Electrical Effects in Organic Thin-Film Transistors Using Polymerized Gate Insulators by Vapor Deposition Polymerization (VDP)

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Abstract

In this paper, it was demonstrated that the organic thin film transistors with the organic gate insulators were fabricated by vapor deposition polymerization (VDP) processing. The configuration of OTFTs was a staggered-inverted top-contact structure and gate dielectric layer was deposited with 0.45 μm thickness. In order to form polyimide as a gate insulator, VDP process was also introduced instead of spin-coating process. Polyimide film was respectively co-deposited with different materials. One was from a 4,4'-oxydiphthalic anhydride (ODPA) and 4, 4'-oxydianiline (ODA) and the other was from 2,2-bis(3,4-dicarboxyphenyl) hexafluoropropane dianhydride (6FDA) and ODA. And it was also cured at 150 ℃ for 1 hour followed by 200 ℃ for 1 hour. Electrical characteristics of the organic thin-film transistors were detailed comparisons between the ODPA-ODA and the 6FDA-ODA which were used as gate insulator.

1. Introduction

The processing technology performances of organic thin-film transistors have improved for the last decade. Gate insulator layer has generally used inorganic layer, such as a silicon oxide that has properties of a low electrical conductivity and a high breakdown voltage.[1]~[4] However, inorganic insulating layers, which are formed at high temperature, may affect other layers formed previous processes.[5] On the other hand, organic insulating layers, which are formed at low temperature, do not affect pre-process. In this paper, we propose the new dry-processing method of fabrication organic gate dielectric film of field-effect transistors. Vapor deposition polymerization that is mainly used to the conducting polymers is introduced to form the gate dielectric. This method is appropriate mass production especially requiring various and complex process, for example, flat panel displays. Because it was taken advantage of following, no need of catalysts to polymerize, ease of preparation conditions, ease of making polymers with another chemical structure and in-situ dry process with flexible low-cost large area displays.[6],[7]

2. Experimental

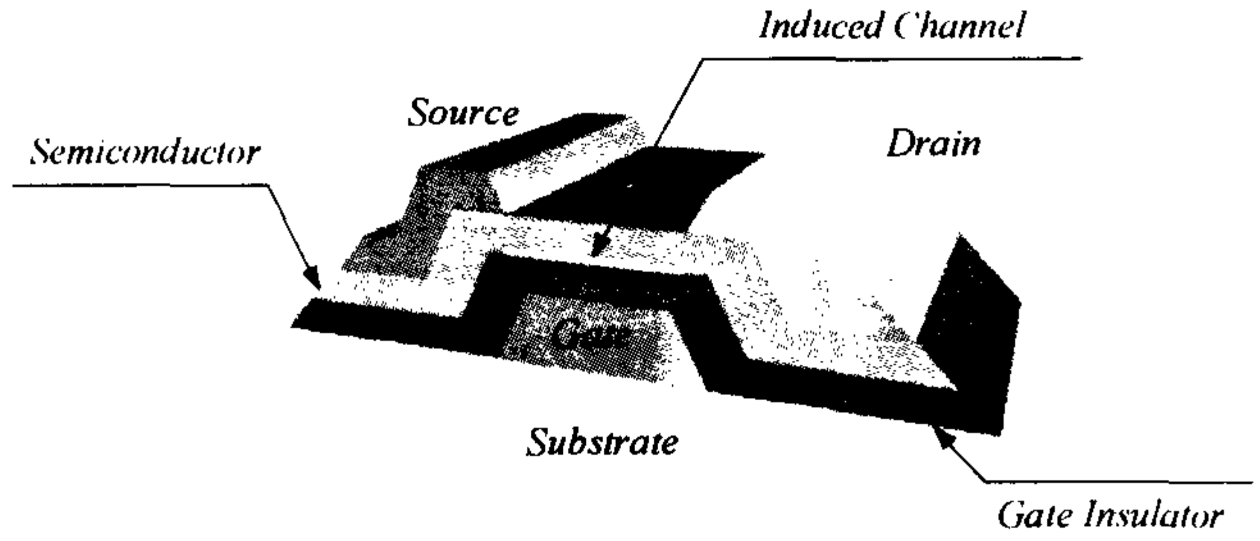


Fig. 1. The device scheme of all-organic thin-film transistors using polymeric gate dielectric.

