Radiation Effects on FinFET ZRAMs

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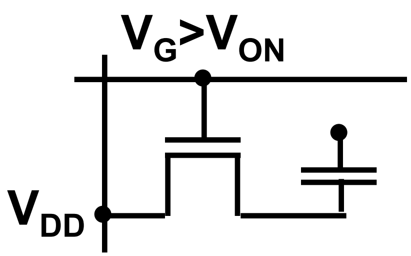
Outline

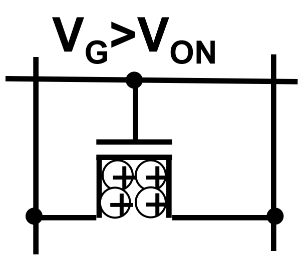
- ZRAM operation
- Experimental conditions
- TID effects and scaling trends
    - Back-gate pulse programming
    - GIDL programming
- Conclusions

Background

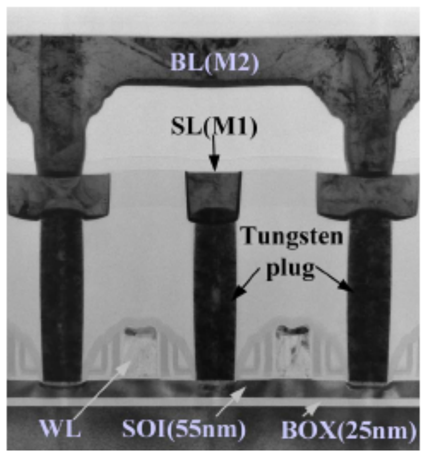
- Zero capacitor DRAM, a real 1T DRAM cell.
- Floating body effects provide the basis for ZRAM operation.
- High speed, low power, and potentially high scalability.



