Extended Abstracts of the 2014 International Conference on Solid State Devices and Materials, Tsukuba, 2014, pp144-145

Fabrication of High Performance Ultra-thin body SnO_2 Thin-Film-Transistors (TFTs) using Microwave Annealing

Sung-Wan Moon, Hyun-Jun Jang, and Won-Ju Cho

Department of Electronic Materials Engineering, Kwangwoon University, Wolgye-dong, Nowon-gu, ,
Seoul 139-701, South Korea, Tel: +81-2-940-5163, E-mail: chowj@kw.ac.kr,

Abstract

We fabricated ultra-thin body dioxdie (SnO_2) thin-film-transistors with high mobility using microwave irradiation at a low process temperature below 100 ℃. The electrical characteristics of SnO_2 TFT were drastically enhanced below the body thickness of 10 nm. Microwave irradiation enhanced the electrical properties of TFTs; a high field-effect mobility of 35.4 cm^2 $V^{-1}s^{-1}$, a high on/off current ratio of 4×10^7, and small subthreshold swing of 613 mV/dec.

1. Introduction

Transparent semiconducting and conducting oxides (TSOs and TCOs, respectively) have been attracting considerable attention for application in transparent electronics, mobile electronics, future displays, and other consumer electronics. Among them, amorphous indium-gallium-zinc oxide (a-IGZO) TFTs is considered as one of the most promising material for backplane electronic devices of next-generation display application, because of their outstanding electrical properties such as high mobility and an excellent on/off ratio even in the amoprohous phase and fully transparent [1]. However, the cost issue due to rare earth metals such as indium, gallium is demanding appropriate alternatives such as zinc oxide (ZnO_2) and tin oxide (SnO_2). A lot of research has been conducted on the ZnO_2 TFTs and SnO_2 TFTs so far. Nevertheless, the performances of these devices are not surpassing the a-IGZO TFTs. In particular, since the SnO_2 shows a metallic conduction characteristic when the thermal process temperature is higher than 400 ℃ [2], it might hamper their diverse applications into plastic and glass substrates.

In this study, we fabricated a high performance SnO_2 TFTs with microwave annealing at a low thermal process temperature below 100 ℃. The body thickness and microwave annealing effects on the performance and instability of TFTs were investigated.

2. Experimental Methods

The TFT device was fabricated on the p-type (100) Si wafer with a resistivity of 10-Ω·cm. After standard RCA cleaning of Si surface, a thermal oxide with a thickness of 100 nm was grown as a gate insulator. The active channel layers of 30, 10 and 5-nm-thick SnO_2 film were deposited by RF magnetron sputtering using argon (Ar) gas with a flow rate of 20 sccm. The deposition condition is as follows: a RF power of 70 W, a pressure of 3×10^{-3} torr. The post-deposition annealing was carried out at two methods to improve the electrical properties of the SnO_2 TFTs; a conventional furnace annealing and a microwave annealing. The temperatures of furnace annealing were ranging from 200 to 400 ℃ for 30 min in nitrogen (N_2) ambient. Meanwhile, the microwave irradiation was carried out with a microwave power of 1000 W for 15 min in air. The process temperature of microwave annealing monitored by a thermocouple in contact with the sample was 89 ℃. The active and source/drain regions were patterned using shadow masks. The source/drain electrodes (Ti/Au=10/100 m) were formed by e-beam evaporation on the active region. Fig. 1 shows the schematic structure of the ultra thin body SnO_2 TFTs with a back gate. The electrical performances of the TFTs were characterized by a probe station in dark box and a semiconductor parameter analyzer (HP 4156B) at room temperature. The instability was measured by threshold voltage shift under the positive/negative gate bias (PBS/NBS) stress (V_{GS}=±20 V, V_{DS}=10 V) for 1 hour.

3. Results and Discussion

Fig. 2 shows the transfer characteristics of SnO_2 TFTs annealed in (a) microwave with a power of 1000 W and (b) conventional furnace with a temperature of 400 ℃. When the body is thick, the TFTs operate in normally-on mode because the electron concentration of SnO_2 channel is very high. As a result, the drain leakage current increases with channel thickness. On the contrary, as the body thickness decreases below 10 nm, the SnO_2 TFTs showe better on/off ratio and subthreshold swing. This indicate that the channel region can be controlled when the body become fully depleted for gate elecrtical field [3].

Fig. 3 shows the transfer curves of 5-nm-thick SnO_2 TFTs. Owing to a large number of defects incorporated in SnO_2 channel and interface states at the gate oxide/channel, as-deposited SnO_2 TFTs shows poor characteristics. However, these defects can be reduced by post deposition heat treatment, leading to improved device performance. Obviously, the annealed samples by furnace or microwave revealed dramatic improvements in transfer curves.

Fig. 4 shows field-effect mobility (μ_{FE}) and subthreshold swing (SS). The low temperature furace anneling below 300 ℃ is found to be unhelpful for improving TFTs performance. But, the furnace anneal at 400 ℃ considerably improved the μ_{FE} and SS to 20.3 $cm^2/V\cdot s$ and 672 mV/dec, respectively.

Fig. 5 shows the instability of the SnO_2. Threshold voltage shift of microwave annealed TFTs is smaller than that of 400 ℃ furnace annealed one. Therefore, we conclude that the microwave annealing effectively removes the defects in SnO_2 channel and improves the gate insulator/channel interfaces at low temperature.

