Extended Abstracts of the 2006 International Conference on Solid State Devices and Materials, Yokohama, 2006, pp. 934-935

D-9-5

Fabrication of Low-Voltage Pentacene Thin Film Transistors with Al_2O_3 gate dielectric grown by oxygen plasma process

Kang Dae Kim and Chung Kun Song*

Dept. of Electronics Eng. Dong-A University
840 Hadan-dong Saha-gu, Busan, 604-714 Korea
Phone: 82-51-200-7711 E-mail: cksong@dau.ac.kr

1. Introduction

The organic thin film transistors are mature to be applied to backplane of flexible displays and RFIDs[1-3]. However a major problem is that current devices require high voltages to operate. The key to low-voltage operation is to decrease the thickness of gate dielectric. Researches to realize a thinner gate dielectric layer have been continuously carried out in the art[4]. The Infenion group teaches a 2.5nm-thick molecular self-assembled monolayer (SAM) gate dielectric on a heavily doped silicon substrate[5]. However, this may not be available since there is no plan to electrically isolate discrete devices under the circumstances the heavily doped silicon substrate is used for gate electrodes. Another paper, proposes anodization of metal to form metal oxide with a thickness of several nanometers as a gate dielectric layer[6]. However, this may lack usability since anodization, a kind of wet process, may often invite an unfavorable peeling of metal. It is therefore required in the art to develop an advanced organic thin film transistor that allows forming an ultra-thin gate dielectric layer in low-temperature process and further permits a low-voltage operation. It is also required to develop an advanced organic thin film transistor that enables IC fabrication and thus is available for flexible displays, RFID, etc.

Here we report on the development of an ultra-thin gate dielectric for low voltage operation of OTFTs. The metal gate electrode is deposited on a glass substrate. By directly oxidizing the gate electrode by using O_2 plasma process, the gate dielectric layer of metal oxide is formed with a thickness of several nanometers on the gate electrode. Thus, the OTFT of the invention requires no process of patterning the gate dielectric layer for isolation. So related fabrication processes are made simpler.

2. Experiments

The fabrication processes were as follows. First, an aluminum gate electrode was deposited on the substrate. Then Al2O3 gate dielectric layer formed by O2 plasma process. The O2 plasma process was carried out for 20min, 60min at 145mTorr pressure with 10sccm O2 flow rate and 150W power. A pentacene active layer was then deposited by thermal evaporation. Finally source and drain electrodes were evaporated on the pentacene active layer yielding bottom gate and top contact structure, as shown in Fig. 1.

3. Results and Discussion

The leakage current through the Al_2O_3 layer was measured using a metal-insulator-metal (MIM) structured device consisting of the bottom Al electrode, the middle self-grown Al_2O_3 layer, and the top Al electrode. Considering the current transport equations with the measured I-V curves, shown in Fig. 2, the transport mechanism appears to be direct tunneling in the voltage region from 0 V to 0.5 V. Meanwhile, in the high voltage region above 1.34 V, the transport mechanism is determined to be Fowler-Nordheim (FN) tunneling. The current-voltage (I-V) curve of the Al-Al_2O_3-Al device was symmetric along the positive and negative voltage axes. However for the Al-Al_2O_3-Au device where the top Al is replaced with Au, the I-V curve was asymmetric. The change in the I-V curve is attributed to the work function difference between the bottom Al and the top Au electrode.

The OTFTs employing a self-grown Al2O3 gate dielectric operated at low voltage, producing 3.5uA at V_{GS} = 2V and V_{DS} = 1.5V, as shown in Fig. 3. The threshold voltage was small at -0.97±0.04 V, the subthreshold slop was 0.109±0.027 V/dec, the mobility was 0.27±0.05 cm^2/Vs and the on/off current ratio was 2.87±1.07 $x10^4$ for the 60min oxygen plasma process. For the 20min oxygen plasma process, the OTFTs exhibited that the performance parameters were inferior to the former. The threshold voltage was -1.19±0.02 V, the subthreshod slop was 0.15±0.016 V/dec, the mobility was 0.14±0.03 cm^2/Vs and the on/off current ration was 5.8±3.06 $x10^3$. The degradation was attributed to the gate leakage. In the output curve the drain current does not converge to 0A but rather the current direction changes as V_{DS} approaches 0V, as shown in Fig. 4. This is also attributed to the gate leakage current and is enhanced as V_{GS} increases. This current direction change disappeared as the oxygen plasma time was increased from 20min to 60min. This improvement is due to a reduction of the gate leakage current. It is believed that the thickness of Al2O3 layer increases with the oxygen plasma time.

4. Conclusions

We report on the implementation of low voltage pentacene TFTs. The method utilized a few nm thick Al2O3 layer as the gate dielectric. The ultra-thin metal oxide is self-grown on a pre-existing gate metal by oxygen plasma process. The performance of OTFTs was acceptable with mobility of 0.27 cm^2/Vs and an on/off current ratio of 10^4. This method can be fabricated by low-temperature process. So the OTFT can employ a plastic or glass substrate. Also, the OTFT has ultra-thin metal oxide as the gate dielectric layer, so operating voltage thereof can be significantly reduced and thus the OTFT is available for flexible displays, RFID, etc. The OTFT requires no process of patterning the gate dielectric layer for isolation. So related fabrication processes are made simpler.