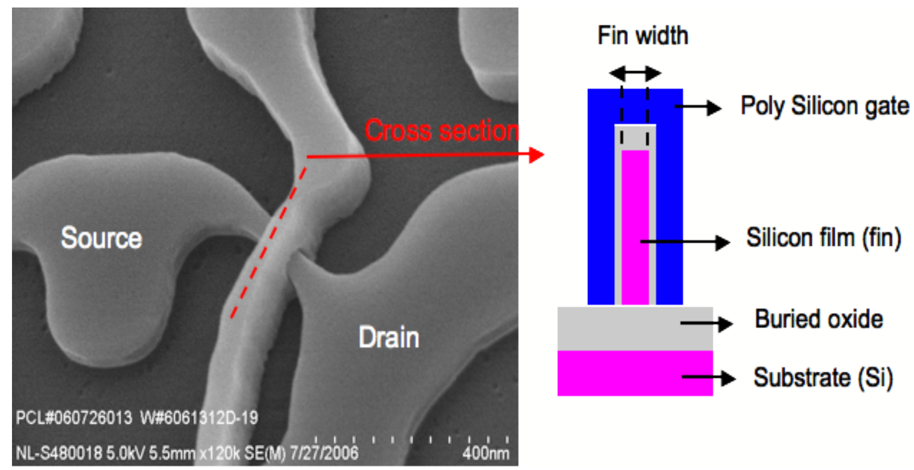
Traditional DRAM cell



Z-RAM cell



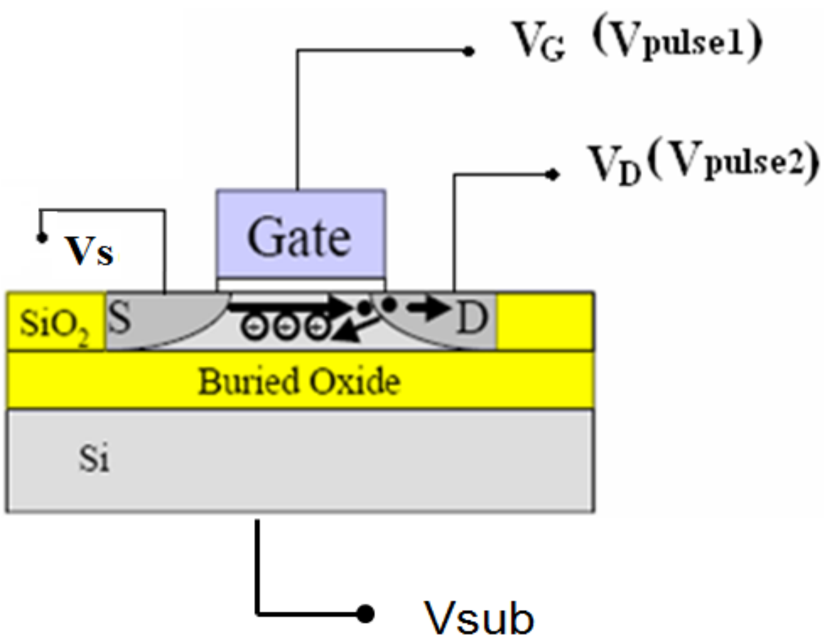
SEM of a ZRAM cell based on 90 nm SOI technology[1]

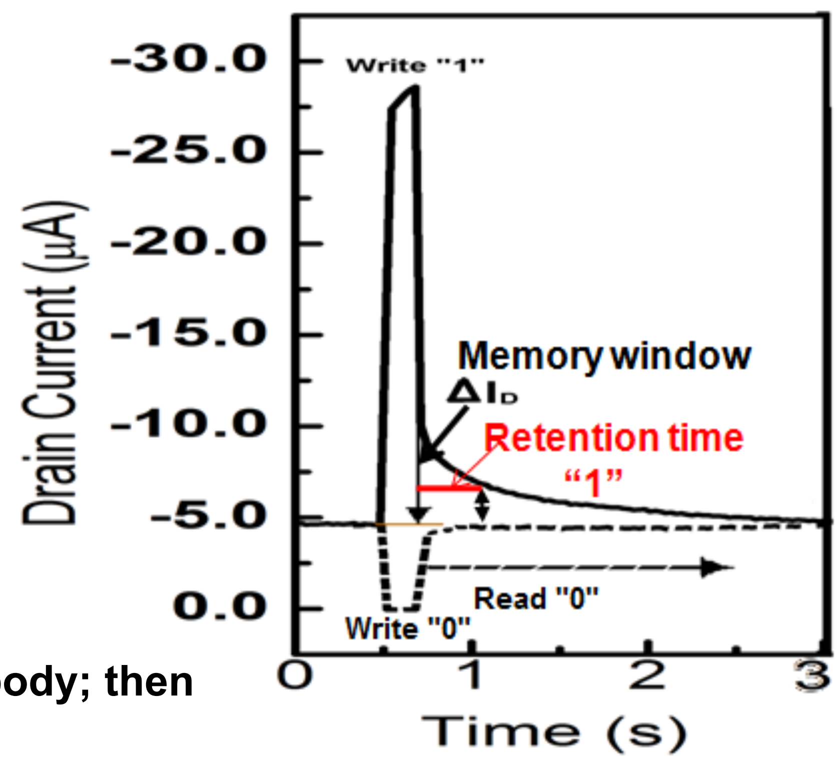


FinFET structure[2]

1. T. Hamamoto, et al., IEEE Trans. Electron. Dev., Mar. 2007
2. F. El Mamouni, et al., IEEE Trans. Nucl. Sci., Dec. 2009

ZRAM Operation





- Method 1: Back-gate pulse stores charge in body; then front gate pulse releases charge from body.
- Method 2: Front-gate pulse combined with drain pulse stores charge in the body by GIDL (gate induced drain leakage), then drain pulse sweeps the charge out of body by forward biasing the body/drain junction.

Programming of ZRAM cell

Experimental Details

Devices

- n-MOS and p-MOS FinFETs on UNIBOND® SOI.
- Fin width ranges from 50 to 2410 nm.
- Channel length ranges from 80 nm to 20 µm.
- The front-gate dielectric is 2 nm SiO_2.

ZRAM Tests

- I_D/I_S current vs. time with V_G/V_{BG} and V_D pulses.
- Programmed via back gate pulse or GIDL.

