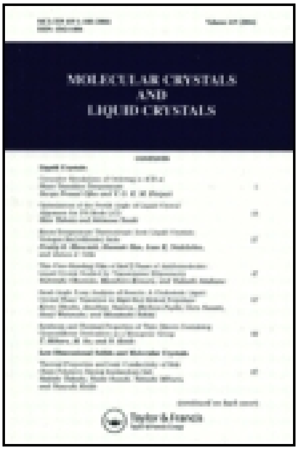

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High Performance Pentacene Thin Film Transistors with a PVA Gate Dielectric

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Pentacene thin film transistors were fabricated and characterized with PVA thin films as a gate dielectric. The maximum process temperature was 70°C, which corresponds to a baking temperature of the spin-coated polymeric dielectric. Glass and flexible PET foils were used as substrates. Theses devices showed high performance electrical characteristics and worked at a low operating voltage of −5 V. The highest field effect mobility of 2.6 cm^2/Vs and the lowest threshold voltage of −1.7 V were obtained on a flexible substrate.

Keywords: field effect mobility; organic thin film transistor; pentacene; PVA

1. INTRODUCTION

Organic thin film transistors (OTFTs) offer a promising technology for low-cost and large-area electronic applications such as active-matrix displays, electronic papers, flexible microelectronics and chemical sensor arrays [1–4]. Over the past ten years, significant progress has been made with respect to increasing the performance of organic semiconductors, such as improving the fabrication processes or applying a new organic material as an active layer. Pentacene TFTs have been reported to show good a performance with room temperature hole mobility of the order of 1 cm^2/Vs, on/off current ratios $>10^6$ and sub-threshold swing $\sim$0.7 V per decade of current [5]. Nowadays, OTFTs are already competitive for applications requiring large-area and low temperature processing compatible with flexible or weightless

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substrates. On the other hand, a gate dielectric for high performance OTFTs should have high gate capacitance (i.e., high-k dielectric, thin insulator films) to allow low-voltage operations [6]. It has been known that polyvinyl alcohol (PVA) is a high-k polymer with many advantages such as good surface alignment effect, processing with a non-harmful solvent (water) and low-cost materials and processing [6–9]. In this article, we report on high performance pentacene TFTs with PVA thin films as a gate dielectric.

2. EXPERIMENTAL

OTFTs were fabricated using the top contact structure shown in Figure 1(a). Al thin films of 100 nm were deposited on glass and flexible polyethyleneterephthalate (PET) substrates to be used as the gate

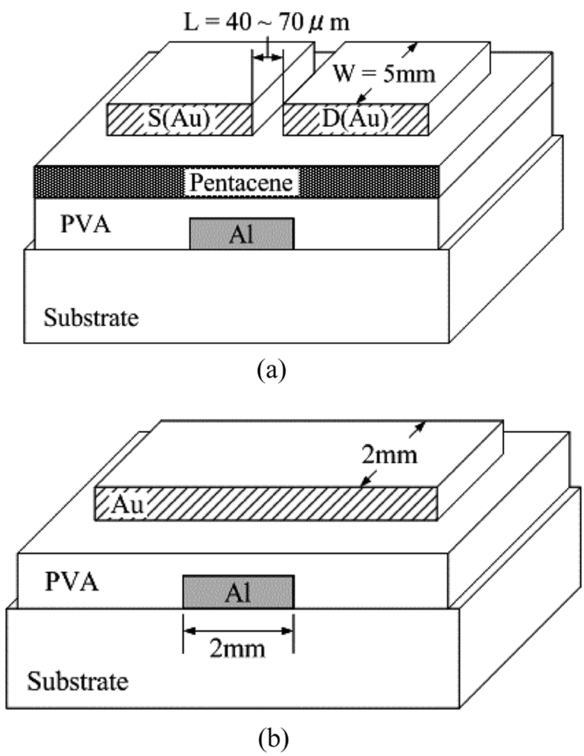

FIGURE 1 Schematic structures of (a) OTFT and (b) MIM capacitor.

electrodes. Hydrolyzed PVA with a typical M_w of 89,000 ~ 98,000 was used, as received from Sigma-Aldrich. PVA (5 wt%) were spun on Al electrodes at 2000 rpm. To ensure that all the solvents were removed from the PVA films, these dielectric films were annealed at 70°C in air atmosphere for 2 h. Pentacene was purchased commercially (98%, Tokyo Kasei Co., Ltd.) and used without further purification. Organic thin films of ca. 50 nm were deposited at room temperature (RT) under a base pressure of less than 1×10^{-3} Pa. Film thickness and growth rates were monitored by a thickness and rate monitor (CRTM-6000, ULVAC). Finally, the source and drain electrodes of 100 nm Au films were deposited through a shadow mask. The channel width is 5 mm and the channel length is 40 ~ 70 μm. The characteristics of OTFTs were measured with a two channel voltage current source/monitor system (R6245, ADVANTEST) under ambient laboratory air conditions. Furthermore, we also fabricated MIM (Metal-Insulator-Metal) capacitors shown in Figure 1(b) to analyze the electrical properties of PVA thin films, and a device area was 2 mm × 2 mm. *C-f* characteristics were measured using a LCR meter (4284A, HP).

