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Fabrication of the low operating voltage Poly(3-hexylthiophene) transistor using sputtering $Al_2O_3/HfO_2/Al_2O_3$ stacking insulator

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1. Introduction

In the past decade, the performance of organic thin-film transistors (OTFTs) has improved evidently and been interested for variety of low cost, large area coverage electronics and flexible electronics. However, current devices still required rather higher operating voltage hinders the practical application. In 1999, C. D. Dimitrakopoulos utilized high dielectric constant materials as insulator on the organic transistor. According to this report [1], the experiment result demonstrated the low operating voltage of device due to the high dielectric contact materials. The higher dielectric constant as gate insulator the more accumulation charge can be hold in the channel. Therefore, using high-K as gate dielectric can result in device operation at lower drive voltage with good electrical characteristics compare to traditional SiO_2 insulator layer [2].

In this paper, we first time to our knowledge use HfO_2 as the high dielectric materials by a simple sputtering method to fabricate the polymer transistor with a low operating voltage. To achieve the better characteristics of organic transistor, the $Al_2O_3/HfO_2/Al_2O_3$ stacking structure as the insulator of organic transistor by sputtering system and the organic semiconductor/insulator interface treated by O_2 plasma and HMDS was proposed in this work.

2. Experimental

The Fig.1 shows the configuration of organic transistor. The glass substrates were cleaned by acetone, IPA and DI water in ultrasonic bath and dried by nitrogen. The Aluminum gate was deposited by thermal evaporation. The insulator adopted $Al_2O_3/HfO_2/Al_2O_3$ stacking structure by sputtering and the thickness was 100nm/100nm/50nm. Source-drain electrode using Al (3nm)/Au (110nm) was deposited by thermal evaporation and channel length was form by lift-off process. The surface of insulator was treated by RF power 100W O_2 plasma. The table 1 shows the different treatment condition. Active layer was solution-base RR-P3HT 0.8wt% and dissolved in P-xylene. The polymer film was deposited by spin coater and baked at 120ºC for 2 hours in glove box. At last, the samples were encapsulated with a protective glass cover and UV-epoxy seal.

The surface morphologies of insulator were analyzed by AFM and the electrical characteristics of organic transistor were extracted C-V measurement with Agilent 4294A and I-V measured by Keithley 4200 at room temperature.

3. Results and discussion

Fig.2 shows the C-V and J-E characteristics of the devices. The capacitance density and breakdown electric field are about 31nF/cm^2 and 1MV/cm, respectively. Fig.4 shows I_D-V_D, I_D-V_G curves of the device without any treatment (sample A) and the device channel length is 25μm, channel width is 3mm. From the $(I_D)^{1/2}$-V_G curve, 1×10^{-3} cm^2/V-s of carrier mobility, 6.9V of threshold voltage and 100 of Ion/Ioff current ratio can be calculated. The characteristics of sample with O_2 plasma treatment (sample B) is shown in Fig.5. The carrier mobility and drain current were improved relative to sample A. From AFM analysis, the rms roughness of insulator has decreased from 21nm to 10.5 nm with O_2 plasma treatment. The surface morphologies of insulator with different treatment conditions were shown in Fig.3 (a) (b). The oxide surface of device (sample B) is smoother than the device without surface treatment (sample A), resulted in influence on the carrier transport in channel [3]. In order to further improve channel roughness, we utilized the O_2 plasma treatment and spin coating HMDS on the oxide stack layer. The electrical characteristics of device were enhanced evidently compared to other devices. The organic transistor device exhibited 3.1×10^{-3} of mobility, 138 of Ion/Ioff current ratio and 3.4V of threshold voltage. The characteristics were show in Fig.6. According to the AFM analysis, the surface roughness was modified further, the rms roughness of the sample C were 4.4nm shown in Fig.3(c). All of the treatment condition and device characteristics were listed in table 1. The electric characteristics of organic transistor were effectively improved with the O_2 plasma and coating HMDS treatment. It can be explained that with O_2 plasma treatment change the surface morphology of insulated layer and the coating HMDS thin film on surface of insulator has fill up the roughness and more smooth. The HMDS film act as an interfacial layer between the interface of dielectric and polymer layer and also offer better crystallinity for P3HT layer [4].

4. Conclusions

We have successfully fabricated the low operating voltage polymer thin-film transistors by using simple sputtering method. The HfO_2 as gate dielectric material is first time using in organic transistor devices process. The O_2 plasma treatment and HMDS both can be used to improve the electrical characteristics.

References

[1] C.D.Dimitrakopoulos, et al., SCIENCE, 283(1999) 822.
[2] Tobat P.I., et al., Synthetic Metals, 148(2005) 267.
[3] Jiyoul Lee, et al., Appl. Phys. Lett., 83(2003) 2689.
[4] S. C. Lim, et al., Synthetic Metals, 148 (2005) 75.

