A Study on the Radiation Hardness of Amorphous Oxide Thin-Film Transistors

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Keywords: AOS TFT, proton irradiation, radiation tolerance

ABSTRACT

We investigated the effects of film thickness (t_{ch}) on the radiation hardness of indium-gallium-tin oxide (IGTO) thin films transistors (TFTs). The IGTO TFT with the 12 nm thick channel layer exhibited the best electrical performance and radiation tolerance. The radiation tolerance significantly decreased as t_{ch} increased.

1 Introduction

Oxide TFTs are known to have better radiation hardness than polycrystalline silicon TFTs or organic TFTs because the electron transport through the overlap of spherical *s* orbitals in metal oxides is largely unaffected by the lattice disorder [1]. To date, a number of studies have been conducted that examine the effects of various process parameters on the radiation hardness of oxide TFTs, including the carrier suppressor content within the channel and the oxygen partial pressure during the channel layer deposition. However, no study has yet reported the effects of channel layer thickness (t_{ch}) on the radiation tolerance of oxide TFTs, even though it is a key parameter that strongly affects the electrical properties and stabilities of the oxide TFTs [2]. In this work, we studied the effects t_{ch} on the radiation damage of indium-gallium-tin oxide (IGTO) thin films and radiation tolerance of IGTO TFTs under proton irradiation. From the experimental results, it was observed that the radiation tolerance of the IGTO TFTs significantly decreased as t_{ch} increased. The reason for the observed phenomenon was studied by examining the effects of proton beam irradiation on the physical and chemical properties of IGTO thin films with different values of t_{ch}. The enhanced oxygen vacancy generation due to the atomic displacement cascades within the IGTO thin film is suggested as the most probable physical mechanism responsible for the decreased radiation tolerance of thick-channel IGTO TFTs.

2 Experiment

The experiments were performed using bottom-gate IGTO TFTs, where a heavily doped p-type Si wafer was employed as the gate electrode. A 100-nm-thick thermal SiO_2 layer was formed as the gate dielectric, and IGTO thin films with thicknesses of 6, 12, 27, and 42 nm were deposited using direct current (DC) magnetron sputtering with a 3-in. IGTO target. The source and drain electrodes were formed using a 100-nm-thick indium-tin oxide (ITO) layer using DC magnetron sputtering. Finally, the TFTs were subjected to thermal annealing at 200 °C for 1 h in air. Fig. 1 shows the cross-sectional view of the fabricated IGTO TFT. The IGTO TFTs were irradiated by a 5-MeV proton beam at a fixed dose of 10^{13} cm^{-2} using an MC-50 cyclotron at the Korea Institute of Radiological and Medical Science. The TFTs were exposed to the proton beam for 102 s after floating all electrodes, and the electrical characterization of the irradiated devices was conducted approximately 6 h after the proton beam irradiation to minimize the effects of dielectric trapped charges on the electrical performance of TFTs by allowing the generated electron-hole pairs recombine within the dielectric. The effects of proton beam irradiation on the chemical properties and surface morphologies of the IGTO thin films having different values of t_{ch} were characterized using X-ray photoelectron spectroscopy (XPS). The electrical characterization of the TFTs was performed in the dark at room temperature in air using a semiconductor parameter analyzer.

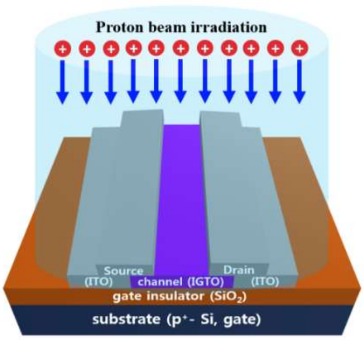

Fig. 1 Cross-sectional view of the fabricated IGTO TFT

3 Results and Discussion

Fig. 2 shows the transfer curves of the pristine IGTO TFTs [width/length (W/L) = 500 μm/300 μm] with t_{ch} values of 6, 12, 27, and 42 nm on a semi-logarithmic scale, where V_{GS}, V_{DS}, and I_D are the gate-to-source voltage, drain-to-source voltage, and drain current, respectively. Measurements were conducted by scanning V_{GS} from −20 to 20 V at V_{DS} = 1 V for all TFTs. Fig. 2 shows that I_D hardly flows when t_{ch} = 6 nm, therefore, the effects of proton beam irradiation on IGTO thin films and TFTs were examined only for samples with t_{ch} values of 12, 27, and 42 nm in this study.