3. RESULTS AND DISCUSSION

Figure 2(a) shows the frequency dependence of the capacitance (C_i) of PVA films coated on glass and flexible substrates. At 1 kHz, C_i of the PVA thin films on glass and flexible substrates were 25.4 nF/cm^2 and 38.1 nF/cm^2, respectively. The dielectric constant ($\varepsilon \sim 7.0$) of PVA films at 1 kHz was obtained from the films coated on a heavily n-doped Si substrate, and a film thickness was determined by ellipsometry (DVA-35, MIZOJIRI Opt. Ltd.). Thus the film thicknesses of PVA coated on glass and flexible substrates were about 240 nm and 160 nm, respectively. Thinner films formed on the flexible substrate originated higher hydrophobicity of the PET substrates. Figure 2(b) shows the leakage current through the dielectric layer as a function of the electric field applied across the capacitor. Any breakdown was not observed under 0.6 MV/cm. At an applied electric field of 0.5 MV/cm, the conductivity of PVA films was about 5.0×10^{-11} S/cm.

Figures 3(a) and 3(b) show the output characteristics of pentacene TFTs on glass and flexible substrates, respectively. These devices typically worked in a *p*-channel accumulation mode. Compared with the device on a glass substrate, the output characteristics of the device on a flexible substrate were well saturated at drain voltage of about −2.5 V. Generally, the device performance of OTFTs is evaluated with field-effect mobility (μ) and threshold voltage (V_T) extracted using

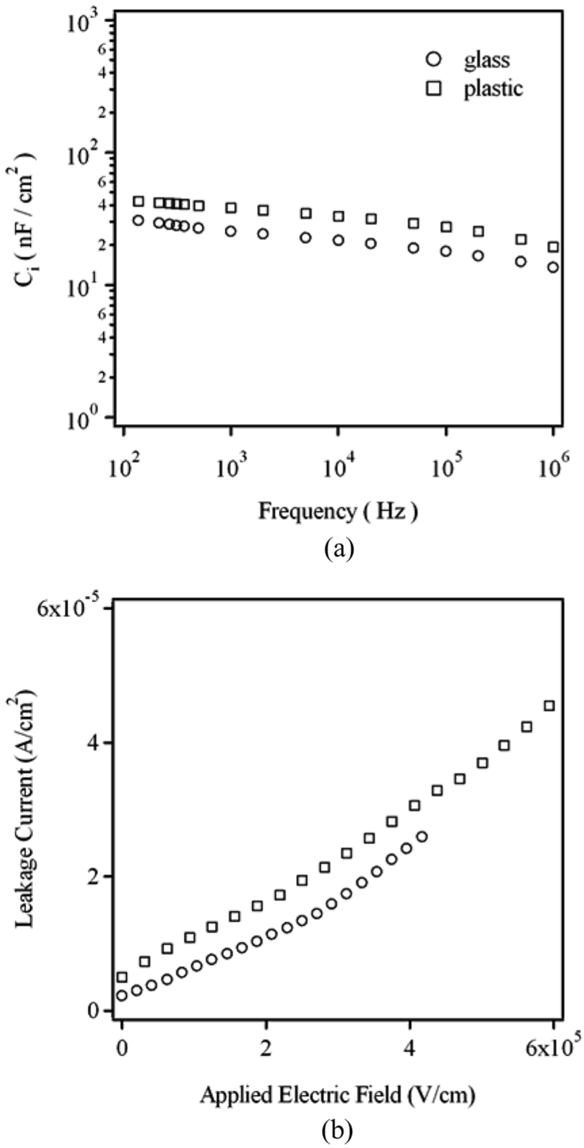

FIGURE 2 (a) Frequency dependence of C_i and (b) leakage current characteristics as functions of the applied electric field of Al/PVA/Au structures on glass and flexible substrates.

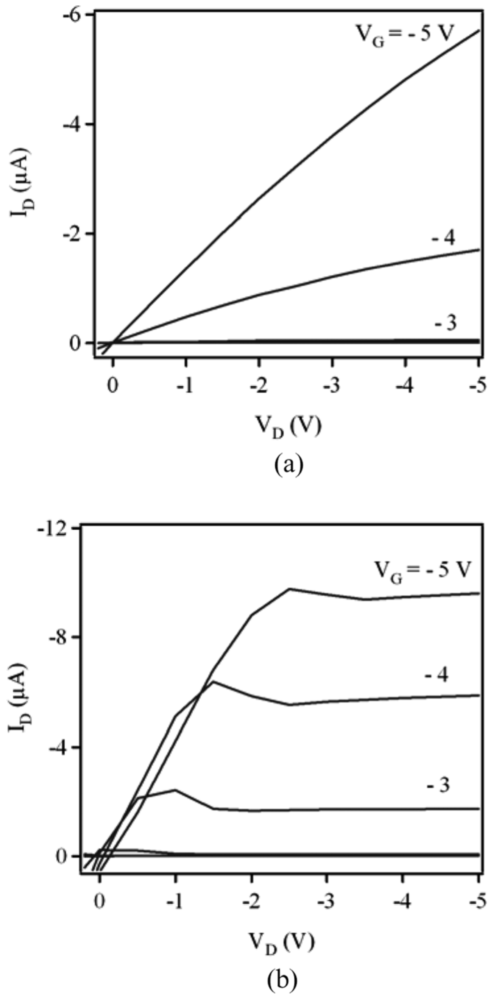

FIGURE 3 Output characteristics of pentacene TFTs with PVA gate dielectric on (a) glass (channel length $L = 65\,\mu m$) and (b) plastic (channel length $L = 45\,\mu m$) substrates.