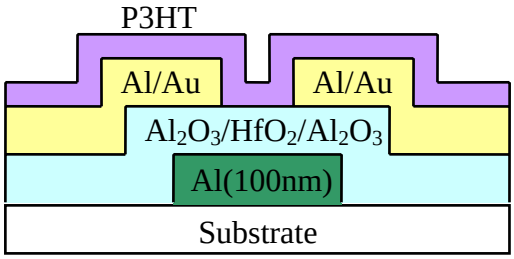

Fig.1 The bottom-contact organic transistor structure

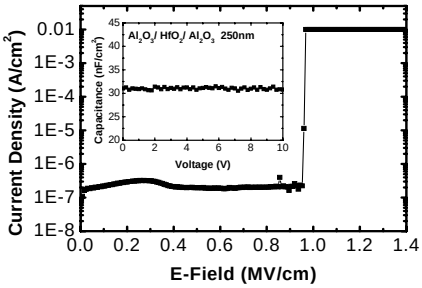

Fig.2 The J-E and C-V characteristics of $Al/Al_2O_3/HfO_2/Al_2O_3/Al/Au$

Table 1: The characteristics of different surface treatment

	Treatment condition	Roughness (rms)	Mobility	Ion/Ioff ratio	V_{Th}
Sample A	Non-treatment	21 nm	1×10^{-3} cm^2/V-s	100	6.9 V
Sample B	O_2 plasma	10.5 nm	1.4×10^{-3} cm^2/V-s	106	6.8 V
Sample C	O_2 plasma + HMDS	4.4 nm	3.1×10^{-3} cm^2/V-s	138	3.4 V

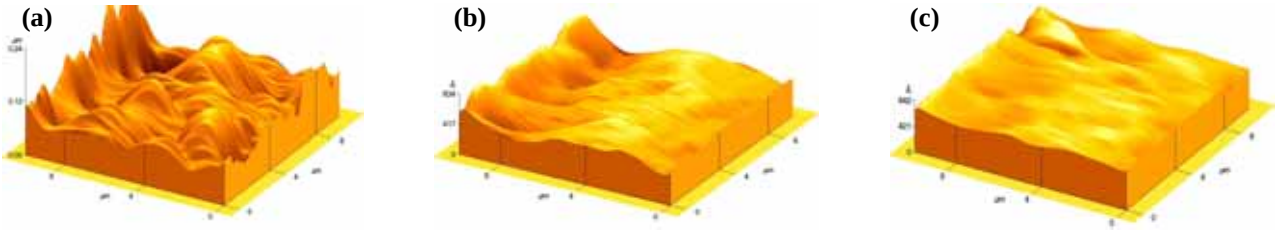

Fig.3 The surface morphology of $Al_2O_3/HfO_2/Al_2O_3$ stacking insulator (a)non-treatment (b) O_2 plasma treatment (c) O_2 plasma and HMDS treatment

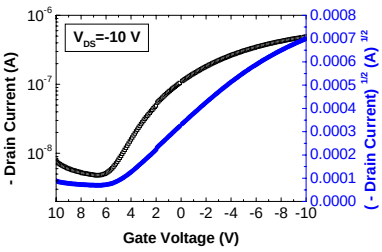

Fig.4 (a) I_D-V_G characteristic of the sample without treatment

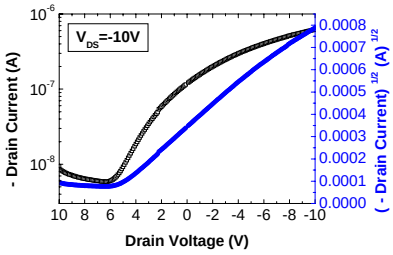

Fig.5 (a) I_D-V_G characteristic of the sample with O_2 plasma treatment

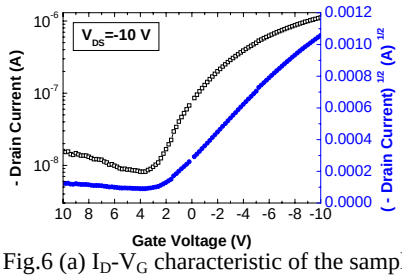

Fig.6 (a) I_D-V_G characteristic of the sample with O_2 plasma and HMDS treatment

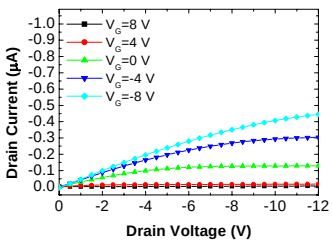

Fig.4 (b) I_D-V_D characteristic of the sample without treatment

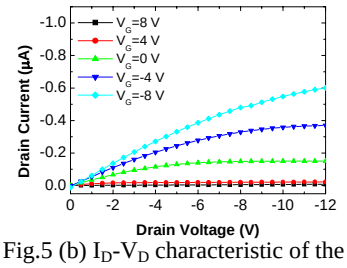

Fig.5 (b) I_D-V_D characteristic of the sample with O_2 plasma treatment

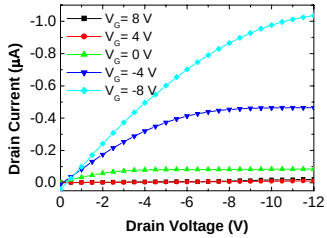

Fig. 6(b) I_D-V_D characteristic of the sample with O_2 plasma and HMDS treatment