Extended Abstracts of the 2011 International Conference on Solid State Devices and Materials, Nagoya, 2011, pp596-597

High Mobility Amorphous Indium-Gallium-Zinc Oxide Thin-Film Transistor with a Strong Reduction Capping Layer

Hsiao-Wen Zan[1], Chun-Cheng Yeh[1], Chuang-Chuang Tsai[1], Hsin-Fei Meng[2], and Chia-Chun Yeh[3]

[1] Department of Photonics and Institute of Electro-Optical Engineering, National Chiao Tung University
[2] Institute of Physics, National Chiao Tung University
1001, Ta-Hsueh Rd, HsinChu, 300, Taiwan
[3] E Ink Holdings Inc., HsinChu, Taiwan Roc
Phone: +886-3-5131305 E-mail: hsiaowen@mail.nctu.edu.tw

1. Introduction

With a high mobility (>10 cm^2/Vs) and a low threshold voltage (< 5 V) under a low temperature process, transparent amorphous oxide semiconductor thin-film transistors (AOS TFTs) draw considerable attention due to their applications on flexible displays, level shifters, drivers, and pixel driving circuits for active-matrix organic light emitting diode (AMOLED) displays [1,2]. AOS TFTs are also promising for the development of radio-frequency identification (RFID) tags, smart cards, and other types of flexible electronics. When AOS TFTs are developed for a low-power high-frequency circuit, high electron mobility is required. Most TFTs fabricated with ZnO, SnO_2, In_2O_3, IGZO or other semiconducting oxide thin films exhibit electron mobilities smaller than 35 cm^2/Vs [3,4]. The electron transport in AOS is governed by percolation transport. The random distribution of Ga ions and Zn ions in the crystal structure forms potential barriers around the conduction band edge [5]. Weak chemical bonds also form shallow traps to reduce carrier mobility and degrade the device stability [6].

In our study, we deposit a reduction layer (calcium) onto the back interface of a-IGZO TFT. Effective field-effect mobility around 80-130 cm^2/Vs is obtained. The mechanism to explain the greatly enhanced mobility after capping is investigated.

2. Device Fabrication

a-IGZO was deposited by radio-frequency (RF) sputtering onto a heavily-doped silicon substrate with a 300-nm thermally grown SiN_x through a shadow mask to form the active layer at room temperature. The 100-nm-thick aluminum (Al) was deposited through a shadow mask to form the source and the drain electrodes. The channel width and length are 1000 μm and 300μm, respectively. Then, the 150-μm-long calcium/aluminum dual layer (Ca: 35nm; Al:100nm) was deposited on the back channel to serve as the reduction layer as shown in Fig. 1. The reduction layer is floated and is located between the source and drain contacts.

3. Results and Discussion

The transfer characteristics of the Ca/Al-capped device and the standard (STD) device are shown in Fig. 2. After Ca/Al capping, the field-effect mobility increases from 13.7 cm^2/Vs to 135 cm^2/Vs. The threshold voltage of the Ca/Al-capped device shifts to be -5.5 V. The device characteristics change fast in air. After 1 day, mobility decreases to be 106 cm^2/Vs and the threshold voltage is +0.9 V. We track the device characteristics for 45 days. The revolution of the mobility and the threshold voltage of the Ca/Al-capped device are shown in Fig. 3. It is observed that, the threshold voltage is stabilized to be around +1 V after one day while the mobility is stabilized to be around 80 cm^2/Vs after 30 days. Detailed parameters are listed in Table I.

Two different mechanisms are proposed to explain the variation of the threshold voltage and the mobility. Firstly, the work function of Ca is 2.8 eV, much higher than the Fermi level of a- IGZO (~ 4.5 eV). The shift of threshold voltage can be explained by the electron injection from calcium into a-IGZO due to the work function difference. A negative gate bias is needed to deplete the active layer and to turn off the device [7]. When devices are exposed to air, the rapid oxidation of Ca eliminates the threshold voltage shift. The enhanced mobility, however, is due to another mechanism. It is proposed that, when calcium is evaporated onto a-IGZO in vacuum system, the strong reduction property of calcium draw the weak-bonded oxygen out from the a-IGZO film. This not only increases the oxygen deficiency but also reduce the amount of shallow traps. The field-effect mobility is therefore greatly enhanced. This trap-reduction effect, however, should be limited in the region close to Ca/a-IGZO interface.