All-organic thin-film transistors were fabricated to demonstrate that thermally evaporated polyimide was used as a gate dielectric. All transistors were fabricated on glass substrates with a staggered-inverted structure as shown in Figure 1. In this structure, two different voltage sources were used, one (V_G) is across the dielectric layer, which generates the charges, and the other (V_D) is along the active layer (channel), which drives them from source to drain. Here, first, 100 nm-thick Al as a gate electrode was evaporated through a shadow mask. Next, polyimide film was co-deposited by high-vacuum thermal-evaporation from ODPA and ODA, and 6FDA and ODA, and cured at 150 ℃ for 1 hour followed by 200 ℃ for 1 hour, respectively. Polyimides are accomplished after these of process. And next, pentacene active layer was deposited by thermal evaporation at 5×10^{-6} Torr with deposition rate of 0.4~0.5 Å/s, and total thickness of 80 nm after material purification by vacuum gradient sublimation. During the deposition of pentacene, the substrates were held at room temperature. Improved purity of the semiconductor material, moderate heating, and low deposition rates have been used to improve the performance of thin-film transistor.[4] Last, the devices were completed by thermal deposition of gold (Au) to form source and drain contacts though a shadow mask.[8] The electrical characteristics were measured by Keithly 238 and 617 source-measurement unit. Because pentacene is a p-type semiconductor, and pentacene thin-film transistors operates in accumulation mode, negative voltage was biased at drain-source and gate-source electrode.

3. Result and Discussion

Polyimide films co-deposited from ODPA and ODA, and 6FDA and ODA are characterized by the presence of the imide functionality, a cyclic tertiary amine bound by two carbonyl groups, and either an aliphatic or aromatic group in the main chain. The curing process and the associated cross-linking will affect mechanical, thermal, and electrical properties of polyimide. Figure 2 was shown that the mechanism of polyimidazation via (a) ODPA-ODA, (b) 6FDA-ODA.[7]

