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

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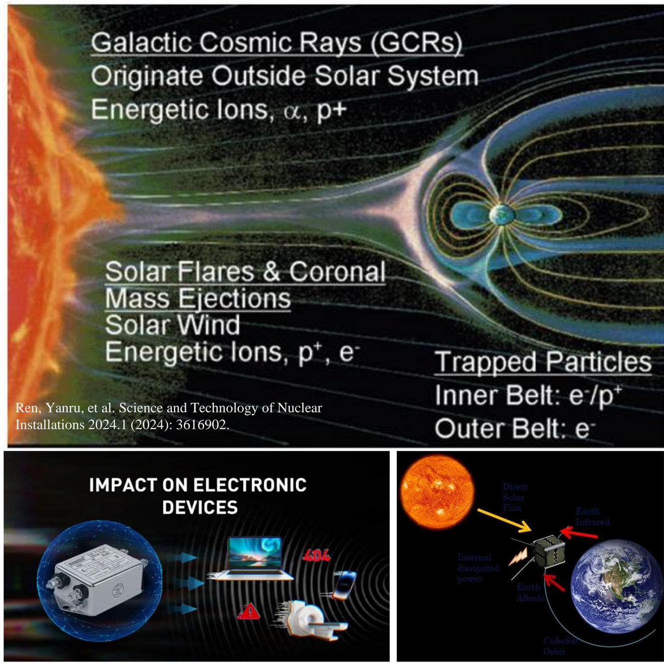
Introduction



♦ Space Radiation Environment

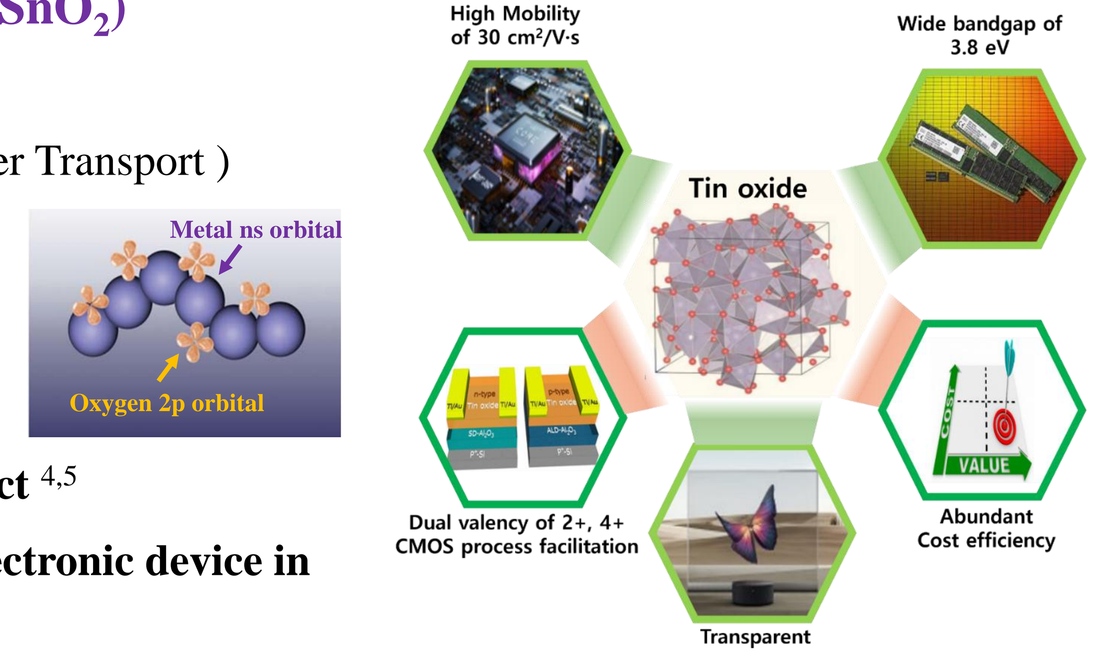
- Galactic Cosmic Rays (GCRs), Solar Particle Event (SPEs) : **Proton**, He ion, electron, heavy ions
- Van Allen Radiation Belts : trapped particle (**Proton**, α-particles, electron) by two main belts (640–58,000 km)
- These radiation particles affect the semiconductor with DD (Displacement Damage), TID (Total Ionizing Dose), SEE (Single Event Effect) [1,2].
- About 30% of electronics anomalies in space are attributed to radiation effect [3].

