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Implementation of Multi-threshold Voltage a-IGZO TFTs with Oxygen Plasma Treatment

Xin He[1], Longyan Wang[1], Shaojuan Li[1], Mansun Chan[2] and Shengdong Zhang[1,3]*

[1] Institute of Microelectronics, Peking University, Beijing 100871, PRC
[2] Hong Kong University of Science and Technology, Kowloon, Hong Kong
[3]Shenzhen Graduate School, Peking University, Shenzhen 518055, PRC
Phone: +86-755-26035356 E-mail: zhangsd@pku.edu.cn

Abstract

A simple method of fabricating multi-threshold voltage a-IGZO TFTs is proposed and demonstrated. The method features a selective oxygen plasma treatment process, in which some devices are selectively covered with photoresist and the others are exposed. Experimental results show that these two kinds of TFTs have much different threshold voltages.

1. Introduction

In recent years, amorphous indium gallium zinc oxide (a-IGZO) thin-film transistor (TFT) has been studied intensively due to their excellent electrical and optical performances, and it is presently considered the most promising device for application to future active-matrix displays, such as AMOLED and flexible transparent displays [1-3]. More importantly, the a-IGZO TFT technology also makes it possible to integrate the peripheral drive circuits with the pixel array on the same panel [4].

It seems impossible to fabricate practical p-type a-IGZO TFT as there is a very high density of subgap states above the valence band maximum of a-IGZO [5]. Therefore, most of the a-IGZO TFT based logic circuits have been implemented with only n-type TFTs. This has been the main drawback to the realization of high performance a-IGZO TFT integrated circuits. One possible solution to this issue is to implement the circuits with multi-threshold voltage (V_{th}) a-IGZO TFTs. An example is using the enhancement/depletion (E/D) type inverters, instead of the enhancement/enhancement (E/E) type ones to construct circuits [6-7]. The E/D inverters usually show much improved performance compared to the conventional E/E ones. The key point for the fabrication of this kind of circuits is to find a reliable method to adjust the threshold voltage of a-IGZO TFTs.

In this work, a simple method of fabricating multi-V_{th} a-IGZO TFTs, which features a selective oxygen plasma treatment to TFTs is proposed and demonstrated.

2. Experiments

The TFTs were fabricated with a bottom-gate inverted staggered structure. A 150 nm thick molybdenum (Mo) film was deposited with e-beam evaporation and patterned via dry etch to form the bottom gates. A 200 nm thick SiO_2 gate insulator was then deposited at 300 ℃ with plasma enhanced chemical vapor deposition (PECVD). Next, a 40 nm thick IGZO film was deposited using radio frequency magnetron sputtering of a ceramic target (In_2O_3 : Ga_2O_3 : ZnO = 1 : 1 : 1 mol %) at room temperature. The IGZO film was patterned via wet etch in hydrochloric acid, and then a Ti/Au stacked film was e-beam evaporated and patterned via lift-off process to form the source/drain electrodes. The wafers were exposed to an oxygen plasma ambience for some time after one more photolithographic step was carried out to selectively expose the channel regions of some devices, e.g. A-TFT as shown in Fig. 1. The oxygen plasma treatment was performed without intentional substrate heating. The wafers were then annealed at 300 ℃.

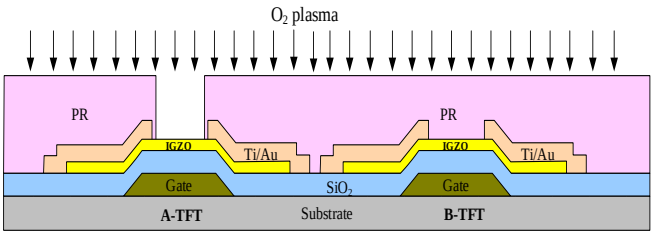

Fig. 1. Cross sectional schematic diagram of a-IGZO TFTs experiencing the O2 plasma treatment. A-TFT with channel region exposed; B-TFT covered by photoresist (PR) layer.

3. Results and discussion

Fig. 2 shows the transfer characteristics of the fabricated a-IGZO TFTs with the O_2 plasma treatment for some time at a fixed RF power. We can see that the B-TFT covered by the photoresist during the oxygen plasma treatment has a V_{th} of −3.3 V, working in a depletion mode. On the other hand, the exposed devices (A-TFT) with 2 mins and 5 mins O_2 plasma treatments have a V_{th} of 0.2 V and 0.6 V, respectively, working in enhancement mode. The source-to-drain voltage V_{ds} is fixed at 10 V in the measurement; and the threshold voltage V_{th} is defined as the gate-to-source voltage V_{gs}, at which I_{ds} equals W/L×1 nA. The shift of V_{th} (ΔV_{th}) increases with the plasma treatment time, indicating that the V_{th} can be adjusted in this process. The V_{th} shift is significant initially, and slows down gradually, and tends to be saturated with the treatment time, as shown in the inset of Fig. 2. It is also observed that the sub-threshold swing (*SS*) of the TFTs is imp-