Two experiments are conducted to verify the proposed trap-reduction mechanism. Firstly, we change the thickness of a-IGZO film as shown in Fig. 4. The transfer characteristics of Ca/Al-capped devices with different a-IGZO thicknesses are compared in Fig. 5. The parameters are shown in Fig. 6 and listed in Table II. It is observed that the mobility enhancement effect becomes inferior when IGZO thickness increases, revealing that the trap-reduction effect is suppressed when the front channel is far from the Ca/a-IGZO interface. The second experiment to verify the trap-reduction mechanism is to compare the activation energy of the standard and the Ca/Al-capped devices. The Arrhenius plots of the standard device and of Ca/Al-capped device are shown in Fig. 7(a) and Fig. 7(b), respectively. The extracted activation energy of these two devices are compared in Fig. 8. The x-axis represents the gate bias minus the initial (room-temperature) threshold voltage. Apparently, devices with Ca/Al capping layer exhibit lower activation energy than the standard ones, suggesting that the energy barrier for electron transport is lower in Ca/Al-capped devices.

4. Conclusions

We used a strong reduction layer (calcium/aluminum dual layer) capped onto the back interface of conventional bottom-gate top-contact a-IGZO TFTs. A high mobility (80-130 cm^2/Vs) is obtained. A trap-reduction mechanism due to the removal of weak-bonded oxygen by calcium capping is proposed to explain the greatly enhanced mobility. The results enables the development of a-IGZO TFT for the applications like RFID and display driving.

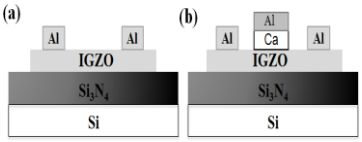

Figure 1-The device structures of (a) the standard and (b) the Ca/Al-capped a-IGZO TFT s.

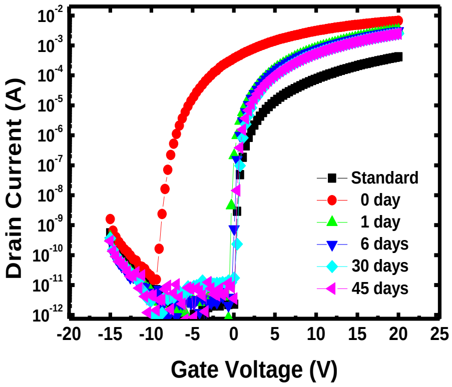

Figure 2-Transfer characteristic of Ca/Al capped a-IGZO TFT during 45 days.

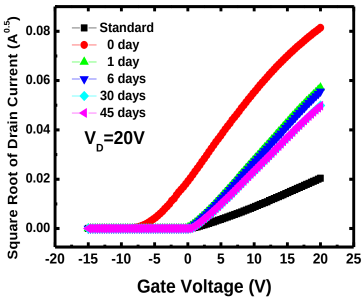

Figure3-Sqrare root of drain current of Ca/Al capped a-IGZO TFT during 45 days.

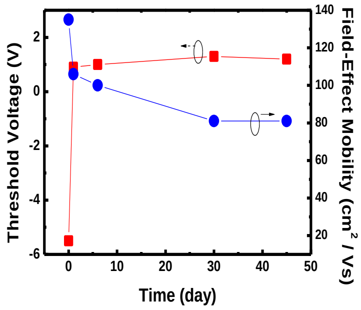

Figure 4-Variation of threshold voltage and mobility during 45 days.

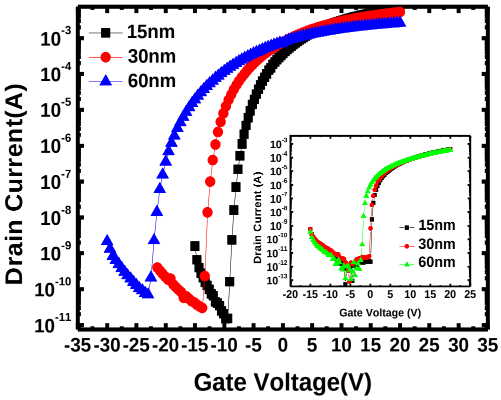

Figure 5-Transfer characteristics of Ca/Al capped devices with various a-IGZO thicknesses. The inset shows the initial transfer characteristics of uncapped devices with various a-IGZO thicknesses.