Acknowledgements

This work was supported by the Information Display R&D Center as part of the 21st Century Frontier R&D Program funded by the Ministry of Commerce, Industry and Energy of Korea.

References

[1] G. H. Gelinck et. al., Nature Mater. **3** (2004) 167.

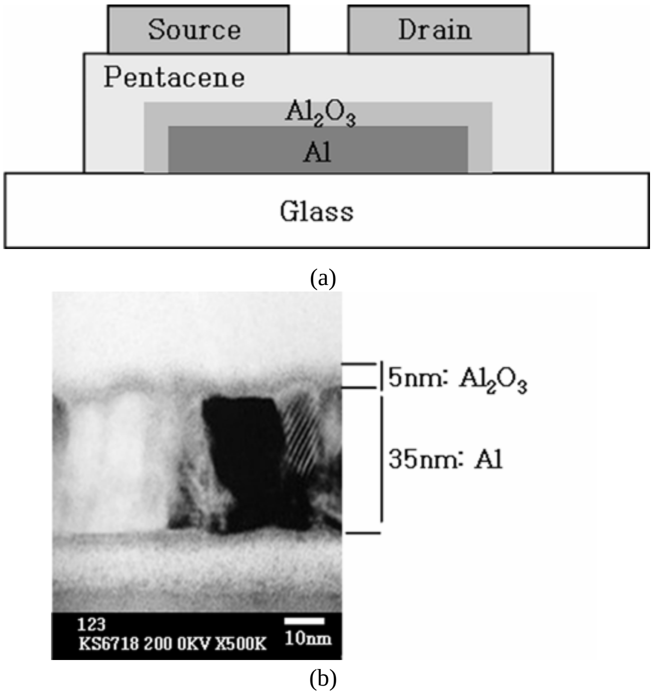
[2] L. Zhou, S. Park, B. Bai, J. Sun, S. C. Wu, T. N. Jackson, S. Nelson, D. Freeman, and Y. Hong, IEEE Electron Device Lett. **26** (2005) 640.

[3] F. Eder, M. Halik, U. Zschieschang, G. Schmid, and C. Dehm, Appl. Phys. Lett. **84** (2004) 2673.

[4] J. Collet, O. Tharaud, A. Chapoton, and D. Vuillaume, Appl. Phys. Lett. **76** (2000) 1941.

[5] M. Halik et al., Nature **431** (2004) 963.

[6] L. A. Majewski, R. Schroeder, and M. Grell, Adv. Mater. **17** (2005) 192.



(a)

(b)

Fig. 1. (a) The device structure of low voltage pentacene TFTs and (b) TEM image of self-grown Al_2O_3 and bottom Al gate electrode.

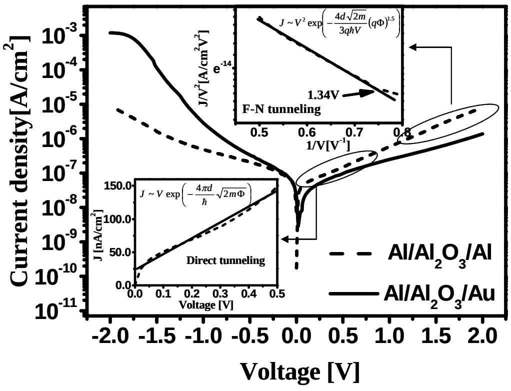


Fig. 2. Comparison of current-voltage curves for Al-Al_2O_3-Al and Al-Al_2O_3-Au MIM device; the insets represent the enlarged direct tunneling (J ~ V) and FN-tunneling (J/V^2 ~ -1/V) relationship in the low voltage and the high voltage region of the Al-Al_2O_3-Al case, respectively.

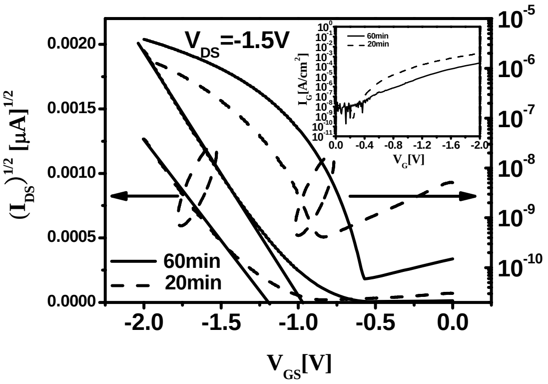


Fig. 3 The transfer characteristics of pentacene TFTs using ultra-thin Al2O3 gate with a 34um channel length and 1035um channel width. Dash line was for 20min and solid line was for 60min oxygen plasma process.

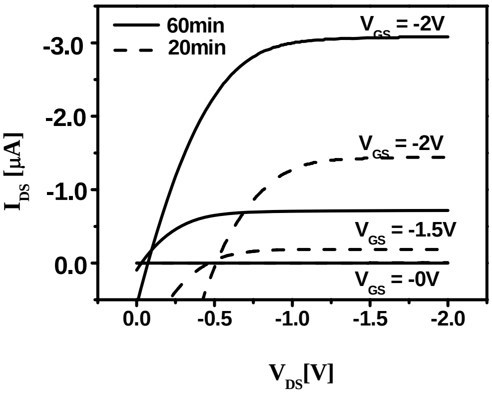


Fig. 4 The output characteristics of pentacene TFTs using ultra-thin Al2O3 gate with a 34um channel length and 1035um channel width. Dash line was for 20min and solid line was for 60min oxygen plasma process.