♦ Advantages of Tin Oxide (SnO_2)

- **s-orbital conduction**
  - Defect-tolerant (Stable Carrier Transport)
- **Wide bandgaps**
  - Suppresses leakage current
  - Strong M-O bonds

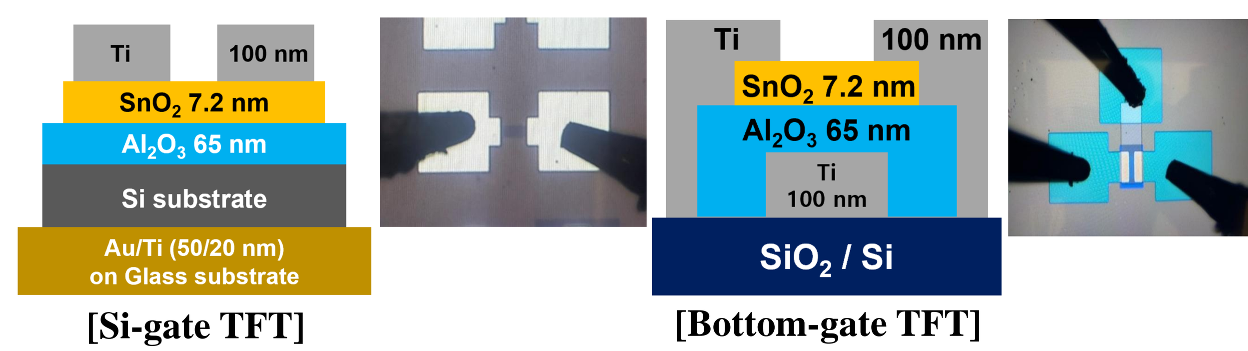
➢ **Resistant to DD and TID effect** [4,5]

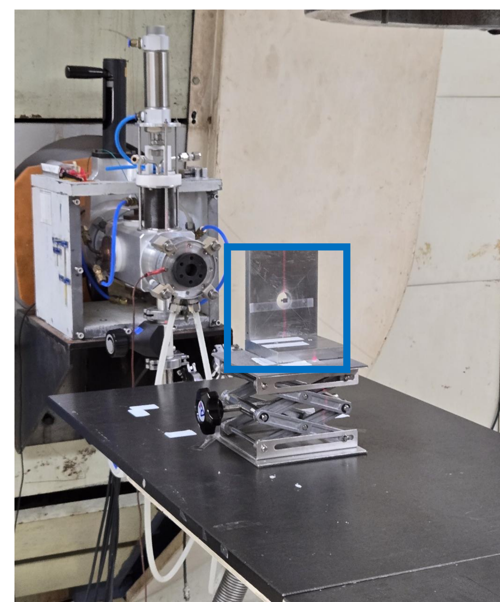
➢ **SnO_2 can be utilized as an electronic device in the aerospace field**



