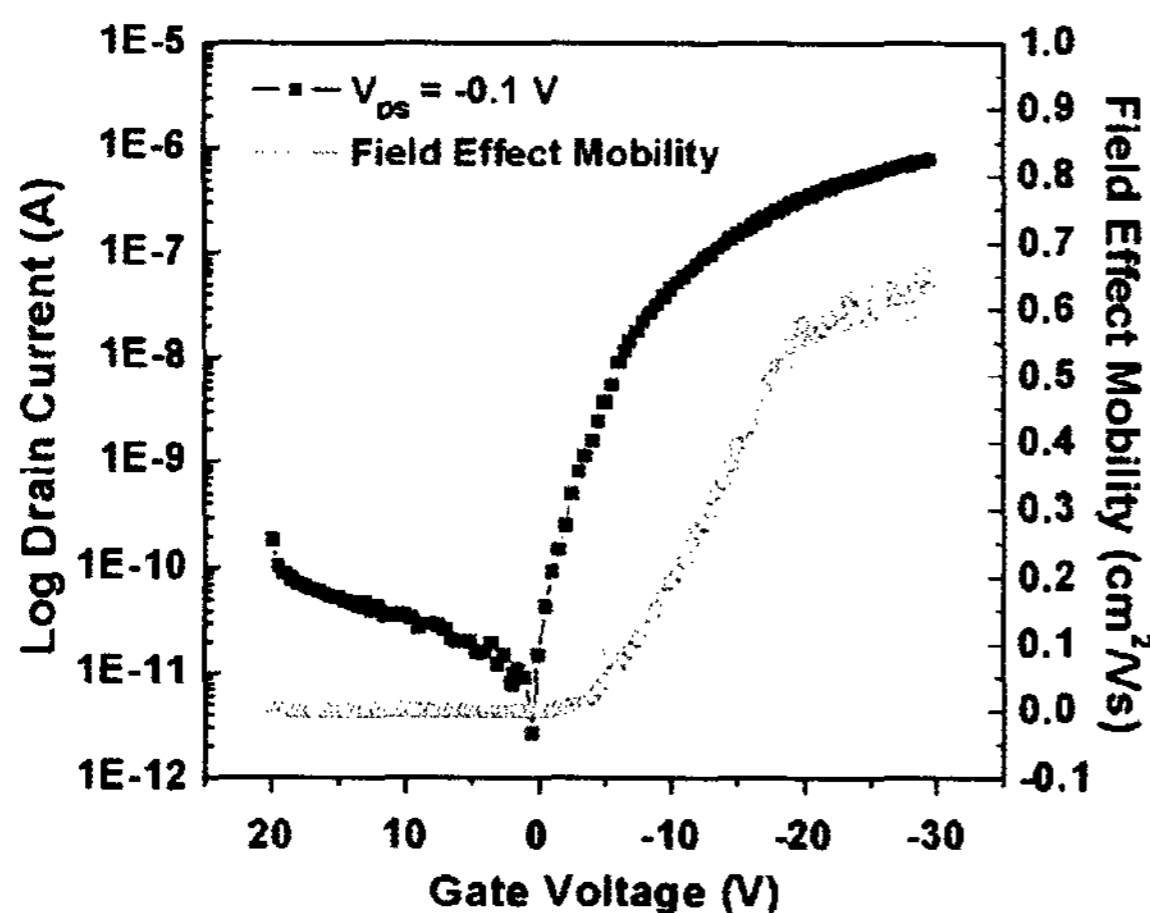
Fig. 3 (a)  $I_D$ - $V_D$  and (b)  $I_D$ - $V_G$  show electrical characteristics for the organic pentacene TFTs with a channel width of  $1000\mu\text{m}$  and a channel length of  $200\mu\text{m}$  in the presence of the KIST-JM-1 surface treatment on the gate dielectrics. It is clear that the organic pentacene TFTs with the KIST-JM-1 treatment show the better device characteristics. The mobility increased upto

0.66 cm<sup>2</sup>/Vs and the on/off current ratio of 10<sup>5</sup> could be obtained. These remarkably improved characteristics of the OTFT seem to be ascribed to the uniformity of the pentacene grain as well as the enhanced contact edge effect between the surface modified gate dielectrics and organic pentacene molecules. In addition, the hydrophobic pentacene molecules became more feasible to bind with the hydrophobic tails of organic molecules on the surface treated gate dielectric layer.

So, it should be noticeable that the intermolecular chemical reaction between the KIST-JM-1 and ZrO<sub>2</sub> brings the more improved device performance. It can be seen that application of the KIST-JM-1 shows the better surface morphology because the KIST-JM-1 makes organic electrostatic interaction of the surface between the pentacene and the ZrO<sub>2</sub> stronger based on the lipophilic aggregation effect.



(a)



(b)

Fig 3. (a) Electrical characteristics of I<sub>D</sub> vs V<sub>D</sub> at various V<sub>G</sub> obtained from the pentacene TFT prepared in the presence of

KIST-JM-1 treatment of the gate dielectrics (b) Electrical characteristics of I<sub>D</sub> vs V<sub>G</sub> and field effect mobility at V<sub>D</sub> of 0.1 V obtained from the pentacene TFT prepared in the presence of KIST-JM-1 treatment of the gate dielectrics.