	V_T (V)	Von (V)	μ (cm^2/Vs)	S.S. (dec./V)	On/Off
Standard	1.9	0.1	13.69	0.11	$1.8x10^8$
0 day	-5.5	-9.4	135.05	0.35	$4.1x10^8$
1 day	0.9	-0.6	106.09	0.19	$7.0x10^8$
6 days	1	-0.3	100.42	0.15	$8.0x10^8$
30 days	1.3	0.1	81.11	0.19	$1.5x10^8$
45 days	1.2	0.1	81.14	0.1	$7.1x10^8$

Table I-Extracted parameters for Ca/Al capped a-IGZO TFT.

Thickness	V_T (V)	Von (V)	μ (cm^2/Vs)	S.S. (dec./V)	On/Off
60nm	-16.5(-2.8)	-22	32.28(7.2)	0.5	$4.4x10^8$
30nm	-10.1(1.2)	-13.8	85.14(11.4)	0.34	$1.80x10^8$
15nm	-5.5(1.9)	-9.4	135.05(13.6)	0.35	$4.4x10^8$

Table II-Extacted parameters for standard (in parentheses) and Ca/Al capped devices with various a-IGZO thicknesses.

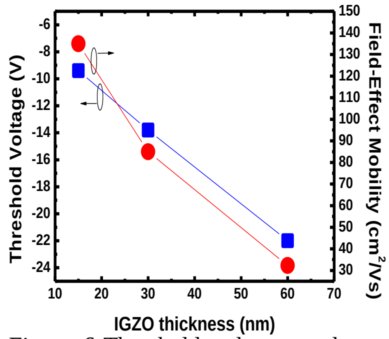

Figure 6-Threshold voltages and mobilities of Ca/Al capped devices with various a-IGZO thicknesses.

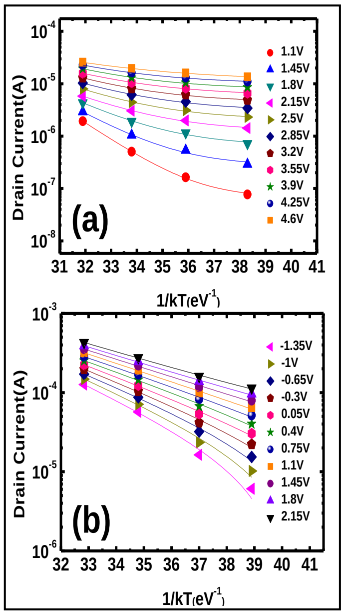

Figure 7-Arrhenius plots of the (a) standard device and of (b) Ca/Al-capped device.

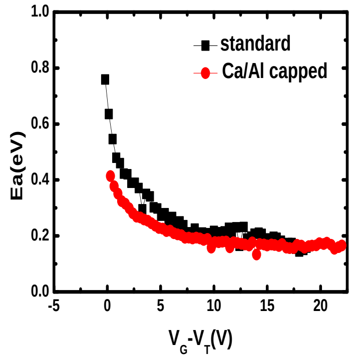

Figure 8-Activation energy extracted from standard and Ca/Al capped devices.

References

[1] Y. Kwon, Y. Li, Y. W. Heo, M. Jones, P. H. Holloway, D. P. Norton, Z. V. Park, and S. Li. *Appl. Phys. Lett.* **2004**, 84, 2685.

[2] H. Q. Chiang, J. f. Wager, R. L. Hoffman, J. Jeong, and D. A. Keszler, *Appl. Phys. Lett.* **2005**, 86, 013503.

[3] H. Seo, Y. J. Cho, J. Kim, S. M. Bobade, K. Y. Park, J. Le, and D. K. Choi, *Appl. Phys. Lett.* **2010**, 96, 222101.

[4] W. Lim, E. A. Douglas, S. H. Kim, D. P. Norton, S. J. Pearton, F. Ren, H. Shen, and W. H. Chang, *Appl. Phys. Lett.* **2009**, 94, 072103.

[5] K. Nomura, T. Kamiya, H. Ohta, K. Ueda, M. Hirano, and H. Hosono, *Appl. Phys. Lett.* **2004**, 85, 1993-1995.

[6] K. Nomura, T. Kamiya, H. Ohta, M. Hirano, and H. Hosono, *Appl. Phys. Lett.* **2008**, 93, 192107.

[7] H. W. Zan, W. T. Chen, C. C. Yeh, H. W. Hsueh, C. C. Tsai, and H. F. Meng, *Appl. Phys. Lett.* **2011**, 98, 153506.