Electrical Effects of the Adhesion Layer Using the VDP Process on Dielectric

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Abstract
In the present paper, it was investigated that adhesion layer on gate insulator could affect the electrical characteristics for the organic thin film transistors (OTFTs). The polyimide (PI) as organic adhesion layer was fabricated by using the vapor deposition polymerization (VDP) processing. It was found that electrical characteristics improved comparing OTFTs using adhesion layer to another. We researched adhesion layer as a function of thickness. For inverted-staggered top contact structure, field effect mobility, threshold voltage, and on-off current ratio of OTFTs using adhesion layer of PI 15 nm thickness on the gate insulator with a thickness of 0.2 μm were about 0.5 cm^2/Vs, -0.8 V, and 10^6, respectively.

1. Introduction
The electrical performances of organic thin-film transistors (OTFTs) have been improved for the last decade. Inorganic materials have been generally used as gate insulating layer, such as silicon oxide that has properties of a low electrical conductivity and a high breakdown field [1-4]. However, surfaces of inorganic insulating layers that have hydrophilic property, may affect most of organic semiconductor materials. It caused the field effect mobility and drain current to decrease due to the mismatching of insulator and semiconductor layer. Since the interface between the inorganic insulator and organic semiconductor layer was formed by two different properties material, such as hydrophilic and hydrophobic, it is of poor quality and may cause a defect and disorder of semiconductor layer. To avoid this problem, various materials are studied in previous report of OTFTs, such as hexamethyldisilazane (HMDS). Other researcher found that the characteristics of pentacene TFTs can be improved by using a self-organizing material like octadecyltrichlorosilane (OTS) between the SiO_2 gate dielectric and the pentacene active layer [4]. But these methods were a wet process, such as spin-casting, dipping and self-assembly, which could be easily contaminated in progress. In order to prevent devices from contamination, we introduced dry-processing method, such as VDP process [5, 6]. In this work, we have investigated OTFTs with the fabricating PI adhesion layer formed by VDP of 6FDA and ODA.

2. Experiment
All our devices were fabricated on glass substrates, which was the staggered-inverted structure as shown in Figure 1. In this structure, the 100 nm-thick indium-tin-oxide (ITO) as a gate electrode was sputtered and the 0.2 μm-thick SiO_2 as gate insulator was deposited by plasma enhanced chemical vapor deposition (PECVD).

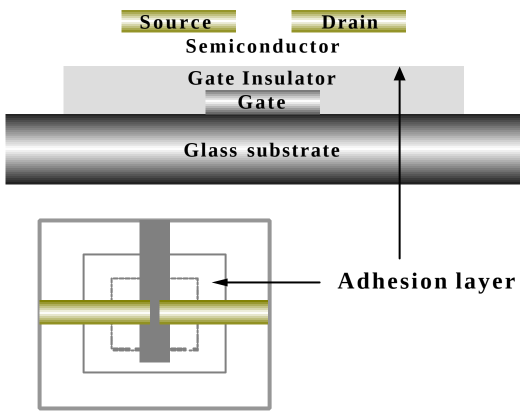


Fig. 1. The structure of OTFTs (side view and top view)

This substrate deposited gate electrode and gate insulator was supplied with the LG-Phillips LCD Company. To improve the quality of the organic semiconductor/dielectric interface, PI film as adhesion layer was co-deposited on the SiO_2 by high-vacuum thermal-evaporation with an acid dianhydride (6FDA) and a diamine (ODA) at 5×10^{-7} torr. Here, deposition rate of 6FDA and ODA was a 5 Å/s, respectively and cured at 150 ℃ for 1 h followed by 200 ℃ for 1 h in the vacuum oven at 5×10^{-3} torr. Figure 2 shows the simplified mechanism of polyimidazation via the condensation of 6FDA and ODA. Pentacene as active layer was deposited by thermal evaporation at 5×10^{-7} torr, deposition rate of 0.3 Å/s, and total thickness of 60 nm after material purification by vacuum gradient sublimation. During the deposition of pentacene, the substrates were held at room temperature. The devices were completed by thermal deposition of gold (Au) to form source and drain electrodes through the shadow mask. The fabricated OTFT has a channel length of 50 μm and width of 1.25 mm (W/L = 25).