For the evidence of the reaction of the KIST-JM-1 with ZrO<sub>2</sub>, we took Infra-Red spectroscopy with the reaction mixture. As shown in Fig. 4, two sharp stretching bands at 2921 and 2850 cm<sup>-1</sup> indicate that the sample has an aliphatic C-H which comes from the reacted KIST-JM-1. Two peaks at 1459 and 1431 cm<sup>-1</sup> are for the aliphatic C-H bending. In addition, one sharp stretching band at 1083 cm<sup>-1</sup> is for C-O single bond.

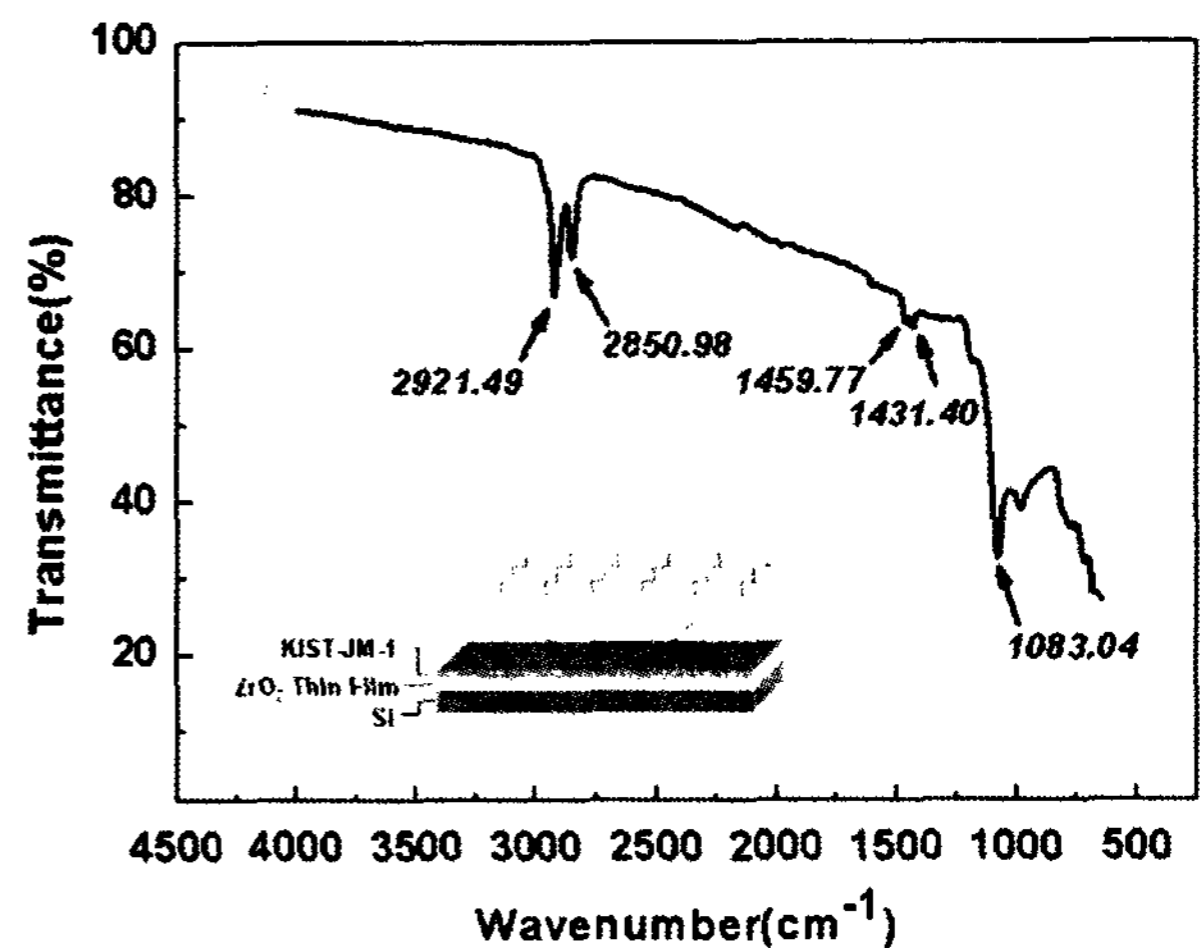


Fig 4. Infra-Red Spectrum of the ZrO<sub>2</sub> - KIST-JM-1 deposition. Sample was prepared by deposition of ZrO<sub>2</sub> on the silicon wafer followed by surface treatment of the KIST-JM-1.

It can also be expected that a substitution reaction of the -OCH<sub>3</sub> group of the KIST-JM-1 with the ZrO<sub>2</sub> gave a ZrO<sub>2</sub>- KIST-JM-1 compound on which the organic pentacene molecule was easily deposited because the van der Waal's lipophilic attraction between the KIST-JM-1 and the pentacene are strong enough to have an intermolecular interaction, providing the excellent adhesion of the organic pentacene molecules on gate dielectric films.

#### 4. Conclusion

In summary, we report the electrical characteristics of the organic pentacene thin-film transistors fabricated on flexible polyethersulfone film by a four-level mask process. It is found that chemical treatment of the gate dielectric surface with KIST-JM-1 gives greatly rise to an increase of field effect mobility. It is thus concluded that the organic pentacene thin film transistors shows the dependence of field effect mobility on the interface surface state of gate dielectric/pentacene, which may be modified by chemical properties in the gate dielectric surface.

## 5. References

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