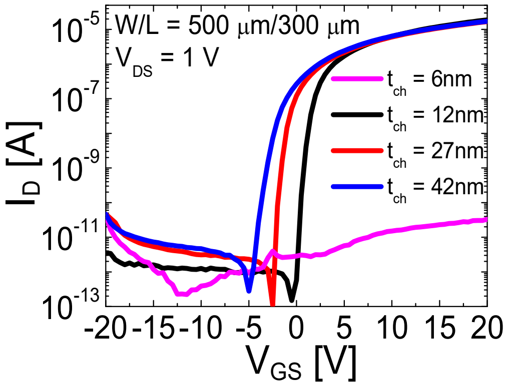

Fig. 2 Transfer curves measured from the pristine IGTO TFTs

From Fig. 2, it is clear that the turn-on voltage (V_{ON}) shifts toward the negative direction and the subthreshold swing (*SS*) increases with increasing t_{ch}, where V_{ON} was determined from the onset V_{GS} at which I_D increases and *SS* was defined as the change in V_{GS} required to change I_D by one decade in the subthreshold region. These observations are consistent with those in previous reports and were mainly attributed to the larger number of free electrons (V_{ON} shift) and higher sheet trap density in the thicker channel layer (*SS* increase) [3].

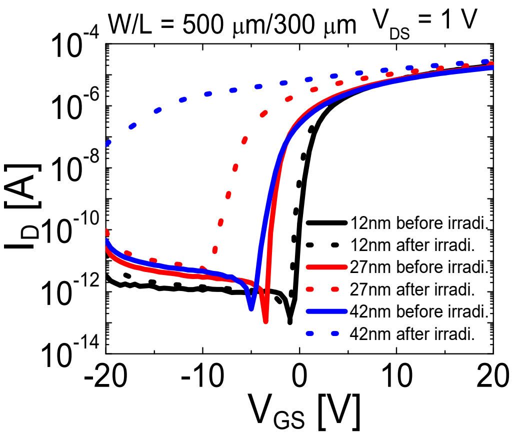

Fig. 3 Transfer curves of the IGTO TFTs with different t_{ch} values measured before and after the 5-MeV proton beam irradiation.

Figs. 3 depict the transfer curves of the IGTO TFTs with t_{ch} values of 12, 27, and 42 nm, respectively, measured before and after the proton beam irradiation. The proton-irradiated IGTO TFTs exhibited poorer electrical performance than the pristine IGTO TFTs, including a negatively shifted V_{ON}, higher off-current, and larger *SS*. From the results shown in Fig. 3, it is clear that the electrical performance of the proton-irradiated IGTO TFTs exhibited the least significant deterioration at t_{ch} = 12 nm and the most significant deterioration at t_{ch} = 42 nm. The results shown in Fig. 3 demonstrate that t_{ch} is an important parameter that strongly affects the radiation hardness of oxide TFTs and that a small value of t_{ch} is advantageous in improving the radiation hardness of oxide TFTs.

To elucidate the physical mechanism responsible for the phenomena observed in Fig. 3, the IGTO thin films with different values of t_{ch} were characterized by XPS before and after the proton beam irradiation.

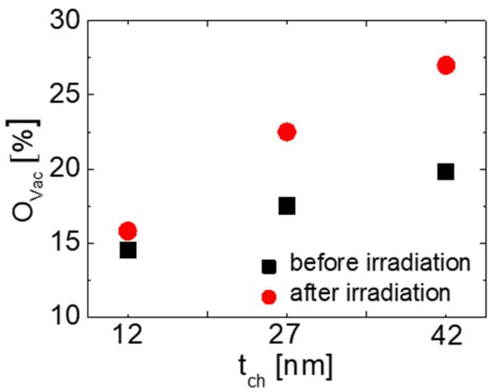

Fig. 4 Relative areas of peaks corresponding to O_{Vac} obtained from the IGTO thin films with different t_{ch} values before and after the proton beam irradiation.