Experiments

♦ SnO_2 TFTs with different structures

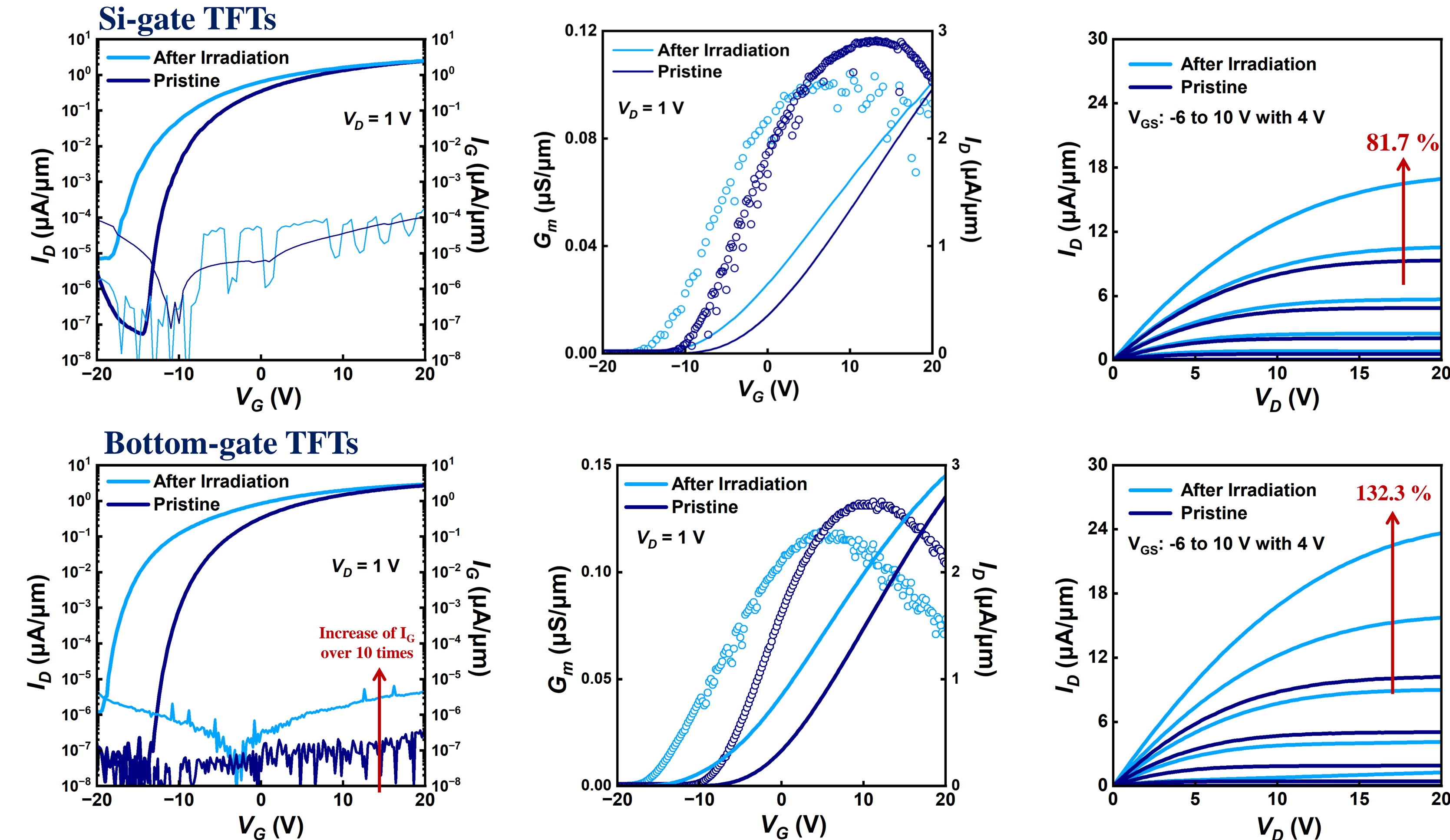




- **Si-gate TFT**: A structure using a Si-substrate as the bottom gate, forming an SnO_2 channel without Al_2O_3 (dielectric) etching.
- **Bottom-gate TFT**: In a conventional TFT structure, after forming individual gate (Ti), SnO_2 channels are formed following Al_2O_3 etching.
- Irradiation was performed using a **5 MeV proton beam** supplied by an MC-50 cyclotron at KIRAMS. The device samples were exposed to **fluences of 1 × 10^{14} cm^{-2}**.

