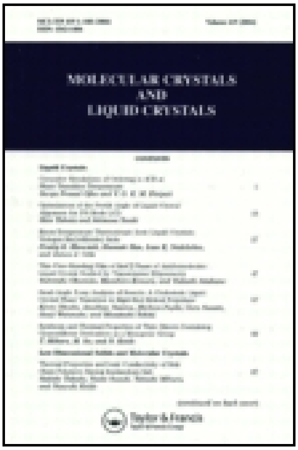

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Characteristics of Inverters Using Pentacene Organic Thin Film Transistors with Printed Ag Electrodes

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Inverters were fabricated with pentacene organic thin film transistors (OTFTs) using inkjet printing method. The gate, source and drain electrodes were printed with Ag ink. The mobility and threshold voltage of the bottom-contact OTFT were 0.078 cm^2/Vs and 2.8 V, respectively. Printed inverters operated well in 200 Hz at $V_{DD} = -20$ V.

Keywords: inkjet printing; inverter; organic thin film transistor

INTRODUCTION

Various printing techniques such as inkjet printing, gravure printing, micro contact printing, have been widely studied for manufacturing low-cost, large-area flexible electronics. Because the ink-jet printing [1,2] is direct printing method, it has considerable merits to produce micro patterned devices compared with complex photolithographic printing [3]. Organic thin film transistors (OTFTs) using pentacene as the active layer have been extensively studied by various groups, and they showed high field effective mobility of $\sim 1\,cm^2/Vs$ [4,5]. In this paper we report inverters with pentacene OTFTs using inkjet-printed Ag electrodes. Although all processes should be done with printable soluble materials in order to fabricate a low cost device, we

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chose pentacene as a active layer because of its high field effective mobility.

EXPERIMENTAL

Pentacene OTFTs with inkjet-printed Ag electrodes were fabricated in a typical bottom-gate bottom-contact configuration, as shown in Figure 1. Gate electrodes were inkjet printed (UJ200, Unijet) with nano-silver ink (ANP co.) on hexamethyldisilazane (HDMS)-treated glass substrate at a frequency of 1 kHz. The substrate temperature was maintained at 130°C during printing Ag electrodes. The insulator was prepared from solutions of poly-(4-vinylphenol) (PVP) (Aldrich Co.) and poly melamine-co-formaldehyde as a cross-linking agent, in propylene glycol monomethyl ether acetate (PGMEA) [6] 1 μm-thick PVP film as a gate insulator was spun at 1000 rpm for 30 sec and cured at 200°C for 30 min. Then Ag source and drain electrode were patterned by inkjet printing method. The thickness of inkjet-printed Ag electrodes was about 200 nm. A 100 nm-thick pentacene as an active layer was vacuum-deposited at the rate of 0.5 Å/s at the pressure $\sim 5 \times 10^{-6}$ Torr. The channel length (L) and width (W) were 55 μm and 3000 μm, respectively. The electrical characteristics of the OTFTs were measured with a semiconductor parameter analyzer (Agilent 4155C) in an N_2 dry box.

RESULTS AND DISCUSSION

The typical characteristics of pentacene OTFTs are shown in Figures 2 and 3. In the saturation regime the drain current is expressed as following equation [7].

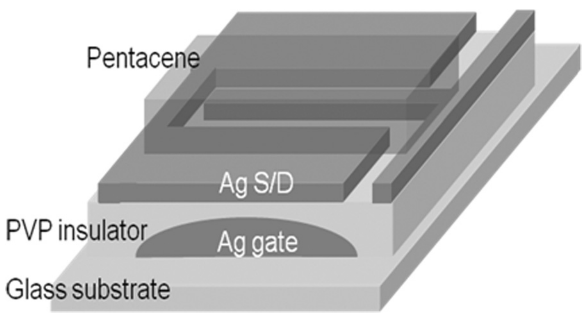

FIGURE 1 Structure of pentacene OTFT with inkjet-printed Ag electrodes and PVP gate insulator.

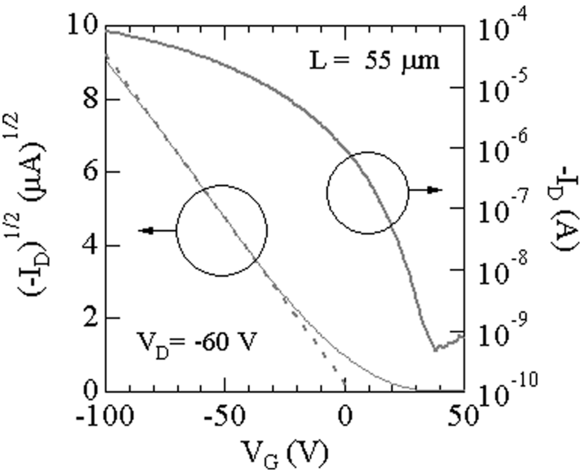

FIGURE 2 I_D-V_G characteristics of pentacene OTFT. The dashed line is fit to Eq. (1) in the saturation regime.

$$I_D = \frac{WC_i}{2L} \mu_{\mathrm{FET}} (V_G - V_T)^2, \tag{1}$$

where I_D is the drain-source current, C_i the capacitance of a gate insulator, μ_{FET} the field-effect mobility, V_G the gate voltage, and V_T the threshold voltage. The field effect mobility and threshold voltage are

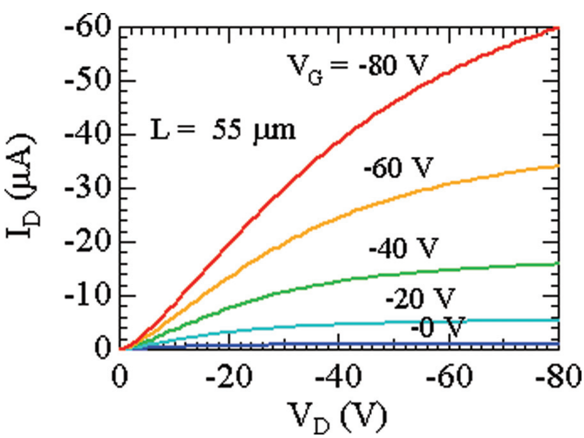

FIGURE 3 I_D-V_D characteristics of pentacene OTFT.

