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High Performance Hydrogenated Oxide Field-effect Transistor

ChangDong Chen and Chuan Liu *

[1] State Key Lab of Opto-Electronic Materials & Technologies, School of Electronics and Information Technology, Sun Yat-Sen University, Guangdong 510275, China
Phone: +86-18102706826 Email : liuchuan5@mail.sysu.edu.cn

Abstract

In this study, we demonstrate simply depositing SiN_X and SiO_X encapsulation layers at a low temperature with proper annealing, however, leads to surprisingly high performance in *a*-IGZO thin-film transistors (TFTs). A series of characterizations suggest that the enhanced apparent mobility is closely related to the reduced oxygen vacancies and stabilized hydrogen that probably heal the defect states.

1. Introduction

Amorphous metal oxide semiconductors (AOS) envision a future of large-area, robust, and transparent electronics, because its' high mobility, good uniformity, low processing temperature and high transparence. Pristine AOS such as InGaZnO exhibit field-effect mobility in tens of cm^2/Vs [1] and higher values around 100 $cm^2/V\cdot s$ have only been achieved by incorporating nano-material composites or partial capping layers [2].

Here we report ultra-high apparent mobility a-IGZO TFTs with simple SiN_X encapsulation layers and proper annealing (referred as IGZO-H in the reaming text) [3]. The field-effect mobility in long-channel TFTs (200 μm length) reaches 345 cm^2/Vs in the linear regime and 402 cm^2/Vs in the saturated regime, respectively. On-off ratio remains high up to 10^8 and reliability during bias-stressing has been improved as compared with regular IGZO TFTs. The enhancement in the drain current and on-off ratio is remarkable in the long-channel devices (e.g. 40 times in 200 μm long transistors) but becomes much less pronounced in short-channel device (e.g. 2 times in 5 μm long transistors), which limits its application to display industry. By applying conventional electrical measurements, gated four probe (GFP) measurements, TCAD device simulation and surface potential profile scanning, we reveal that the anomalous high mobility is attributed to the hydrogenation of most of the channel, while the region near contact remain barely doped.

2. Device Fabrication

Both regular and treated IGZO TFTs are developed on a heavily doped silicon wafer with 105 nm thick SiO_X which serves as the bottom-gate electrode and the gate dielectric layer. To build a regular IGZO TFT, a 60 nm thick active layer are RF sputtered on top of the dielectric, followed by patterning and wet-etch. The 200 nm thick source/drain electrodes are DC sputter grown and patterned *via* lift off.

To build a treated IGZO-H TFT, a bilayer encapsulation (350 nm thick SiO_X and 100 nm thick SiN_X) is further deposited on top of a regular IGZO TFT through PECVD at 180 °C. Contact holes are developed through reaction ions etch (RIE). The fabrication ends with a 1h 350 °C annealing process at N_2 atmosphere. A schematic view of a IGZO-H TFT is shown in **Fig. 1**.

3. I-V measurements

The transfer curves of both TFTs in linear regime are given in **Fig. 2**. The result show that the on current are substantially increased by the encapsulation, while the off current remain below 100 pA, which is probably related to the gate leakage current (dark line). The average field effect mobility are extracted through the slope of I_D-V_G in linear scale. In contrast to 8.0 cm^2/Vs in regular IGZO TFT, the mobility is orders increased to 345 cm^2/Vs in treated IGZO-H device.

4. Effect of encapsulation

To understand the impact of encapsulation layer on IGZO TFTs, we have built devices with various passivation layer. As observed from **Fig. 3a**, SiN_X is vital for the achievement of drain current increase, while SiO_X paly the role as a buffer layer which improves the subthreshold properties. Further, the effect of SiN_X thickness is investigated for devices with SiO_X/SiN_X encapsulation (see in **Fig. 3b**). The result suggest that the doping concentration of H can be controlled by adjusting the thickness of SiN_X layer.

5. Elemental profiles

To further understand the mechanism, second ion mass spectroscopy (SIMS) is used to measure the elemental profiles of IGZO and IGZO-H film. By using the strongest In signal as reference, the result show that the H signal in treated IGZO-H film is higher than that of regular IGZO film (**Fig. 4a**). Given that evidence, we propose that the anomalous high mobility is attributed to the incorporation of H which is diffused from SiN_X into IGZO layer during the post-annealing process (as illustrated in **Fig. 4b**).

6. Surface potential profiles

We proposed an intrinsic-doped-intrinsic channel model to explain the enhancement of current (**Fig. 6a**). By setting the mobility value as 12 cm^2/Vs for both intrinsic and doped channel, the simulated transfer curve fits well with the experimental data (**Fig. 6b**). The proposition is further verified with

scanning Kelvin probe microscope measurement (**Fig. 6c**), and the measured potential profile along the top channel surface of both devices (**Fig. 6d**) is in good accordance with the simulation (**Fig. 6e**). As the potential drop along IGZO-H TFT is smaller than that of IGZO TFT, it is confirmed that the central of the channel for IGZO-H device is highly conductive due to doping, while the region near contact remain almost intrinsic.

7. Conclusions

A IGZO-H TFT with ultra-high apparent mobility are demonstrated with simple PECVD grown SiN_X encapsulation and annealing. The result suggest that the enhanced performance is related to H doping which probably form an intrinsic-doped-intrinsic channel.