Device performance after proton irradiation

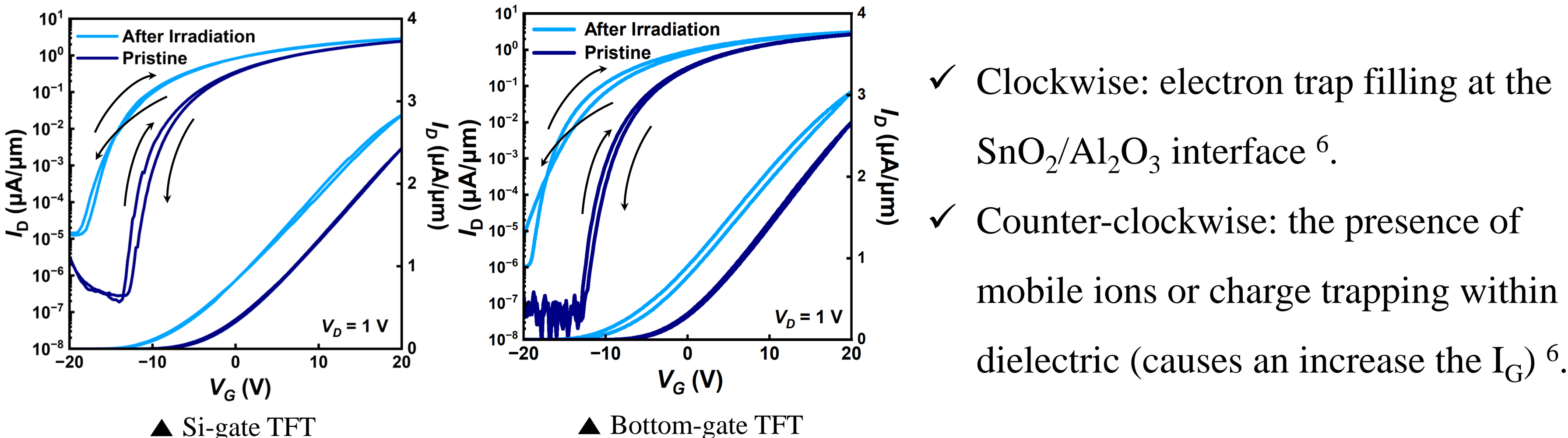
♦ I-V characteristics of SnO_2 TFTs after proton irradiation



- After proton irradiation, both devices exhibited a negative shift in the threshold voltage (V_{th}) and a increase in the output current (I_D).
- Increases in the carrier concentration in the channel induced by proton irradiation **(DD effect).**

♦ Dual-transfer characteristics after proton irradiation

: Hysteresis curves in the form of a mixture of clockwise and counter-clockwise was confirmed.