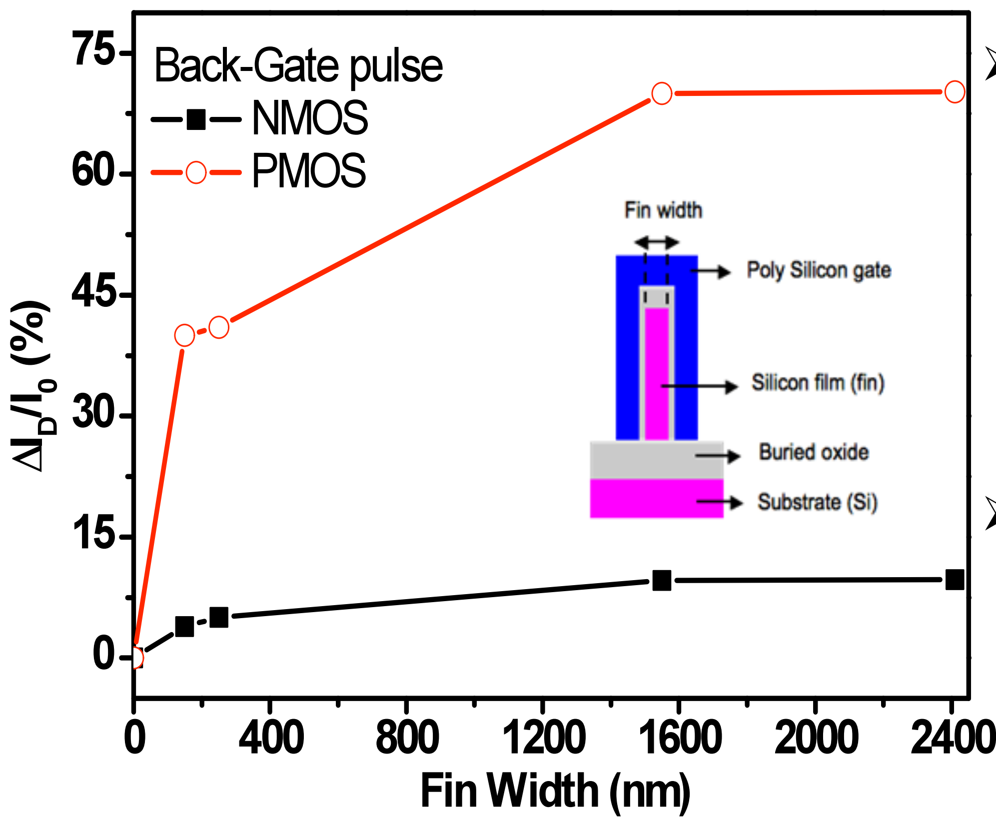
Irradiation Test Conditions:

ON-state: $V_G = 0.5$ V, $V_D = V_S = V_{sub} = 0$ V (NMOS);

OFF-state: $V_G = V_S = V_{sub} = 0$ V, $V_D = -0.5$ V (PMOS);

