Effect of Surface-Modified Poly (4-vinyl phenol) Gate Dielectric on Printed Thin Film Transistor

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Abstract

Surface modification of the gate dielectric has a strong influence on the performance of printed transistors. The surface modification occurs between the gate dielectric and semiconductor. The printed transistor with evaporated vanadium pentoxide (V_2O_5) modification exhibits a mobility of 0.2 cm^2 V^{-1} s^{-1} and a subthreshold slope of 1.47 V/decade.

1. Introduction

In recent years, organic semiconductor devices have attracted considerable attention because of their potential use in easy processing, low cost, and feasible large area fabrication by printing techniques [1]. Organic thin-film transistors (OTFTs) have been studied extensively for application in active-matrix (AM) displays and radio frequency identification tags (RFID) [2]. Several research groups have reported the integration of OTFTs with liquid crystal related displays on plastic substrates to demonstrate the feasibility of OTFTs in display applications [3,4]. The performances of OTFTs strongly depend on the use of semiconductors and dielectrics. In addition to material selection, surface properties between a gate dielectric and an organic semiconductor also play an important role in determining performance in electric characteristics of OTFTs [5–7]. A properly treated interface that promotes synergistic interactions between the semiconductor and dielectric is essential for achieving high performance of FET performance.

2. Experimental

The device geometry and the fabrication were described previously and are shown in Figure 1. The devices were fabricated on ITO-coated glass substrates (10-20 Ω/sq sheet resistance), in which ITO was used as the interconnection pads for easy probing measurement. Coffee ring ridges of insulating polymer were first formed on a substrate by ink-jet printing. Then, the insulator film was subjected to proper plasma etching and treatment to afford a tiny ridge with hydrophobic surface. Adjacent to the ridge, conductive polymer ink was printed as source and drain electrodes. Subsequently, Regioregular poly(3-hexylthiophene)(P3HT) purchased from Rieke was printed upon the ridge and the polymer conductive electrodes and then dried on a hot plate at 90 °C for 20 min. Thin V_2O_5 was employed for P3HT surface modification. Finally, the polymer dielectric was formed by spin-coating propylene glycol monomethyl ether acetate solution of Poly (4-vinyl phenol)(PVP) and the top electrode was ink-jet printed sequentially to complete the OTFT fabrication. The channel length (L) and width (W) were 10 and 1000 µm, respectively. The current–voltage (I–V) characteristics of OTFTs were measured in N_2 by Keithley semiconductor analyzer (4200-SCS)

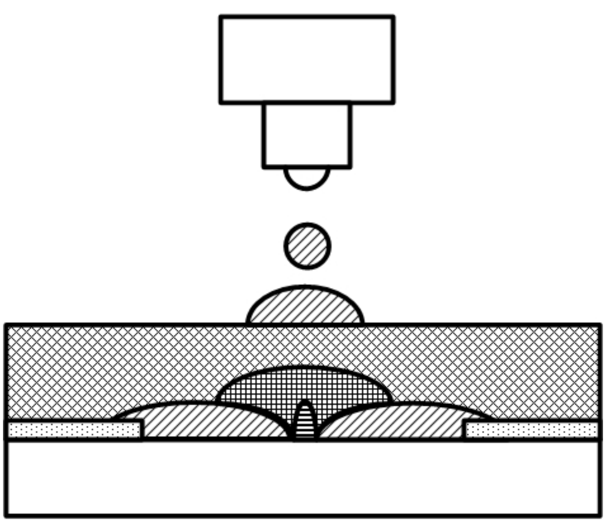

FIG. 1. Schematic structure of printed OTFT.

3. Results and discussion

Figure 2 and Figure 3 show characteristics of the transfer curve in the saturation region and the square root value of the current versus the gate voltage at source-drain voltage of -8V. The carrier mobility was calculated at the saturation region with the following equation:

$$I_{DS} = (W/2L)C_i\mu(VG - VT)^2 \qquad (1)$$

,where μ is the field-effect mobility, L and W are channel length and width, respectively, C_i is the insulator capacitance per unit area, and VG and V_T are the gate and the threshold voltage.

The low-voltage operation characteristics of OTFTs have been realized with a hygroscopic gate dielectric such as PVP. These results, with good current saturation and current modulation at low gate voltages, indicate that the device absorbs moisture in ambient environment. The gate field modulation of the drain current is enhanced by an ionic process that occurs in the moisturized gate dielectric close to the semiconductor interface [8]. Compared with Figure 2 and Figure 3, the device with V_2O_5 modification exhibited larger current than the device without surface modification. The performance of OTFTs, without V_2O_5, had mobility of 0.049 $cm^2\ V^{-1}\ s^{-1}$, V_T of 2.6 V and the subthreshold slope of 1.77 V/decade. When the OTFT was modified with V_2O_5, the mobility was improved to 0.27 $cm^2\ V^{-1}\ s^{-1}$. Threshold voltage V_T and the subthreshold slope were reduced to 1.55 V and 1.47 V/decade, respectively. The purpose of introducing an additional thin layer V_2O_5 is to promote the adhesion between P3HT and PVP to get an intimate contact [9].

Table 1 summarizes the results of the electrical characteristics of various OTFTs. Mobility and V_T are extracted at source-drain voltage of -8V. On/off current ratio is the ratio of the highest current and the lowest current on the curve of source-drain voltage of -8V. The channel resistance (R_{CH}) and the contact resistance (R_C) were extracted at the linear region of transistor operation.