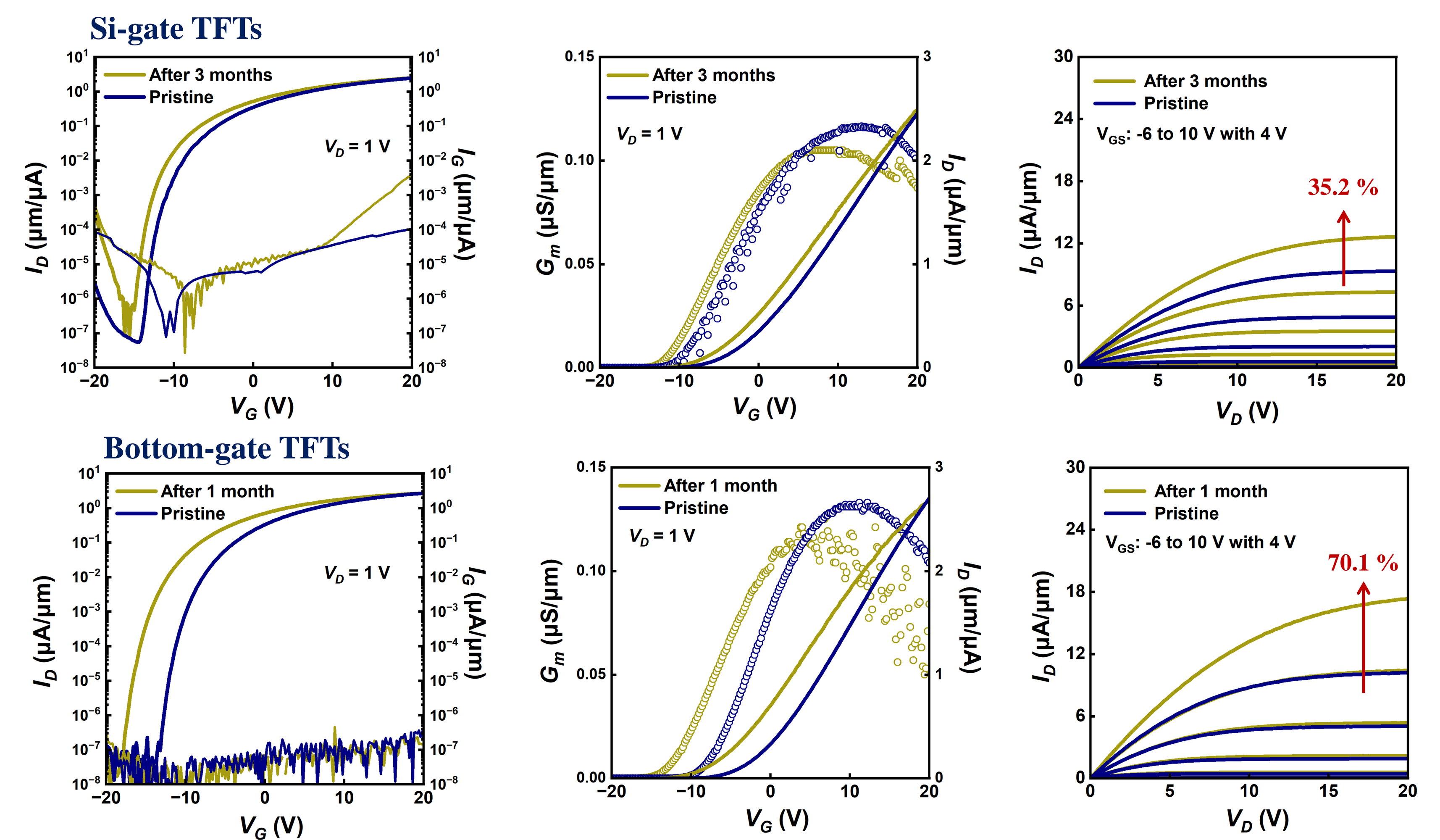
▲ Si-gate TFT ▲ Bottom-gate TFT

✓ Clockwise: electron trap filling at the SnO_2/Al_2O_3 interface [6].

✓ Counter-clockwise: the presence of mobile ions or charge trapping within dielectric (causes an increase the I_G) [6].