Total dose: 0 ~ 1000 krad(SiO_2) with 10-keV X-ray

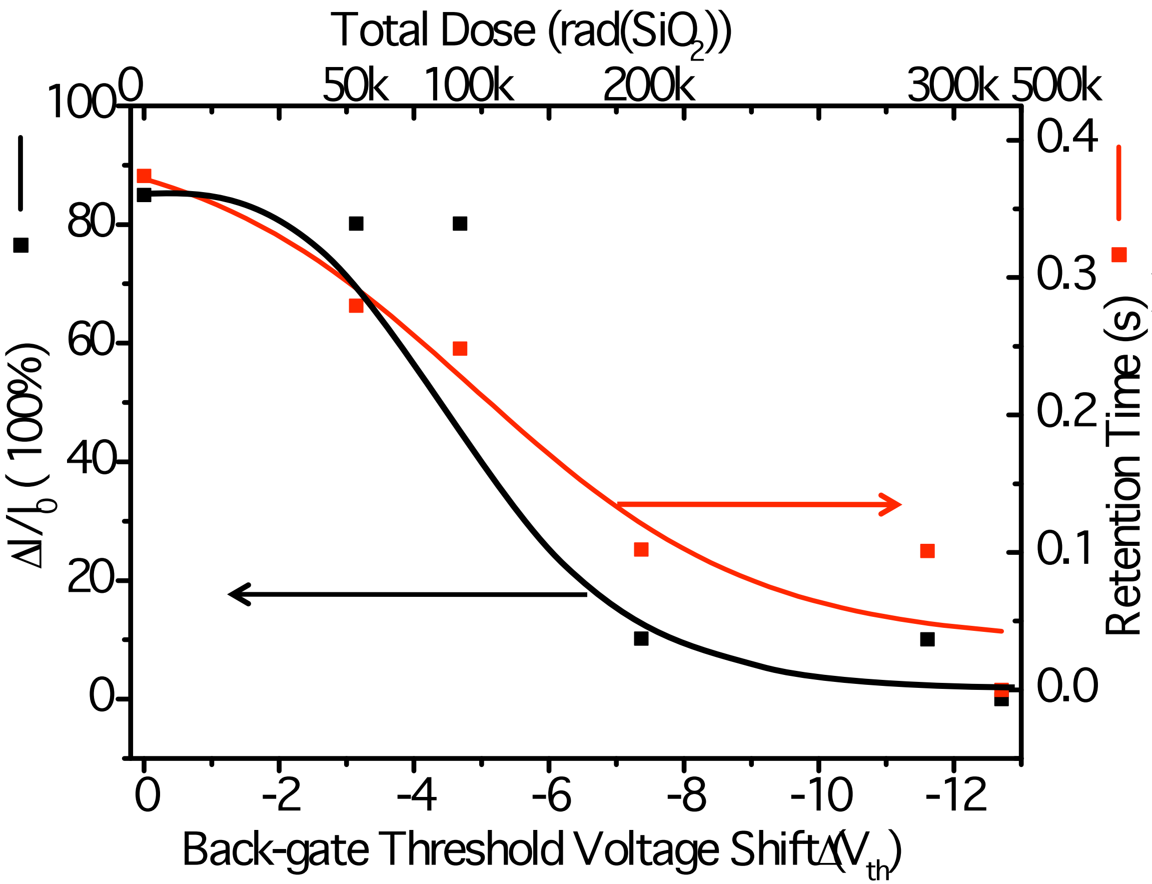
Transient Effects on ZRAM Cell Back-Gate Pulse Programming



Fin width dependence of ΔI_D back-gate pulse

- **ZRAM/pMOS has larger memory window than nMOS with same fin width, for these devices and programming conditions.**
  - **For other technologies, relative nMOS/pMOS responses may be different.**
- **Memory window of ZRAM cell decreases with decreasing fin width.**
  - **Side gate E-field limits charge storage for narrow fin devices.**
  - **Negative scaling trend.**