The effect of the surface polarization is superimposed on the drain current. This effect surpasses the gate bias stress and cause an increase in the drain current. The on/off current ratio in the saturation region with a hygroscopic gate dielectric is not good enough as compared to OTFTs with conventional polymer dielectrics, such as poly(methyl methacrylate) (PMMA).

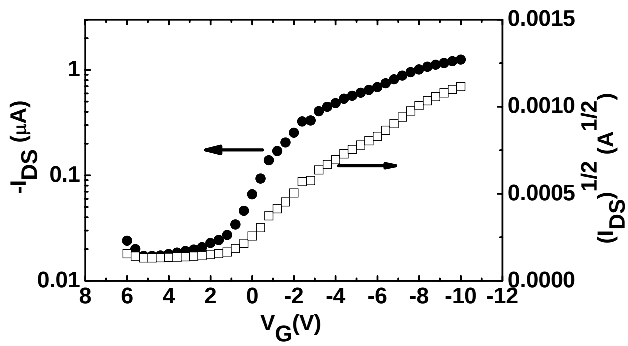

Fig.2 I_D-V_G characteristics of the OTFT without V_2O_5 modified

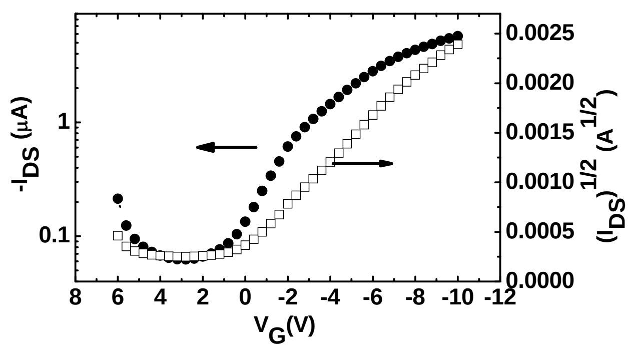

Fig.3 I_D-V_G characteristics of the OTFT with V_2O_5 modified

The contact angle of PVP on P3HT film is larger than that on the V_2O_5/P3HT film. The output current of device with V_2O_5 is about 5 times larger than that of device without V_2O_5, indicating better hole injection after inserting the V_2O_5. Therefore, the inserted V_2O_5 is not only for surface energy modification [10], but also a hole injection layer. We have also analyzed the channel resistance (R_{CH}) and contact resistance (R_C) values at the pinch-off point of the various OTFTs. In the linear region of transistor operation, the total device resistance R_T can be written as

$$R_T = R_{CH} + R_C \qquad (2)$$

Here

$$R_{CH} = \frac{L}{WC_i(V_G - V_T)}\frac{1}{\mu} \quad (3)$$

The performance of OTFTs with V_2O_5 surface modification was improved and the device exhibited R_{CH} of 0.97 MΩ and R_C of 0.42 MΩ. The improvement of device performance can be explained by the better contact and improved hole injection at the semiconductor-dielectric interface with a thin layer of V_2O_5.

Figure 4 shows the corresponding output characteristic from V_G = 1 V to -4 V. Good saturation behavior is obtained and only P-channel activity is observed for the device. With the increase of V_D, linear and saturation regions can be observed clearly in the plot.

TABLE 1. Electrical characteristics of the various OTFTs.

	Device without V_2O_5 modified	Device with V_2O_5 modified
Mobility (cm^2/V.s)	0.049	0.27
Threshold Voltage(V)	2.6	1.55
subthreshold slope (V/dec.)	1.77	1.47
On/Off Ratio	72	91
Channel Resistance(MΩ)	4.92	0.97
Contact Resistance(MΩ)	1.51	0.42

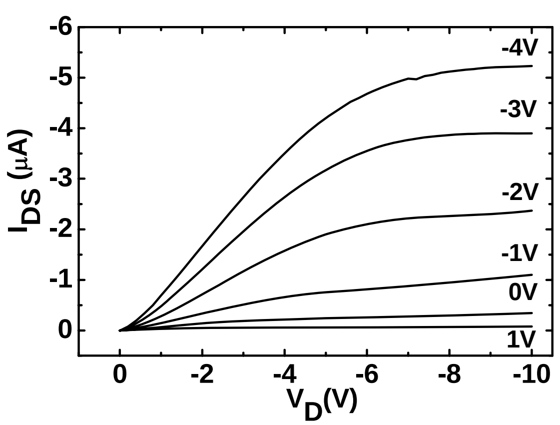

FIG.4. I_D-V_D characteristics of the OTFT with V_2O_5 modified

4. Summary

In summary, we have successfully demonstrated an excellent solution for processing P-type organic field-effect transistors by employing V_2O_5 modification between PVP gate dielectric and P3HT semiconductor. The V_2O_5 layer can reduce the channel resistance (R_{CH}) and contact resistance (R_C) and therefore the resulting device exhibited R_{CH} of 0.97 MΩ and R_C of 0.42 MΩ. The device exhibits excellent field-effect performances with a high mobility of up to 0.2 $cm^2V^{-1}s^{-1}$, a V_T of 1.55 V, and a subthreshold slope of 1.47 V/decade in the saturation region at room temperature.

5. References

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