the saturated drain current I_D vs. V_G relation [10]:

$$I_D = \frac{W}{2L} C_i \mu (V_G - V_T)^2, \qquad (1)$$

where W, L and C_i are channel width, channel length and gate dielectric capacitance per unit area, respectively. From the transfer characteristics (shown in Fig. 4) expressed as the square root of I_D with V_G, we found $\mu = 1.2\,\text{cm}^2/\text{Vs}$ and $V_T = -2.8\,\text{V}$ for the device on a glass substrate, and $\mu = 2.6\,\text{cm}^2/\text{Vs}$ and $V_T = -1.7\,\text{V}$ for the device on a flexible substrate. The higher mobility and lower voltage threshold obtained from the device on a flexible substrate are due to a higher gate capacitor, which allows a higher charge density to be induced at

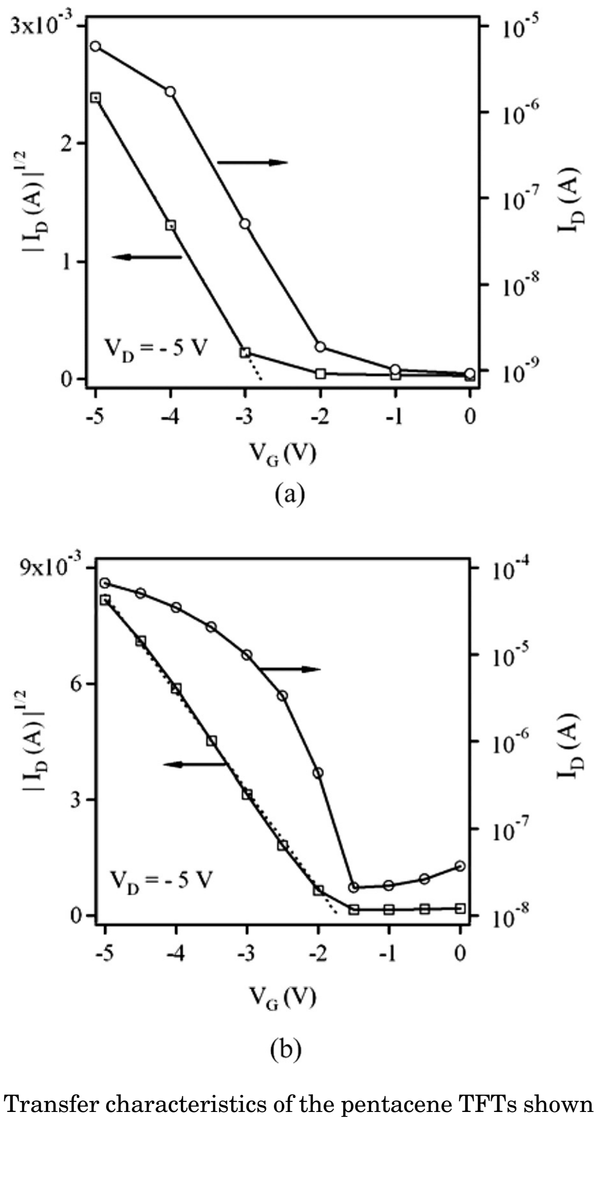

FIGURE 4 Transfer characteristics of the pentacene TFTs shown in Figure 3.

lower voltages and increases drive capability [5]. The flexible device shows mobility that is about 5 times greater than that of the reported high-performance TFTs only with 400 nm thick SiO_2 gate insulator at the same gate electrical field [11]. The result proves a PVA is an effective gate dielectric layer that greatly enhances carrier mobility at the same electric field condition in only a SiO_2 insulator OTFT. Furthermore, from Figure 4 we calculated that the current on/off ratio is an order of 10^3 for these devices when V_G changes from 0 to -5 V.

4. CONCLUSIONS

Pentacene thin film transistors were fabricated and characterized with PVA thin films as a gate dielectric. Glass and flexible PET foils were used as substrates. The maximum process temperature was 70°C, which correspond to the baking temperature of the polymeric gate dielectric. The breakdown voltage and the conductivity of the PVA films were over 0.6 MV/cm and 5.0×10^{-11} S/cm, respectively. Theses OTFTs showed high performance electrical characteristics and worked at a low operating voltage of -5 V. The highest field effect mobility of 2.6 cm^2/Vs and the lowest threshold voltage of -1.7 V with an order of 10^3 of the current on/off ratio were obtained on a flexible substrate.

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