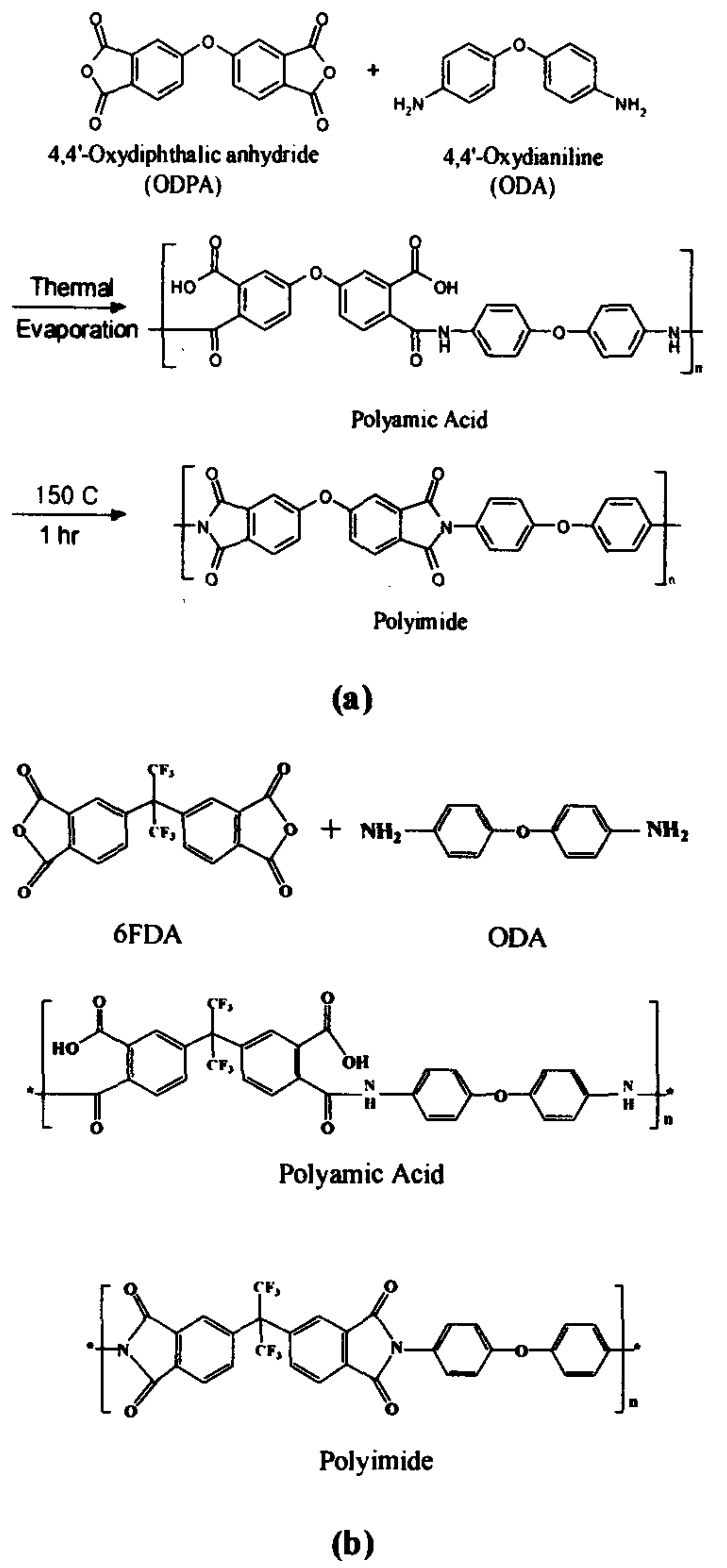


Fig. 2. Polyimide is the polymer made from the polymerization of a (a) ODPA-ODA and (b) 6FDA-ODA for using gate insulator.

In order to characterize the organic polymeric film layers, 6FDA and ODA were deposited on a silicon wafer, and analyzed by FT-IR. Figure 3 shows the spectrum of a deposited layer annealed at 150 ℃ for 1 hour followed by 200 ℃ for 1 hour after co-deposition. It is seen that the first step reaction occurred immediately after the deposition in vacuum without annealing and the deposited monomers converted to polyamic acid. But it had not completely polymerized to polyimide. After annealing at 150 ℃ for 1 hour followed by 200 ℃ for 1 hour, the imide peak appeared at 1380 cm^{-1} and the amide acid peak disappeared at 1660 cm^{-1}.[9],[10]

In the ITO-polyimide-Al structure, metel-insulator-metal (MIM) structure was fabricated to analyze the electrical characteristic of photoacryl as shown in Figure 4. For the MIM structure, aluminum was thermally deposited with 150 nm thickness, and ODPA-ODA polymeric film and 6FDA-ODA polymeric film were co-deposited with 0.45 μm and 0.3 μm thickness respectively, and cured at 150 ℃ for 1 hour followed by 200 ℃ for 1 hour. Since breakdown field was larger than 0.3 MV/cm and 0.9 MV/cm, it seems that polymeric materials can be used as a gate dielectric instead of silicon dioxide.

