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Proton Radiation Effects in Tin Oxide Thin-Film Transistors with Different Device Structures

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1. Introduction

The space environment is continuously exposed to high-energy radiation particles such as protons, electrons and heavy ions, which can lead to performance degradation and functional failures in electronic systems [1, 2]. It has been reported that approximately 30% of anomalies observed in space-operated electronic components are attribute to radiation effects, highlighting radiation reliability as a critical challenge for space electronics [3]. Tin oxide (SnO_2) exhibits a high mobility of 20-30 $cm^2/V\cdot s$ even under low processing temperature below 400 °C, and its wide bandgaps of over 3.8 eV provides strong tolerance to extreme environment, making it a highly promising candidate for space electronics [4, 5].

In this work, the proton radiation tolerance of SnO_2 field-effect transistors (FETs) with difference in electrode materials and device structures was investigated. Titanium (Ti) and indium tin oxide (ITO) were employed as source and drain electrodes, respectively, while the device structures were categorized into configurations with an independently formed gate electrode and those utilizing the Si substrate as the gate. The electrical characteristics of both devices before and after proton irradiation were analyzed to discuss the impact of proton-induced displacement damage (DD) on the degradation of device characteristics.

2. Experiments, Results and Discussion

2.1 Device fabrication & Proton Irradiation

SnO_2 thin-film transistors (TFTs) with different device structures were fabricated: Si-gated TFT and bottom-gated TFT.

Si-gated TFT was fabricated on Si substrate with Au/Ti as the gate electrode. A 65 nm-thick Al_2O_3 gate dielectric layer and 6.5 nm-thick SnO_2 channel layer sequentially deposited on the Si substrate by atomic layer deposition (ALD). After patterning the SnO_2 channel by etching, Ti metal source/drain (S/D) electrodes were formed.

Bottom-gated TFT was fabricated on SiO2/Si substrate. A Ti gate electrode was first deposited on the substrate using an e-beam evaporator, followed by the deposition of a 65 nm-thick Al_2O_3 dielectric layer and a 7.2 nm-thick SnO_2 channel layer by ALD, and patterning by etching. Subsequently, ITO S/D electrodes were formed on the SnO_2 channel. The cross-sectional schematics of the fabricated Si-gated and bottom-gated TFTs are illustrated in Figures 1(a) and (b), respectively.

5 MeV proton irradiation was performed using an MC-50 cyclotron at Korea Institute of Radiological & Medical Sciences (KIRAMS). Both TFTs were exposed to fluence of 1×10^{14} p/cm^2 by maintaining a constant beam flux of ~1.6×10^{10} /cm$^2\cdot$s. Irradiation ambient was in air.

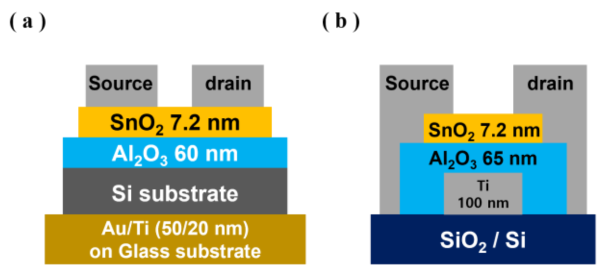

Figure 1. Cross-sectional schematics of fabricated (a) Si-gated TFT and (b) bottom-gated TFT

2.2 Device characteristics before and after irradiation

Figure 2(a) and (b) show the electrical characteristics of the Si-gated TFT with Ti electrodes and the bottom-gated TFT with ITO electrodes before and after proton irradiation, respectively. The I-V transfer characteristics of both devices were measured with the gate voltage swept from −20 V to 20 V. The extracted threshold voltage (V_{th}), subthreshold swing (SS), field-effect mobility (μ_{FE}), and on/off current ratio ($I_{on/off}$) from the I_{DS}–V_{GS} curves of the pristine and proton-irradiated devices were summarized in Table 1.

After proton irradiation, both devices exhibited a pronounced negative shift in V_{th}. In the case of the Si-gated TFT, V_{th} shifted from 0.24 V to −6.08 V (Δ-6.32

V). In contrast, the bottom-gated TFT showed a much larger shift of V_{th} from 0.60 V to −9.64 V (Δ-10.24 V). The drain current (I_{DS}) of the Si-gated TFT increased from 2.88 to 3.78 μA/μm, corresponding to an increase of 138%, whereas the bottom-gated TFT exhibited a significantly larger enhancement, increasing from 2.84 to 4.68 μA/μm, corresponding to a 165% increase.

The negative shift in V_{th} and the increase in I_{DS} indicated an increase in the carrier concentration within the SnO_2 channel. This behavior is attributed to proton-induced displacement damage (DD), which related to an increase in oxygen vacancies caused by the breaking of metal–oxygen bonding in the channel. In particular, differences in the source/drain electrode material and the gate configuration may contribute to variations in the impact of proton-induced DD.

Table I: Comparison of electrical properties of both TFTs before and after proton irradiation

Device Structures	Proton Irrad.	V_{th} [V]	μ_{FE} [cm^2/V·s]	S.S [V/dec]	$I_{on/off}$
Si-gated TFTs with Ti	Before	0.24	15.32	0.82	5.22×10^5
	After	-6.08	15.44	1.12	3.60×10^5
Bottom-gated TFTs with ITO	Before	0.60	16.42	0.87	1.16×10^8
	After	-9.64	17.82	2.12	5.08×10^3

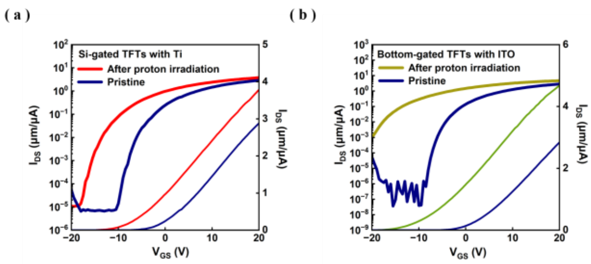

Figure 2. I-V transfer characteristics of (a) Si-gated TFT with Ti and (b) bottom-gated TFT with ITO.

3. Conclusions

The proton irradiation effects on SnO_2 TFTs with different gate configurations and source/drain electrode materials were investigated. Both Si-gated and bottom-gated TFTs exhibited a pronounced negative threshold voltage shift and enhanced drain current after proton irradiation. The bottom-gated TFT with ITO electrodes showed a more significant change in electrical properties, which is attributed to the combined effects of electrode material and device structure. These results exhibited Si-gated TFT with metal source/drain electrodes has the radiation tolerance compared to SnO_2 TFT with oxide electrodes expecting due to the decrease of radiation sensitive volume.

ACKNOWLEGMENTS

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