Acknowledgements

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References

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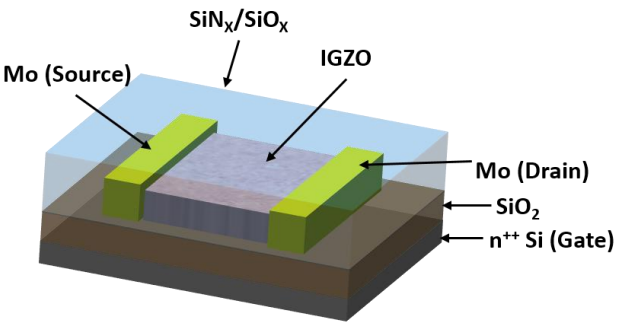

Fig. 1 Schematic view of a IGZO-H TFT device.

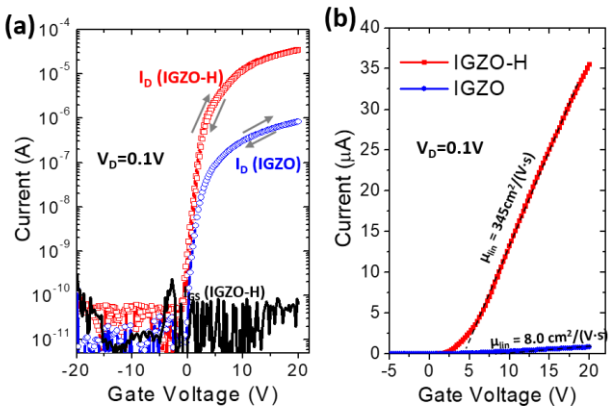

Fig. 2 Transfer curves of the IGZO-H (red) and IGZO (blue) TFTs at linear regime (V_{DS} = 0.1 V) in log scale (a) and linear scale (b). The black line denotes the gate leakage current of the IGZO-H device.

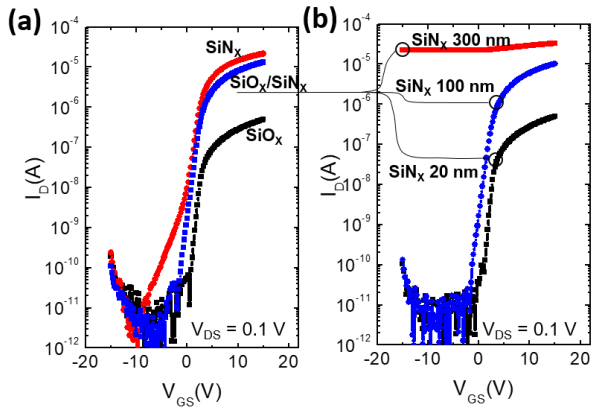

Fig. 3 Transfer curves of the IGZO TFTs with various passivation layer (a) and various thickness SiNX layerat linear regime (V_{DS} = 0.1 V) in log scale (a) and linear scale (b). The black line denotes the gate leakage current of the IGZO-H device.

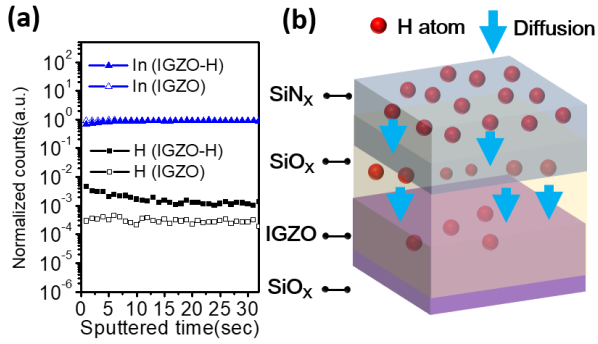

Fig. 5 Elemental profiles measured from IGZO and IGZO-H films (a) and a schematic representation of the H doping process.

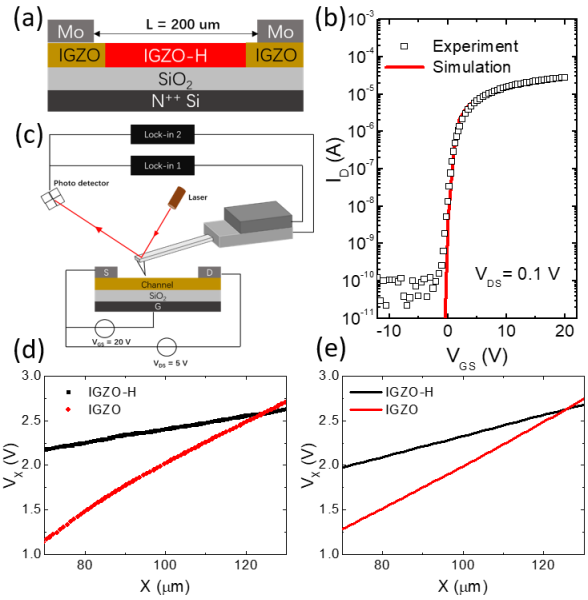

Fig. 6 (a) The intrinsic-doped-intrinsic channel model and (b) the comparison of the measured and simulated transfer curves. (c) A schematic view of SKPM set up with the measured potential profile (d) and simulation (e).