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Low-Voltage Operation of Organic Thin Film Transistors by using Dual Gate Dielectrics

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1. Introduction

Organic thin film transistors (OTFTs) have become the subject of considerable interest in recent years because of their unique advantages for the application in low cost, large area, and flexible electronics, and OTFT device performances have been achieved, which are comparable to those of amorphous silicon transistors.[1-3] However, OTFT devices still require rather high operating voltages. For portable applications, especially for RFIDs requiring low power consumption, it is necessary to reduce the operating voltage to below 5V. Polymeric OTFT insulators (e.g., poly(vinyl phenol (PVP), poly(vinyl alcohol (PVA), poly(methcarylate) (PMMA), etc.) usually have rather low surface polarities and can be processed from solution. [4-5] However, polymeric insulators have to be fairly thick, to avoid the formation of pinholes, and their dielectric constants are rather small. To produce low-voltage operating OTFTs, there have been many attempts to obtain a high capacitance with gate dielectrics by reducing their thickness or increasing their dielectric constant.

In this paper, we report dual gate dielectric for low voltage operation of OTFTs. The dual gate dielectrics is composed of the self-grown Al_2O_3 and polystyrene (PS).

2. Experiments

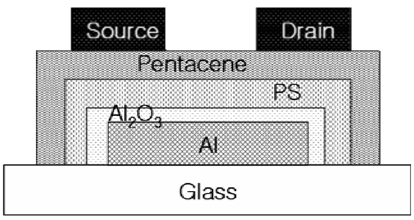


Fig. 1. The device structure of low voltage pentacene TFTs

The fabrication processes were as follows. First, an aluminum (Al) gate electrode was deposited on the substrate through a metal shadow mask by thermal evaporation to a thickness of about 40nm. Then Al_2O_3 gate dielectric layer formed by O_2 plasma process. The O_2 plasma process was carried out for 60min at 145mTorr pressure with 10scm O_2 flow rate and 150W power. The thickness of the self-grown Al_2O_3 on Al gate electrode was 5nm . After, polystyrene(PS) was spin coated onto the Al_2O_3 at 3000rpm for 30sec, and the cured in vacuo at 100-110℃ overnight.[6] The cross-linkable Polystyrene(PS) solution was composed of PS polymer , toluene, 1,6-bis (trichlorosilyl)hexane. The thickness of PS dielectrics was 10nm. A pentacene active layer was then deposited by thermal evaporation with 450nm thickness at a substrate temperature of 80℃. Finally, Au of source and drain electrodes was evaporated on the pentacene layer through a shadow mask, yielding bottom gate and top contact structure, as show in Fig. 1.

3. Results

The leakage current through the Al_2O_3 and Al_2O_3 + PS layer were measured using a metal-insulator-metal(MIM) structured device consisting of the bottom Al electrode, the middle Al_2O_3 and Al_2O_3 + PS layer, and the top Au electrode as shown in Fig.2. The cross-linkable PS on Al_2O_3 reduced gate leakage current. The capacitance was 166nF/cm^2 at 1MHz.

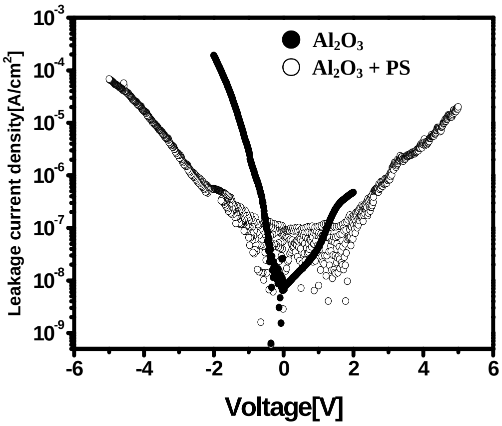


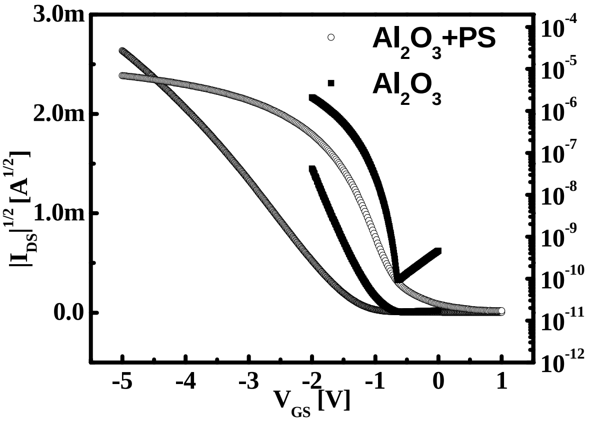
Fig. 2. Comparison of leakage current density for Al- Al_2O_3-Au and Al- Al_2O_3 + PS-Au MIM devices

