Fabrication of soluble organic thin film transistor with ammonia (NH_3) plasma treatment

Dongwoo Kim, Doohyun Kim, Keonsoo Kim, Hyoungjin Kim, Hong Choi
Donghyeok Lee and Munpyo Hong*
Dept. of Display and Semiconductor Physics, Korea University, Chungnam, KOREA

TEL:82-41-860-1321, e-mail: goodmoon@korea.ac.kr

Abstract

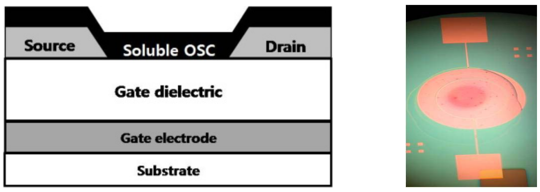
We have examined the silicon nitride (SiN_x) as gate insulator with the ammonia (NH_3) plamsa treatment for the soluble derivatives of polythiophene as p-type channel materials of organic thin film transistors (OTFTs). Fabrications of the jetting-processed OTFTs with SiN_x as gate insulator by NH_3 plasma treatment can be similar to performance of OTFTs with silicon dioxide (SiO_2) insulator.

1. Introduction

Recently, Organic thin-film transistors (OTFTs) have been researched for many applications such as sensors, smart cards, identification tags, and the display devices including flexible displays [1]. High performance OTFTs has been mostly achieved in top-contact device configuration rather than bottom-contact device configuration [2, 3]. However, top-contact device configuration is incompatible with lithography process due to the sensitivity of organic semiconductors to ultraviolet, electron beam, and chemical wet processes. This limitation makes top-contact configuration undesirable for manufacturing [4]. Bottom-contact configuration source–drain (S–D) electrodes can be easily fabricated by lithography process and thus are much more promising than top-contact configuration for large scale integration and manufacture of OTFTs. In this paper, we have investigated the soluble OTFT through the NH_3 plasma Treatment for the SiN_x as a gate insulator for mass-productions. For enhancement of performance OTFTs, The SiN_x is improved by optimized NH_3 plasma treatment [5].

2. Experimental Procedure

To compare effects of the NH_3 plasma treatment on SiN_x surface, we fabricated bottom contact OTFT devices with circle type source-drain electrode by solution jetting process as shown in Fig.1.



(a) (b)

Figure 1. Configurations of (a) bottom-gate & bottom contact structure and (b) circle type source-drain electrode with SiN_x as gate insulator.

The thermally SiO_2 wafer with the total thickness about 3000 Å was prepared. The OTFTs devices are fabricated for a bottom contact configuration on a degenerately doped *n*+ silicon wafer used as a gate electrode. Also, Chrome (Cr) metal layer as gate electrode was deposited by a sputter with the thickness of 300 Å on galss substrate. SiN_x films were deposited in a parallel-plate plasma enhanced chemical vapor deposition (PECVD) reactor operating at an excitation frequency of 13.56 MHz. The process pressure was maintained at 800 mTorr, the substrate temperature was 300 °C, and the rf power was 300 W. The nitrogen (N_2), ammonia (NH_3) and silane (SiH_4) gas flow rate ratio are 8:1:2. After SiN_x film deposition with the thickness about 2000 Å, it is annealing by the Rapid Thermal Annealing (RTA) at 300 °C. SiN_x films were treated by the nitrous oxide (N_2O) / NH_3 plasma. The N_2O / NH_3 plasma were generated under the conditions of the working pressure 250 mTorr, the substrate temperature 300 °C, the RF power 50 W and the gas flow rate 100 sccm for 12 min, respectivly. For the formation of circle type source-drain electrodes, Au metal layer was deposited by a thermal evaporation with thickness of 300 Å, and patterned by photo-lithography and wet chemical etching processes; the channel width (W) and length

(L) were defined as 3000 μm and 5 μm, respectively. The Poly(3-hexylthiophene) (P3HT) precursor was dissolved in tetralin solvent. This solvent was chosen over chloroform due to its slower evaporation rate, making it more suitable for our home-made jetting system. After jetting the OSC on circle type Au electrodes, the device samples were annealed at 150 °C for 30 min in N_2. The performances of OTFTs were measured by semiconductor parameter analyzer (HP4156C) in dark spaced probe station at room temperature.