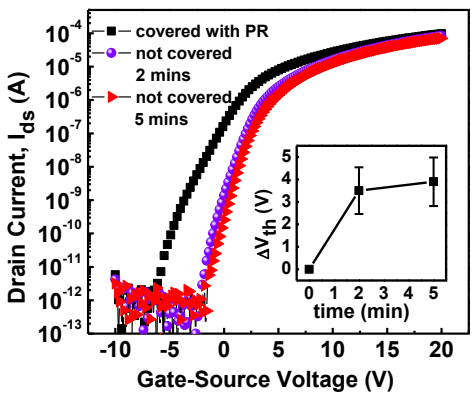

Fig. 2. Transfer characteristics of the fabricated TFTs with and without channel regions covered by photoresist (PR) during the O2 plasma treatment. Shown in the inset is the dependence of ΔV_{th} on the treatment time.

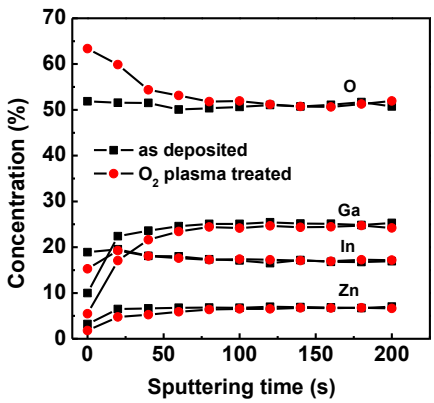

Fig. 3. XPS depth profile of the as-deposited a-IGZO film and O2 plasma treated a-IGZO film.

roved with the O_2 plasma treatment. The *SS* for the covered device is about 1.1 V/dec, 0.7 V/dec for the 2 mins treated one and 0.77 V/dec for the 5 mins treated one.

It is inferred that the positive shift of the transfer characteristics in the TFTs with the O_2 plasma treatment results from the reduction of oxygen vacancy concentration in the IGZO film. In order to manifest the oxygen absorption on the back channel and penetrating into the channel after the O_2 plasma treatment, an X-ray photoelectron spectroscopy (XPS) analysis was performed on the a-IGZO films with and without the O_2 plasma treatment. It is seen from Fig.3 that the reduction of oxygen vacancy concentration does happen at the back surface and inside the channel layer. The *SS* improvement is likely attributed to the passivation of the electron traps such as oxygen vacancy in the channel with the O_2 plasma treatment [5].

Fig. 4 shows the transfer characteristics of the fabricated a-IGZO TFTs with the O_2 plasma treatment at different RF powers for a fixed treatment time. The photoresist covered TFT has a V_{th} of −2.1 V; however, the exposed devices with the 80 W and 150 W O_2 plasma treatments have a V_{th} of 1.7 V and 2.7 V, respectively. Moreover, the sub-threshold swing (*SS*) is 0.73 V/dec for the covered device, 0.62 V/dec

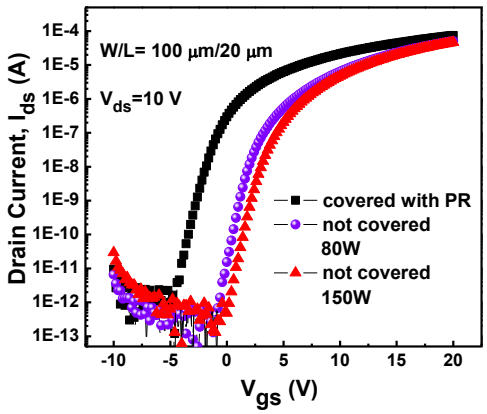

Fig. 4. Transfer characteristics of the fabricated a-IGZO TFTs versus the O2 plasma RF power.

for the 80 W treated device, and 0.71 V/dec for the 150 W treated device. The slight *SS* deterioration in the 150 W treated device implies that the plasma treatment would induce some damage to device performance when the RF power is high enough.

4. Conclusions

In this paper, we have demonstrated a simple method of fabricating multi-V_{th} a-IGZO TFTs which is compatible with current main-stream AMFPD technology. Results have shown that the TFTs covered by photoresist during the oxygen plasma treatment have a negative value of V_{th} and those exposed directly to the oxygen plasma have a positive value of V_{th} as well as an improved sub-threshold swing. Both enhancement and depletion mode TFTs are thus fabricated successfully on one single substrate. Moreover, the plasma induced threshold voltage shift amount could be adjusted by the exposure time and RF power. The threshold voltage shift and *SS* improvement originate possibly from the defect passivation and oxygen vacancy concentration reduction in the channel region.

Acknowledgements

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