The transfer characteristics of pentacene TFTs using dual gate dielectrics and Al_2O_3 as shown in Fig.3(a). The OTFTs parameters compared Al_2O_3 with Al_2O_3 + PS as shown in Table. 1. The OTFTs using Al_2O_3 has parameters that the threshold voltage was -1.05V, the sub-threshold slop was 0.1Vdec, the mobility was 0.29 cm^2/Vs, on/off current ratio was 2.2x10^4 , off state current was 0.12pA/um. The OTFT using the dual gate dielectrics operated at low voltage, producing 6.8uA at V_{GS}=-5 V and V_{DS}=-1.5 V. The threshold voltage was -1.36 V, the sub-threshold slop was 240mV/dec , the mobility was 0.63cm^2/Vs at 2.5V and on/off current ratio was 3.6x10^5 and off state current was

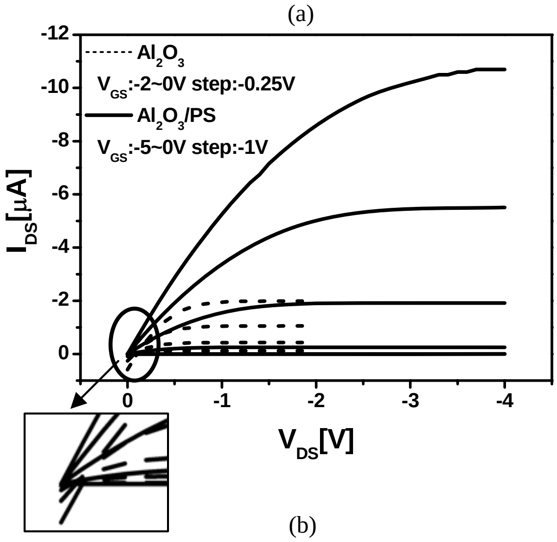
0.024pA/um.

The cross-linkable PS on Al_2O_3 reduced off current, and also improved mobility. In the output curve of Al_2O_3 the drain current does not converge to 0V but the output curve of Al_2O_3 + PS converged to 0V.

We measured the contact angle of the Al_2O_3 and Al_2O_3 + PS. Contact angle of the Al_2O_3 was not measured, but contact angle of the Al_2O_3 + PS was 98 deg. It meant that the surface state was transferred from hydrophilic to hydrophobic.



(a)



(b)

Fig. 3. (a)The transfer characteristics and (b)the output characteristics of pentacene TFTs using dual gate dielectrics and Al_2O_3 with a 50um channel length and 790um channel width.

Table. 1. Parameters characterized by gate dielectrics.

Gate dielectrics	Mobility (cm2/V·s)	On/Off	Vth (V)	SS (V/dec)	Off state current (pA/um)
Al_2O_3	0.29	$2.2x10^4$	-1.05	0.1	0.12
Al_2O_3 + PS	0.63	$3.6x10^5$	-1.36	0.24	0.024

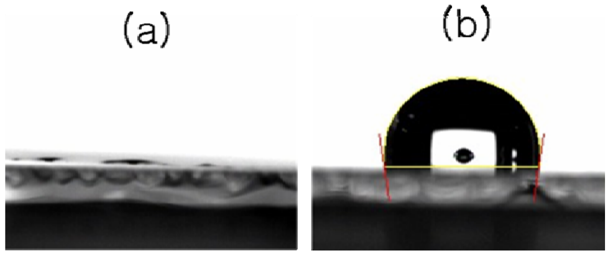


Fig. 4. (a) water contact angle onto the Al_2O_3, (b) water contact angle onto the Al_2O_3+PS.

3. Conclusions

We developed the performance of low-voltage pentacene TFTs. The cross-linkable PS film on Al_2O_3 reduced gate leakage current, and off current. The mobility was improved from $0.29cm^2/Vs$ to $0.63cm^2/Vs$. The method of using the dual gate dielectrics can be fabricated by low-temperature process. So the OTFT can employ a plastic substrate.

Acknowledgements

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