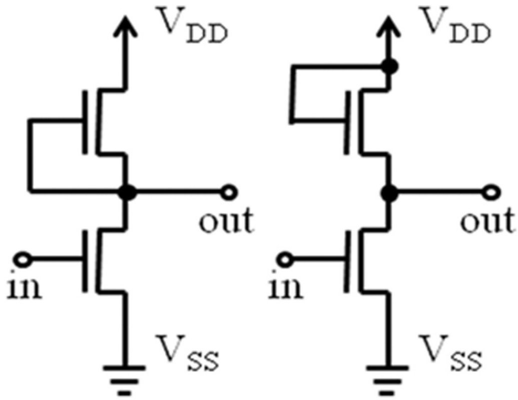

FIGURE 4 Circuit diagrams of printed inverters, depletion-mode type (left) and enhancement-mode type (right).

obtained as $\mu_{FET} = 0.078\,cm^2/Vs$ and $V_T = 2.8\,V$, respectively. The on/off current ratio (I_{on}/I_{off}) was about 10^5. If there was no overlap capacitance between the gate and source/drain electrodes, the operating frequency of the OTFT could be calculated roughly as 51 kHz with channel length ($L = 55\,\mu m$), mobility ($\mu_{FET} = 0.078\,cm^2/Vs$), and operating voltage ($V = -20\,V$).

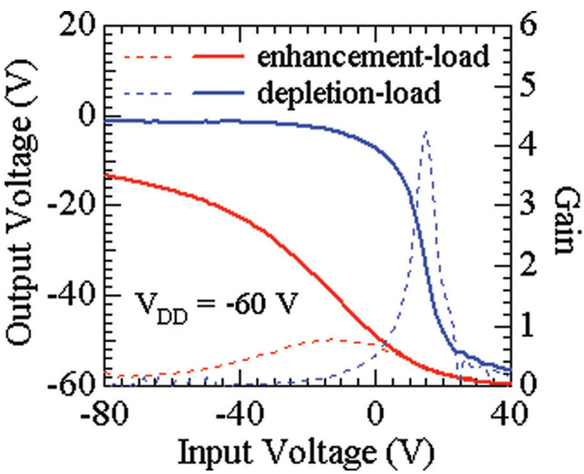

FIGURE 5 Transfer characteristics of printed inverters. The dashed lines are inverter gains. Gains of inverter with depletion-load and enhancement-load were 0.78 and 4.2, respectively.

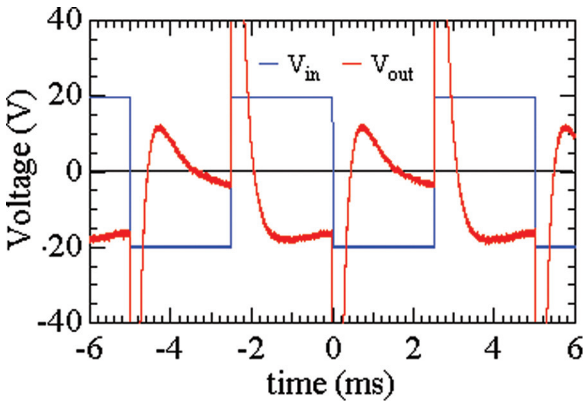

FIGURE 6 Dynamic switching characteristics of depletion-mode type inverter for the input signal of 20 V at 200 Hz.

Two types (depletion-mode and enhancement-mode) of inverters using pentacene OTFTs with inkjet-printed Ag electrodes were fabricated and their circuit diagrams are shown in Figure 4. Figure 5 shows their voltage transfer characteristics. Because the resistance of OTFT in saturation region was very low, the enhancement-mode inverter showed low gain <1 at $V_{DD} = -60\,V$. However, the depletion mode inverter showed higher gain 4.2. Both types of inverters operated well at 200 Hz frequency. Figure 6 shows the dynamic switching characteristics of depletion-mode type inverter for the input signal of 20 V at 200 Hz. The overlap capacitance between the source/drain and gate electrodes can limit the speed of the inverter [8]. Therefore, the operating frequency is expected to be over 1 kHz by reducing parasitic resistance and capacitance and shortening the channel length of transistors.

CONCLUSIONS

Pentacene OTFTs using inkjet-printed Ag electrodes were fabricated and their transistor characteristics were analyzed. The field effect mobility, threshold voltage and I_{on}/I_{off} are $\mu_{FET} = 0.078\,cm^2/Vs$, $V_T = 2.8\,V$ and $I_{on}/I_{off} \sim 10^5$, respectively. The pentacene inverters in the depletion mode showed a gain 4.2 and operated well in 200 Hz at $V_{DD} = -20\,V$.

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