P-10-4

Electrical Characteristics of Organic Field Effect Transistor by Forming Gas Treatment of High-k Al_2O_3 at Low Temperature

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1. Introduction

Since the discovery of organic materials with high conductivity, organic materials have been attracting attention due to its large area application, low cost, and flexibility [1]. These materials were widely applied in field of organic field effect transistor (OFET), organic light emitter display (OLED), smart card, polymer random access memory (PoRAM) and radio frequency identification (RFID) [1]. However, organic materials as a channel layer has serious issues related to gate oxide engineering [3] as well as stack structure, life time [2], channel engineering [4], and threshold voltage shift. Recently, high dielectric constant layer as an alternative to SiO_2 was applied in order to limit the gate leakage current at equivalent oxide thickness. As reported by Veres et al. [5], when high dielectric constant layer was applied, the mobility was significantly decreased due to the charge trap at channel layer.

In this study, in order to minimize charge trap at channel layer, surface modification of high dielectric constant Al_2O_3 at low temperature was carried out. The electrical characteristics depending on surface modification will be discussed in detail.

2. Experiment

Ta bottom gate electrode with sheet resistance of about 31 Ω/□ and 500 Å thickness was patterned using shadow mask on thermal SiO_2 with 1500 Å thickness which was employed as a buffer layer to exclude the influence of Si wafer. Al_2O_3 as a gate oxide was deposited in the range of ~ 400 Å by rf magnetron sputtering system and patterned. Prior to deposition of pentacene, Al_2O_3 gate oxide was annealed with forming gas (5% H_2 and 95% N_2 gas) at low temperature of 100°C for 30 minutes. Pentacene was deposited using organic thermal evaporation under high vacuum (10^{-6} torr) without purification. Deposition rate of about 1 Å/sec was obtained. Gold (Au) was deposited on top of pentacene using shadow mask to form source and drain (S/D) electrodes. The structure of OFET with L/W=200/800 μm is shown in Fig. 1. The electrical characteristics of pentacene FET were measured by HP 4145B semiconductor parameter analyzer in the dark at room temperature. Topography image of pentacene were analyzed by atomic force microscope (AFM).

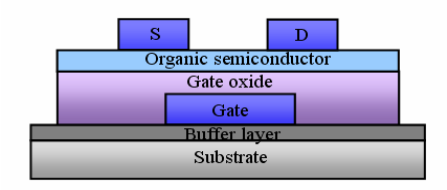

Fig. 1. Structure of organic field effect transistor.

3. Results and discussion

Transfer curve of drain current versus gate voltage of as-fabricated (as-fab.) device depending on forming gas annealing (FGA) treatment was shown in Fig. 2.

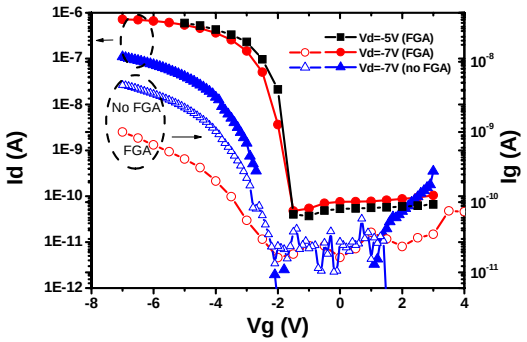

Fig. 2. Transfer curves of OFET depending on surface treatment.

After FGA treatment, maximum value of drain current was induced at drain voltage of -5V. And drain current of treated device was increased over one order of magnitude compared to that of untreated device at drain voltage of -7V. As shown in Table 1, subthreshold slope was decreased from the 0.35 to 0.26 V/decade with FGA treatment. On/off current ratio was ~9.7×10^3 and ~ 9.4×10^3 on untreated and on treated Al_2O_3, respectively. Performance of treated device was improved because the carrier concentration was enhanced at channel layer close to the surface of gate oxide under the constant electric field. This phenomenon is closely related with charge carrier scattering that was significantly decreased by the decrease of charge trap after FGA treatment.