4. Conclusions

A high performance SnO_2 TFTs with a ultra-thin body was fabricated by using the microwave annealing process at low process temperature. The electrical characteristics of SnO_2 TFT were enhanced with decreasing body thickness. Microwave irradiation enhances the electrical properties of TFTs; a high field-effect-mobility of 35.4 $cm^2\ V^{-1}s^{-1}$, a high on/off current ratio of 4×10^7, and small subthreshold swing of 613 mV/dec. Therefore, the ultra-thin body SnO_2 TFTs and the microwave annealing are very promising to transparent display applications owing to a low cost, fully transparency, and high performance.

Acknowledgements

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education, Science and Technology (No. 2013R1A1A2A10011202).

References

[1] K. Nomura, H. Ohta, A. Takagi, T.Kamiya, M.Hirano, and H.Hosono, Nature, 432, 488 (2004).

[2] C. W. Lee, A. Afzalian, N. D. Akhavan, R. Yan, I. Ferain, And j.p. colinge, Appl. Phys. Lett., vol. 94, no. 5, pp. 053 511-1–053 511-2, Feb. 2009.

[3] C. W. Lee, A. Afzalian, N. D. Akhavan, R. Yan, I. Ferain, And j.p. colinge, Appl. Phys. Lett., vol. 94, no. 5, pp. 053 511-1–053 511-2, Feb. 2009.

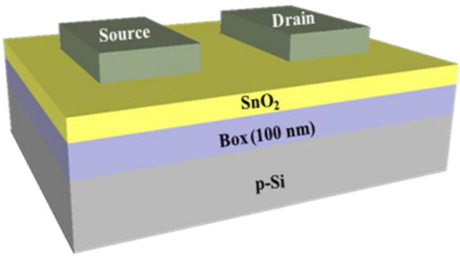

Fig.1. Schematic structure of the ultra thin body SnO_2 TFTs with a back gate electrode.

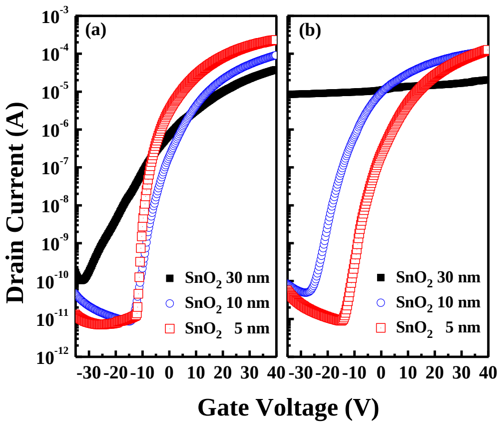

Fig.2. Transfer curves of SnO_2 TFTs: (a) microwave annealing with 1000 W/15 min, (b) furnace annealing at 400 ℃/30 min.

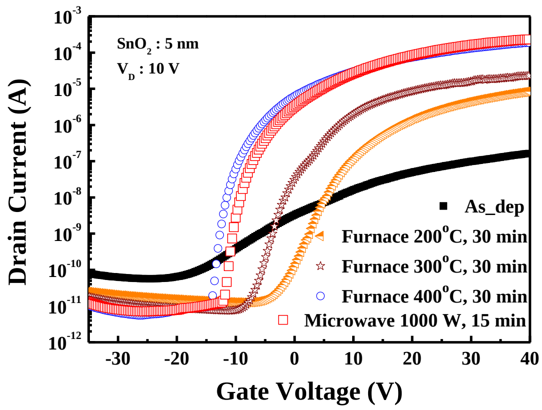

Fig.3. Transfer curves of SnO_2 TFT with different annealing conditions.

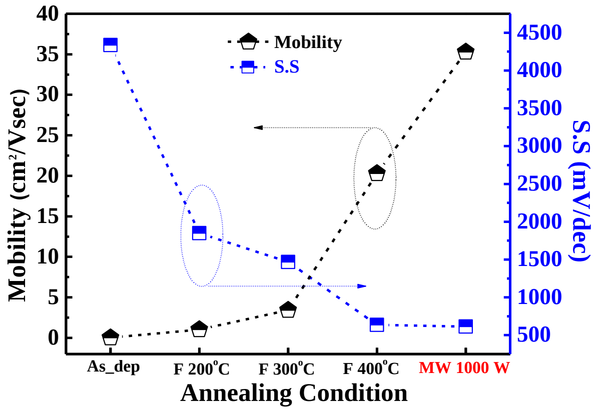

Fig.4. Field-effect mobility and subthreshold swing of SnO_2 TFTs of 5-nm-thick channel with different annealing conditions.

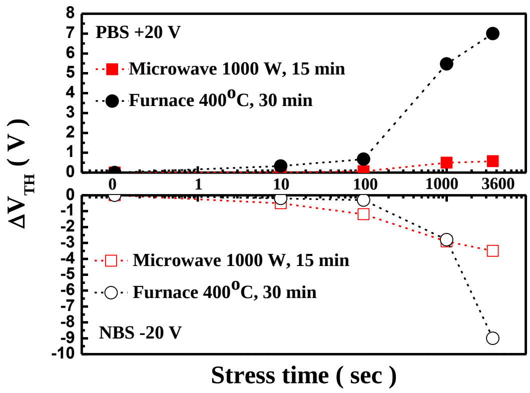

Fig.5. Threshold voltage shift of SnO_2 TFTs with a body thickness of 5 nm as a function of PBS/NBS time.