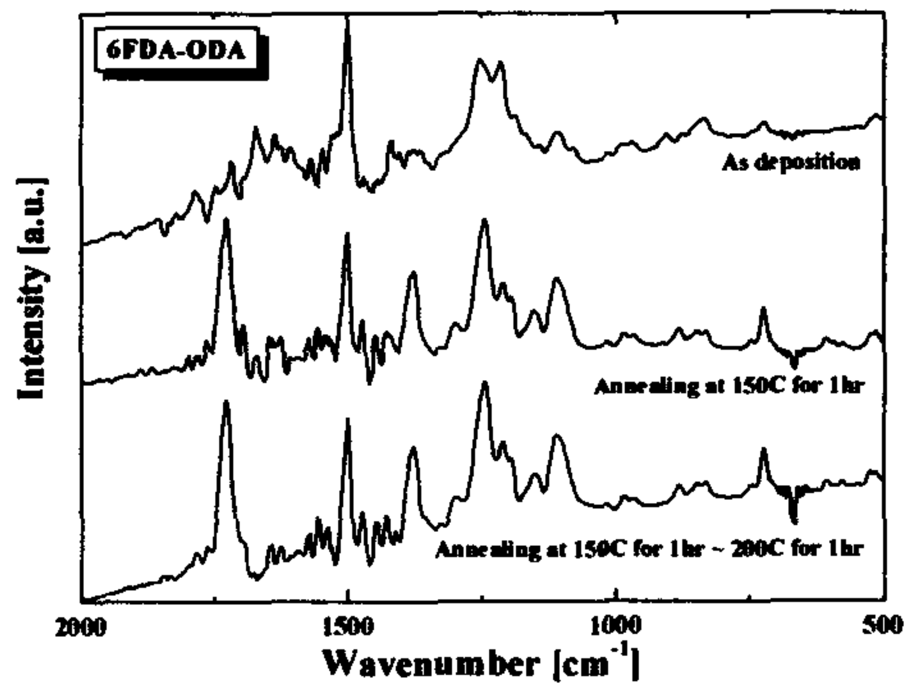


Fig. 3. Fourier Transform Infrared (FT-IR) spectra of a cured polymeric films.