Fig. 4 shows the relative areas of peaks corresponding to O_{Vac} obtained from the IGTO thin films with different t_{ch} values before and after the proton beam irradiation. A slightly higher area percentages of O_{Vac} were observed from the thicker IGTO thin films before the proton irradiation, which is considered as a result of the increased ion bombardment damage during the sputtering due to the longer sputtering time. The XPS results indicate that the area percentage of O_{Vac} increased after the proton irradiation in all TFTs. This phenomenon was already reported in the previous works for oxide TFTs and was mainly attributed to the formation of oxygen vacancies within the oxide thin film by high-energy particle collisions with the metal-oxide lattice [4]. An important thing to note from Fig. 4 is that the difference between the area percentage of O_{Vac} before and after the proton irradiation increases with increasing t_{ch}. O_{Vac} acts as a shallow donor as well as a deep donor in IGTO [5].

The larger increase in the O_{Vac} concentration in the thicker-channel IGTO TFTs after proton irradiation is considered as the result of the enhanced atomic displacement cascades within the IGTO thin film. Because incoming proton particles have significantly higher energy than the displacement energy for the creation of Frenkel pairs in metal oxides, atoms ejected from their normal lattice position by the protons can initiate multiple displacement chain reactions before exiting from the thin film [6]. The characterization results revealed that the decreased radiation tolerance of the thicker-channel IGTO TFTs were mainly attributed to the further enhanced oxygen vacancy generation due to the atomic displacement cascades within the IGTO channel layer after the proton irradiation. The results of this study demonstrate that t_{ch} is a key parameter determining the radiation tolerance of oxide TFTs and a thin channel layer is advantageous in improving the radiation tolerance of oxide TFTs.

4 Conclusion

In this study, the effects of t_{ch} on the radiation hardness of IGTO TFTs were examined using TFTs with t_{ch} values of 12, 27, and 42 nm. The radiation tolerance of the IGTO TFTs was evaluated by comparing the transfer curves of every device measured before and after 5-MeV proton beam irradiation. From the experimental results, it was observed that the IGTO TFT exhibited the best electrical performance and radiation hardness when t_{ch} = 12 nm. The radiation hardness of the IGTO TFTs decreased significantly as t_{ch} increased. The XPS characterization results showed that the O_{Vac} concentration within the thin film increased after the proton irradiation in all TFTs, however, it was more significant in IGTO thin films with a larger value of t_{ch}. The strong atomic displacement cascades within the channel layer were proposed as the most plausible reason of the poor radiation tolerance of thick-channel IGTO TFTs.

References

[1] K. Yapadandara, V. Mirkhani, S. Wang, M. P. Khanal, S. Uprety, T. I.-Smith, M. C. Hamilton, M. Park, “Proton-induced displacement damage in ZnO thin film transistors: Impact of damage location”, Microelectron. Rel. 91 (2018) 262-268.

[2] S. Y. Lee, D. H. Kim, E. Chong, Y. W. Jeon, D. H. Kim, “Effect of channel thickness on density of states in amorphous InGaZnO thin film transistor”, Appl. Phys. Lett. 98 (2011) 122105.

[3] P. Barquinha, A. Pimentel, A. Marques, L. Pereira, R. Martins, E. Fortunato, “Influence of the semiconductor thickness on the electrical properties of transparent TFTs based on indium zinc oxide”, J. Non-Cryst. Solids 352 (2006) 1749–1752.

[4] Y.-K. Moon, S. Lee, D.-Y. Moon, W.-S. Kim, B.-W. Kang, J.-W. Park, “Effects of proton irradiation on indium zinc oxide-based thin-film transistors”, Surf. Coat. Technol. 3 (2010) S109-S114.

[5] H.-J. Jeong, H.M. Lee, K.-T. Oh, J. Park, J.-S. Park, “Enhancement of In-Sn-Ga-O TFT performance by the synergistic combination of UV + O_3 radiation and low temperature annealing”, J. Electroceram. 37 (2016) 158-162.

[6] M. -G, Shin, S. -H. Hwang, H. -S. Cha, H. -S. Jeong, D. -H. Kim, and H. -I. Kwon “Effects of proton beam irradiation on the physical and chemical properties of IGTO thin films with different thicknesses for thin-film transistor applications”, Surf. Interfac. 23 (2021) 100990.

Acknowledgements

This work was supported by a National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (No. 2020R1A2B5B01001765).