Device performance after aging in room-temperature

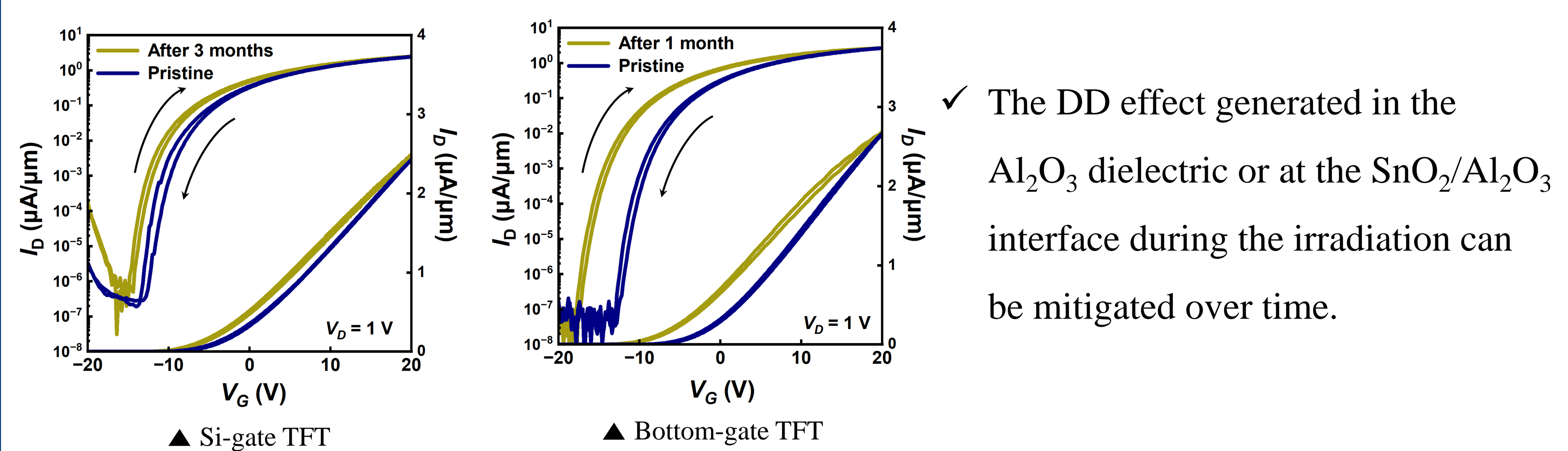
♦ I-V characteristics of SnO_2 TFTs after aging in room temperature



- After aging in room-temperature (RT), the both devices mitigated toward pre-irradiation states, with the Si-gate TFT exhibiting more pronounced mitigation.
- In addition, the leakage current (I_G) of the bottom-gate TFTs decreased to level a comparable to that after irradiation.

♦ Dual-sweep transfer characteristics after aging in RT

: The hysteresis curves showed a tendency to return to their pre-irradiation states. (exhibiting a clockwise hysteresis curve)



▲ Si-gate TFT ▲ Bottom-gate TFT

✓ The DD effect generated in the Al_2O_3 dielectric or at the SnO_2/Al_2O_3 interface during the irradiation can be mitigated over time.

♦ Summary of the device parameters

	Conditions	V_{th} [V]	μ_{FE} [cm²/Vs]	SS [V/dec]	$I_{on/off}$
Si-gate TFT	Pristine	-2.73	17.30	0.86	4.48 × 10^7
	Proton Irrad.	-6.67	15.44	1.03	3.60 × 10^5
	After Aging	-4.80	15.64	0.73	5.33 × 10^6
Bottom-gate TFT	Pristine	-1.95	19.73	0.93	2.87 × 10^7
	Proton Irrad.	-8.81	17.64	0.85	2.47 × 10^6
	After Aging	-6.44	18.00	0.97	8.51 × 10^7

Conclusion

- Proton irradiation induced a negative V_{th} shift and increased I_D in both SnO_2 TFTs structures, indicating increased channel conductivity after irradiation due to DD effect.
- The irradiated-SnO_2 TFTs after aging in room-temperature, both devices showed a tendency to return to their pre-irradiation state, which was particularly pronounced in the Si-gate TFT.
- The dual-sweep I-V results indicated the DD effect caused by irradiation on the dielectric, which suggests the possibility that it caused an increase in leakage current (I_G) in the bottom-gate TFT.

References & Acknowledgment

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Acknowledgment: This work was supported by the National Research Foundation of Korea(No. RS-2024-00437064) and the National Research Council of Science & Technology(NST) grant(No. CAP23031-200) by MSIT (Ministry of Science and ICT).