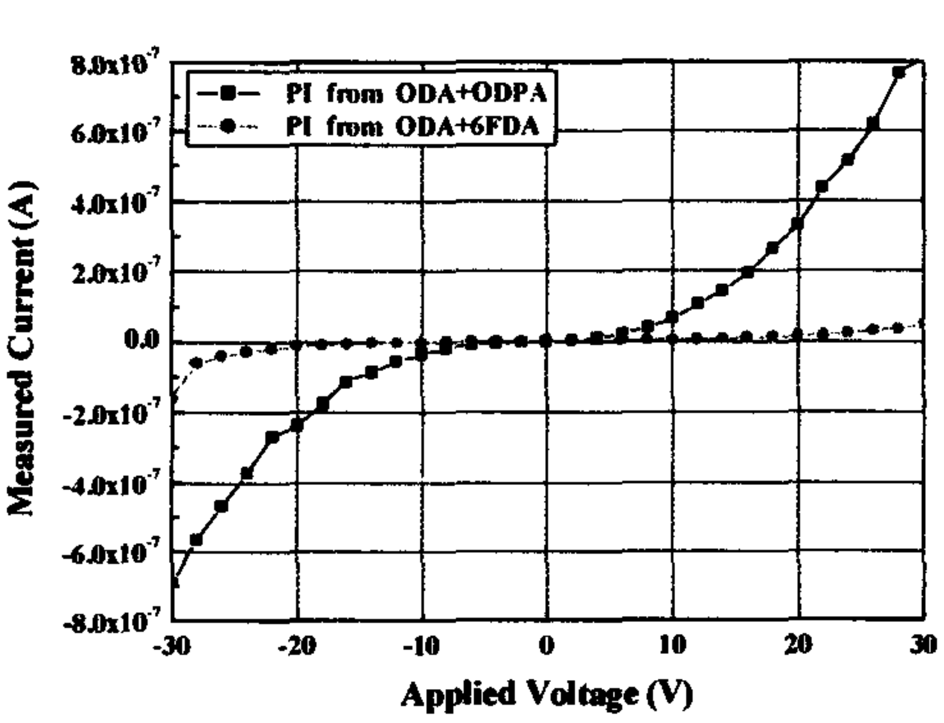
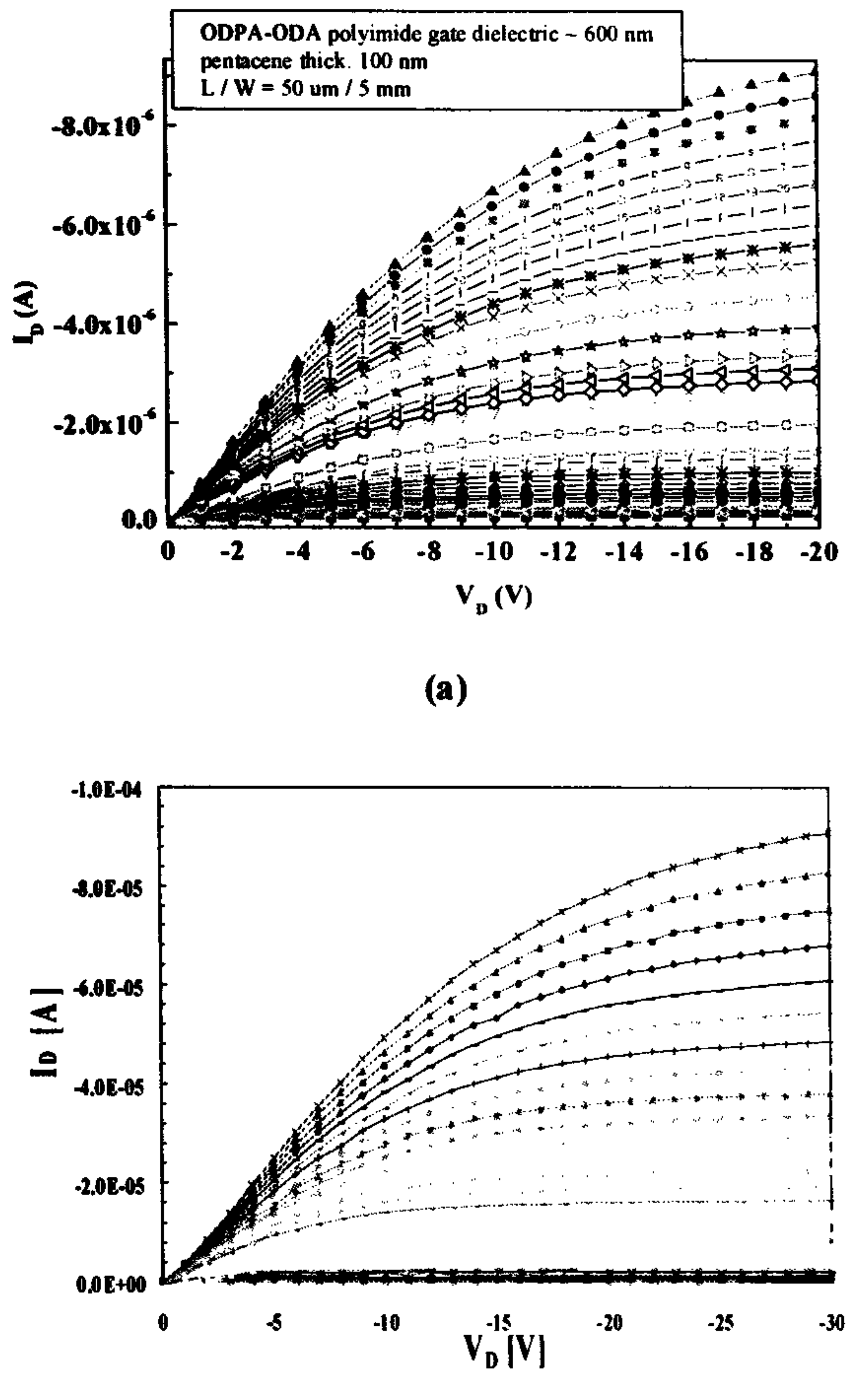


Fig. 4. The breakdown field characteristic of polyimide films that co-deposited by high-vacuum thermal-evaporation from ODPA-ODA, and 6FDA-ODA.