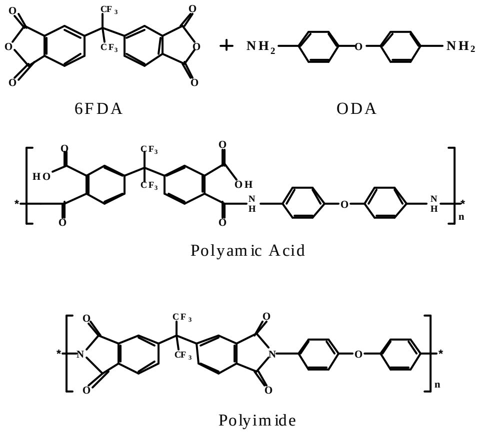


Fig. 2. Simplified mechanism of polyimidazation via the condensation of 6FDA and ODA.

3. Result and Discussion

In order to confirm formation of PI film, 6FDA and ODA were deposited on a silicon wafer, and analyzed by FT-IR. Figure 3 shows FT-IR spectrum of PI. The first step reaction took place immediately after the deposition in vacuum without annealing and the deposited monomers were converted into polyamic acid. But it had not yet polymerized to PI.

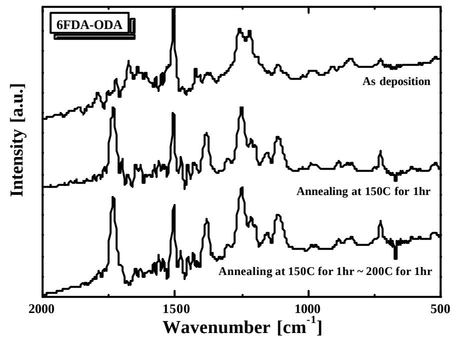
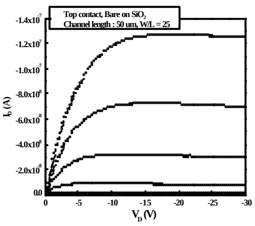


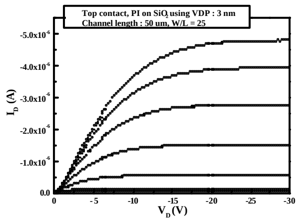
Fig. 3. Fourier transforms infrared (FT-IR) spectra of polymeric films.

After annealed at 150 ℃ for 1 h followed by 200 ℃ for 1 h, the C-N imide peak appeared at 1380 cm^{-1} and the amide acid peak disappeared at 1660 cm^{-1}, and there was difference in the intensity of all the imide peaks as compared with the annealing at 150 ℃ for 1 h. Besides it appeared that ether peak is at 1210 cm^{-1}, C-N stretching is at 1300~1325 cm^{-1}, C=C stretching mode of the ODA moiety (excess ODA) is at 1500 cm^{-1} and anhydride stretching is at 1780 ~ 1850 cm^{-1} .

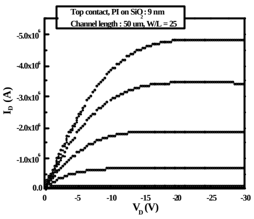
This study of OTFTs is the understanding about the effect of an adhesion layer for OTFTs. Therefore, transfer and output electrical characteristics of OTFTs were investigated as a function of the PI thickness. PI as adhesion layer was deposited on top of the SiO_2 dielectric layer of OTFT and the thickness of adhesion layer was sequentially increased from 0 to 15 nm. Figure 4 and 5 show output characteristics of OTFTs and transfer characteristics as a function of various thickness of PI. It was observed that the difference of PI thickness resulted in the effect of the electrical characteristics for OTFTs. Not only I_D increased to a maximum current value from -1.3×10^{-7} to -1.5×10^{-5} A when using a 15-nm-thick PI adhesion layer, but also on/off current ratio increased from 10^4 to 10^6. This indicates that the electrical properties of the OTFTs were improved by using adhesion layer. The field effect mobility μ_{FET} is generally determined in saturation region, which could be evaluated simply from $V_D > V_G - V_T$ where V_G is the gate voltage. In this region, the current can be modeled as $I_{Dsat} = (W/2L)\mu_{FET}C_i(V_G-V_T)^2$, where W and L are the channel width and length, and C_i is the capacitance of the gate dielectric layer [7]. The field effect mobility



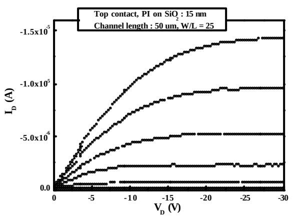
(a) bare SiO_2



(b) 3 nm thick PI



(c) 9 nm thick PI



(d) 15 nm thick PI

Fig. 4. Electrical out put characteristics of OTFTs as function of PI thickness.

is therefore estimated from the slope of the square root of the saturation current, $I_D^{1/2}$ as a function of V_G. We determined that the μ_{FET} of an OTFT with PI thickness of 15 nm were about 0.4 cm^2/Vs. At $V_D = -20$ V, a threshold voltage of about -0.8 ~ -1 V, an on/off current ratio of 10^6, and subthreshold slope of 2.0 ~ 2.5 V/decade are extracted.