3. Results and discussion

The field-effect mobility at $V_D=V_G$ was calculated by

$$I_{D,sat} = \left(\frac{W}{2L}\right)\mu C_i (V_G - V_T)^2 \qquad (1)$$

where μ_{fe} is the field-effect carrier mobility, V_T is the threshold voltage, W is the channel width, L is the channel length, C_i is the capacitance per unit area.

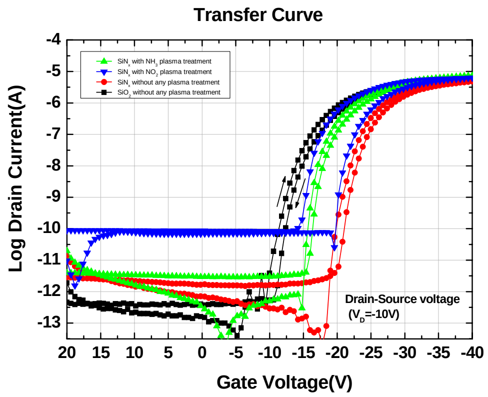


Figure 2. The electric characteristics of OTFTs with various films I_D-V_G, (W/L = 3000 μm / 5 μm)

Figure 2 illustrates the transfer characteristics of a typical P3HT OTFT on SiO_2, SiN_x and SiN_x with N_2O / NH3 plasma treatment. In SiO_2 insulator without any plasma treatment, the field-effect mobility of OTFTs with jetting process is about 0.002 $cm^2V^{-1}s^{-1}$. On the other hand, the performance OTFTs using the SiN_x as gate dielectric without any plasma treatment drive as the field effect mobility (μ_{fe}) of 0.002 $cm^2V^{-1}s^{-1}$, the threshold voltage (V_T) of -22.0 V, the sub-threshold slope (S-S) of 0.74 V/dec and the on-off currents ratio (I_{on}/I_{off}) of 10^7. However, the result by N_2O plasma treatment is inferior to that by bare SiN_x to the effect of damage of N_2O plasma.

In our experiment, the SiN_x with NH_3 plasma treatment drive best results as μ_{fe} of 0.003 $cm^2V^{-1}s^{-1}$, the V_T of -17.0 V, the S-S of 0.53 V/dec and the I_{on}/I_{off} of $5*10^6$, due to the effect of nitrogen-rich nitride.

Table I. Summary of the electrical parameters for the OTFTs. μ_{fe} is the room temperature field-effect mobility, S is the sub-threshold swing, V_T is the threshold voltage.

Gate Insulator	μ_{fe} ($cm^2V^{-1}s^{-1}$)	S (V/dec)	V_T (V)	I_{on}/I_{off}
(a) SiOx	0.002	0.98	-14.0	$5*10^7$
(b) SiNx	0.002	0.74	-22.0	10^7
(c) SiNx with N_2O plasma treatment	0.001	1.30	-21.0	10^5
(d) SiNx with NH_3 plasma treatment	0.003	0.53	-17.0	$5*10^6$

4. Summary

P3HT OTFTs on SiN*x* (i.e., nitrogen-rich nitride) gate dielectric have performance comparable to that of OTFTs fabricated on thermal SiO_2 gate dielectric (average mobility of 0.002 cm^2/Vs and on/off ratio of over 10^7). Consequently, OTFTs on SiN*x* using NH_3 plasma treatment is similar to performance of OTFTs with SiO_2 insulator. Also, Investigation of lower temperature SiN*x* using various plasma treatments as gate dielectric for Soluble OTFTs is currently in progress.

Acknowledgements

This research was supported by a grant (F0004012-2009-32) from information display R&D Center, one of Knowledge Economy Frontier R&D of Korean Government and Korea University Grant.

5. References

[1] C. D. Dimitrakopoulos, P. R. L. Malenfantols, Adv. Mater., **14**. 99 (2004)
[2] G.R. Dholakia, M. Meyyappan, A. Facchetti, T.J. Marks, Nano Lett. 6 (2006) 2447.
[3] I. Kymissis, C.D. Dimitrakopoulos, S. Purushothaman, IEEE Trans.Electron Devices 48 (2001) 1060.
[4] M.M. Ling, Z. Bao, Chem. Mater. 16 (2004) 4824.
[5] F. M. Li, A. Nathan, Y. Wu and B. S. Ong, Appl. Phys. Lett. **90**, 133514 (2007)