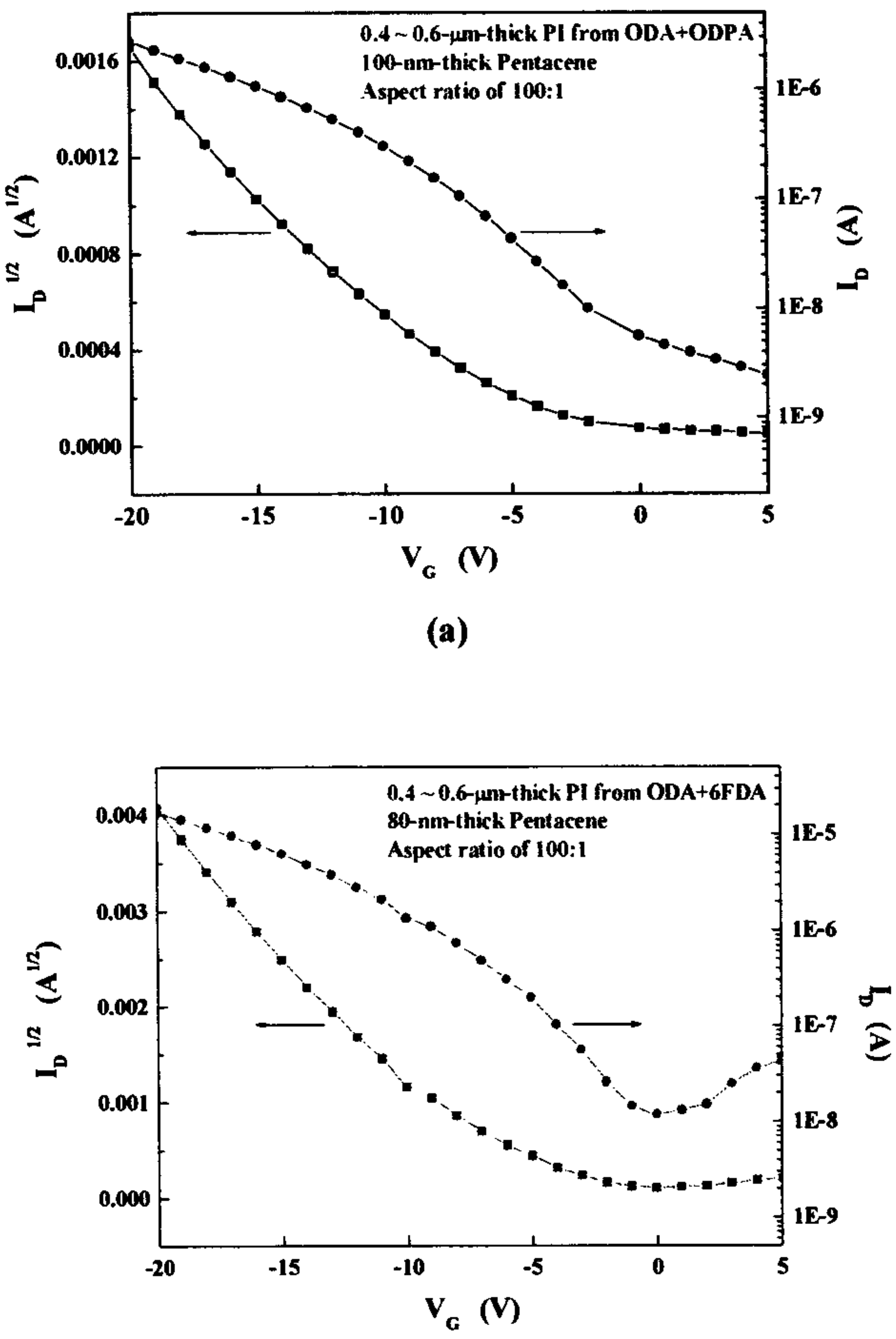
The Electrical characteristics of the individual organic thin film transistor using (a) ODPA-ODA polymeric material and (b) 6FDA-ODA polymeric material as gate insulators are shown enhancement mode operation in Figure 5. It shows the output I_D-V_D characteristics for an organic thin-film transistor with channel length and width of 50μm and 5mm, respectively. According to incensement of gate voltage and drain voltage, drain current was getting increased and saturated. The field effect mobility (μ_{FET}) is generally determined in the region where the drain current (I_D) is saturated i.e.; μ_{FET} could be evaluated simply from $V_D > V_G - V_T$ where V_G is the gate voltage. In this region, the drain current can also be modeled by $I_Dsat = (W/2L)\ \mu_{FET}\ C_i\ (V_G - V_T)^2$, where W and L are the channel width, length, and C_i is the capacitance of the gate dielectric layer. μ_{FET} is therefore estimated from the slope of the square root of the saturation current, $I_D^{1/2}$ as a function of the gate voltage, V_G. The drain bias (V_{DS}) got changed from 0 to -20 or -30 V and gate bias (V_{GS}) was also gotten changed from -45 to 0 V with -5 V intervals. The charge carrier mobility of a OTFTs using ODPA-ODA polymeric film and using 6FDA-ODA polymeric film were 0.13 cm^2/Vs and 0.17 cm^2/Vs, respectively. These are typical bias conditions for p-type channel operation.