Fig. 2 indicates that gate leakage current at on-state significantly decreased at -7V drain voltage due to the decrease of dangling bond at oxide surface after FGA

treatment. In case of off-state, gate leakage current on treated Al_2O_3 was relatively steady because oxide charge trap was decreased. On the contrary, gate leakage current on untreated Al_2O_3 is fluctuating. From these FGA results, it is considered that H_2 gas plays an important role in decreasing of carrier trap site of channel layer through removing the defective bonds of Al_2O_3 gate oxide.

Plot of the square root of drain current is shown in Fig. 3. Threshold voltage of as-fab. device extracted by transconductance change method was about -1.8V on treated Al_2O_3 and -2.3V on untreated Al_2O_3, respectively, at the constant drain voltage of -7V. Minimum threshold voltage of about -1.3V was obtained at drain voltage of -5V on treated device.

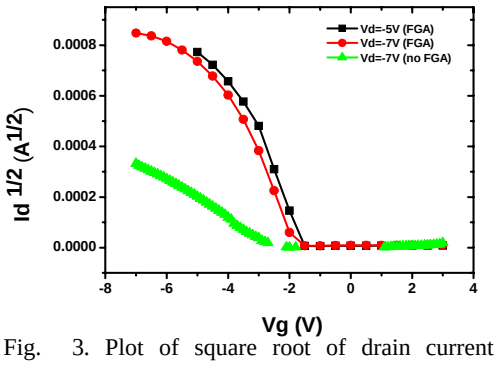

Fig. 3. Plot of square root of drain current of OFET depending on surface treatment.

Fig. 4 shows the transconductance curves of OFET depending on FGA treatment. Transconductance as well as mobility ($\mu=LG_m/(WC_{ox}V_{ds})$ is significantly improved by FGA at at electric field of about -0.6 MV/cm. It implies that when FGA treatment was carried out, carrier transport between source and drain was increased at channel layer. As surmaried in Table 1, high mobility of about 0.5 cm^2/Vs on treated Al_2O_3 was obtained.

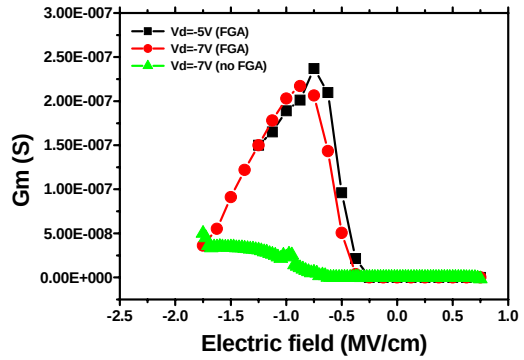

Fig. 4. Transconductance curve of OFET depending FGA treatment.

Surface images of pentacene with and without FGA treatment are shown in Fig. 5. Pentacene has island structure with similar grain size in range of about 110-120 nm on Al_2O_3 dielectric layer both on treated and on untreated device.

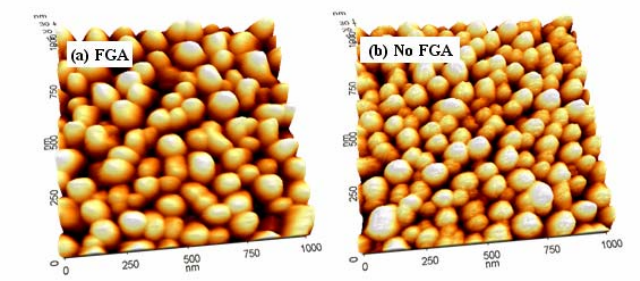

Fig. 5. Surface images of pentacene on (a) FGA and (b) no FGA Al_2O_3 depending on surface treatment.

Table 1. Electrical characteristics of pentacene FET.

Properties / Device	Mobility (cm^2/Vs) (saturation region)	Subthreshold swing (V/decade)	Threshold voltage (V)	On/off ratio
Vd= -5V (FGA)	5.17e-1	0.18	-1.3	1.1×10^4
Vd= -7V (FGA)	5.08e-1	0.26	-1.8	9.4×10^3
Vd= -7V, (No FGA)	2.64e-2	0.35	-2.3	9.7×10^3

4. Conclusions

In order to increase the performance of OFET, surface treatment with forming gas on high-k gate oxide close to channel layer was necessarily required. It was found that FGA treatment gave rise to an increase of mobility of OFET devices over one order of magnitude even though it was conducted at low temperature.

Acknowledgements

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