Figure 5 shows the log (I_D) and I_D vs V_G transfer characteristics for the OTFTs with various PI thicknesses. It indicates that the electrical transfer characteristics of the OTFTs without an adhesion layer have the poorest electrical performances.

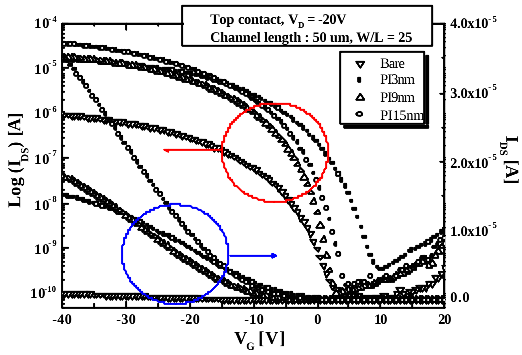


Fig. 5. Electrical transfer characteristics of OTFTs (V_D = -20 V) as a function of PI thickness

With increasing PI thickness, the transfer characteristic of OTFTs was improved, especially 15-nm-thick PI. Since PI with a hydrophobic property was deposited on SiO_2 with a hydrophilic property, the interface property between pentacene and PI is better. These results proved that PI used as adhesion layer enhances pentacene ordering due to the good matching of insulator and semiconductor layer.

In case of the PI film having not enough thickness, it caused leakage current and it is able to confirm from gate leakage current. I_G-V_G characteristics as a function of PI thickness showed in Figure 6. For the OTFTs with 3-nm-thick PI, I_G increased according to increasing V_G at V_D of -20 V. We suggest that the PI formed the island and it cause induced charge carrier to pass through the gate insulator. Therefore, in order to carry out function of adhesion layer, the above 9 nm thickness of PI film is required.

Several papers proved that carrier transport in field effective channels of pentacene is dominated by defects which can form trapping site [3, 8-9]. Therefore, the interface quality between the semiconductor and the gate dielectric is a critical part of the field-effect device and its control is important. We suggested that pentacene molecules were densely packed onto an adhesion layer than onto a bare SiO_2 dielectric. It was believed that the most important factor for obtaining better mobility reported here is improved adhesion quality between pentacene and PI layer and appropriate PI thickness. As the results, mobility was obtained about 0.01 cm^2/Vs for bare SiO_2, whereas when using adhesion layer, it shows the improvement in value of 0.1 – 0.4 cm^2/Vs according to the thickness of PI

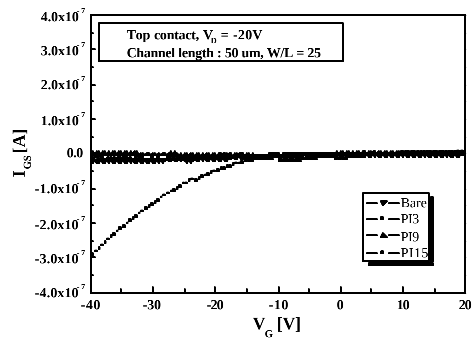


Fig. 6. I_G as a function of gate voltage for the OTFTs (V_D = -20 V) as a function of PI thickness

Based on these results, we also have investigated its application for bottom contact configuration for OTFTs. In case of bottom contact configuration, contact resistance between electrode and active layer would be expected to reduce by employing PI adhesion layer because it fills up the edge of electrode and pentacene. Furthermore, PI adhesion layer, in bottom contact structure, would facilitate pentacene molecular ordering on the PI surface.

4 Conclusion

We demonstrated electrical effect of adhesion layer on dielectric for OTFTs. Using of these PI adhesion layer, the performance of OTFTs with top contact structure was enhanced, which represents the possibility of application on bottom contact structure. For 15 nm-thick-PI, the mobility of OTFT was about 0.4 cm^2/Vs and at V_D = -20 V, a threshold voltage of about -0.8 ~ -1 V, an on/off current ratio of 10^6, and subthreshold slope of 2.0 ~ 2.5 V/decade are extracted.

5. Acknowledgements

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6. References

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