(a)

(b)

Fig. 5. The output characteristics of the individual organic thin film transistors using (a) ODPA-ODA polymeric material and (b) 6FDA-ODA polymeric material as gate insulators.



(a)

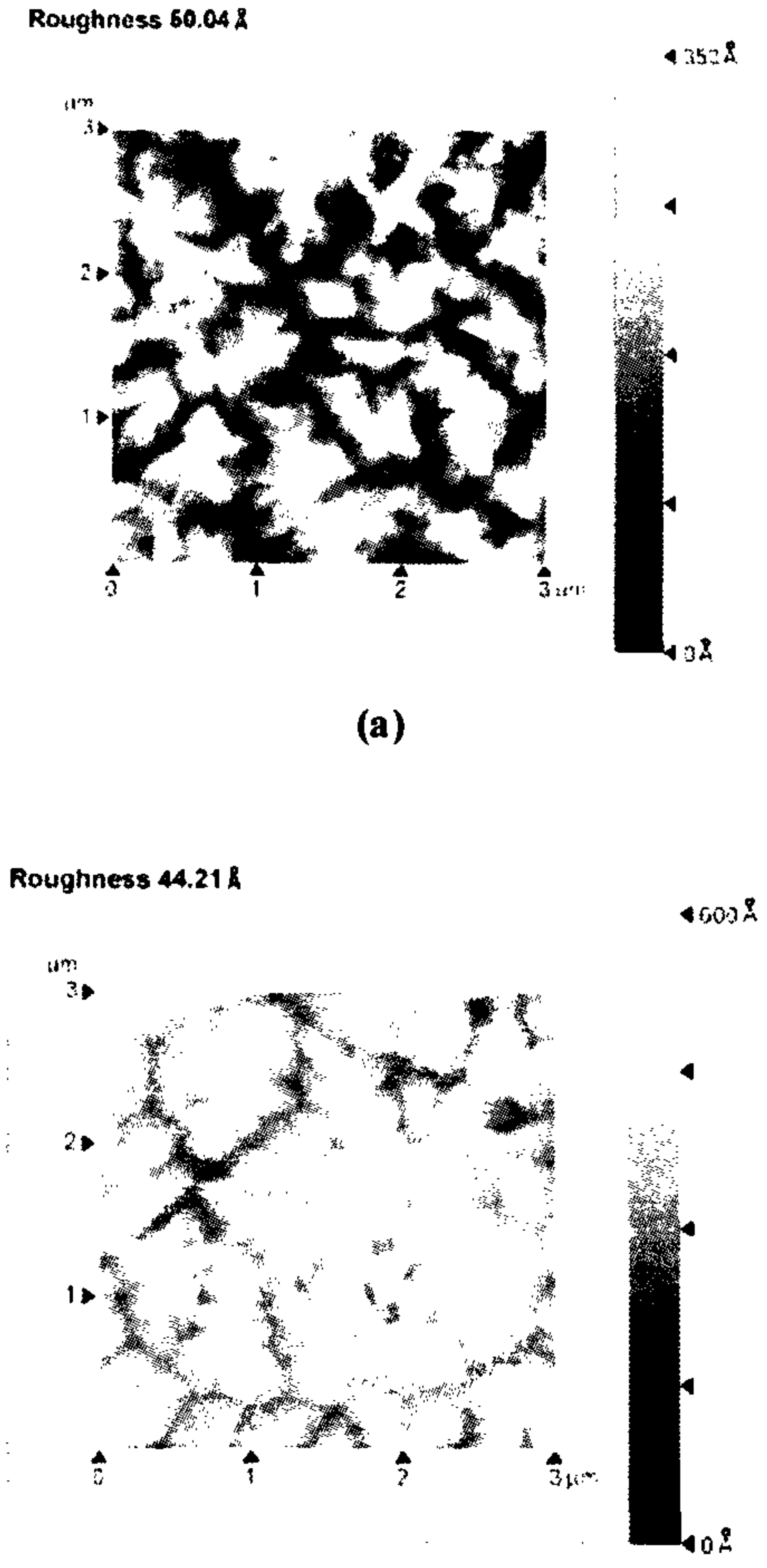
(b)

Fig. 6. Transfer characteristics of transistor using (a) ODPA-ODA polymeric material and (b) 6FDA-ODA polymeric material as a gate insulator.

We extracted the field effect mobility, threshold voltage and on/off ratio by using the log (I_D)-V_G characteristics in Figure 6. The values of those were about 0.13 cm^2/Vs at V_D = -25 V, -7 V and 10^6 A/A, respectively. It was also found that the leakage current occurred.

Figure 7(a), (b) shows the Atomic Force Microscopy (AFM) images of 80 nm thick pentacene deposited onto different substrates. Compared to AFM images, Figure 7(b) indicates the morphology of pentacene on the 6FDA-ODA polymeric film surface is more dendritic with lager grain size than the other one. In large grain size pentacene tends to characterize a faster field effect mobility because it reduces the grain boundaries, in which may disturb the carrier movement. Therefore, the field effect mobility might be enhanced.[11] Since the interface between the organic active material and the gate dielectric material is a critical part of the field-effect device, control of this interface is important. Because the charge carrier transport in active layer, pentacene deposited, is dominated by the defects such as disorder and chemical impurities which can form trapping sites, we believe the most important factor to obtain better mobility is to improve quality of the evaporated pentacene layer.

Recently other researcher found that the characteristics of pentacene TFT's can be improved by using a self-organizing material like octadecyltrichlorosilane (OTS) which could make a good packing for pentacen on the SiO_2 gate dielectric.[4] When we use a 6FDA-ODA polymeric materials as gate dielectric, additional process like as OTS treatment is not required to improve morphologies because 6FDA-ODA forms sufficiently large size grain.



(a)

(b)

Fig. 7. Surface morphologies of pentacene film (a) on the ODPA-ODA, and (b) on the 6FDA-ODA polymeric film

4. Conclusion

We proposed the new dry-processing method of organic gate dielectric film in organic field-effect transistors. Vapor deposition polymerization (VDP) that is mainly used to the conducting polymers is introduced to form the gate dielectric. This method is appropriate to mass production in various end-user applications, for example, flat panel displays, because it has the advantages of shadow mask patterning and in-situ dry process with flexible low-cost large area displays. Proposed method can be applied to in-situ solution-free process to fabricate all-organic thin-film transistors during overall fabricating steps. Also, it is more suitable material on the 6FDA-ODA polymeric film than ODPA-ODA polymeric film as a gate insulator, and it was found that the properties of the organic thin-film transistors containing 6FDA-ODA as a gate insulator material with different electrical characteristics was better than that of the organic thin-film transistors containing ODPA-ODA in spite of the higher leakage current.

5. Acknowledgements

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6. References

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