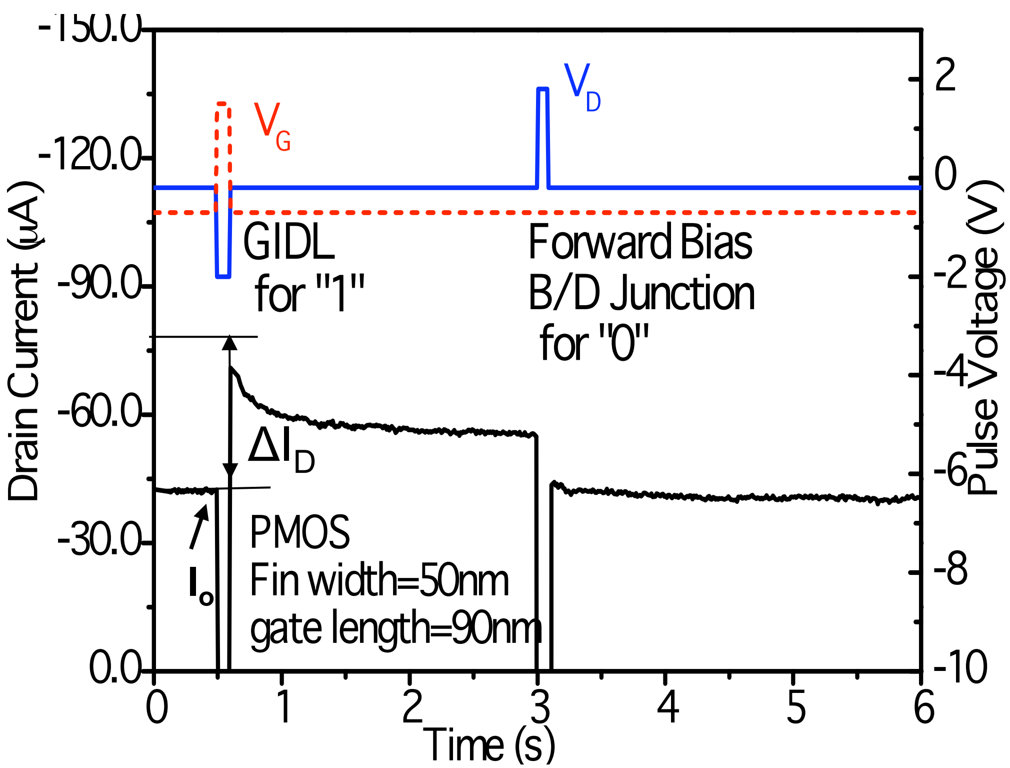
Total Dose Effects on ZRAM Programmed by Back-Gate Pulse

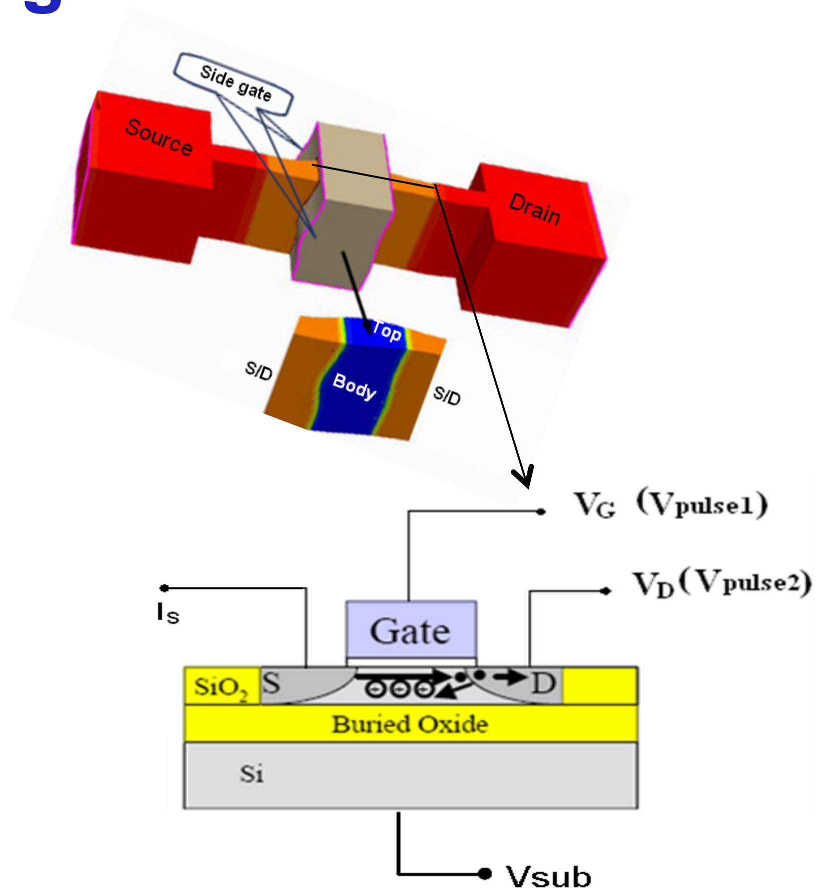


Program window and retention time vs. ΔV_{th} shift for back-gate for different doses

- **Memory window and retention time decrease with back-gate threshold voltage shift, and increasing dose.**

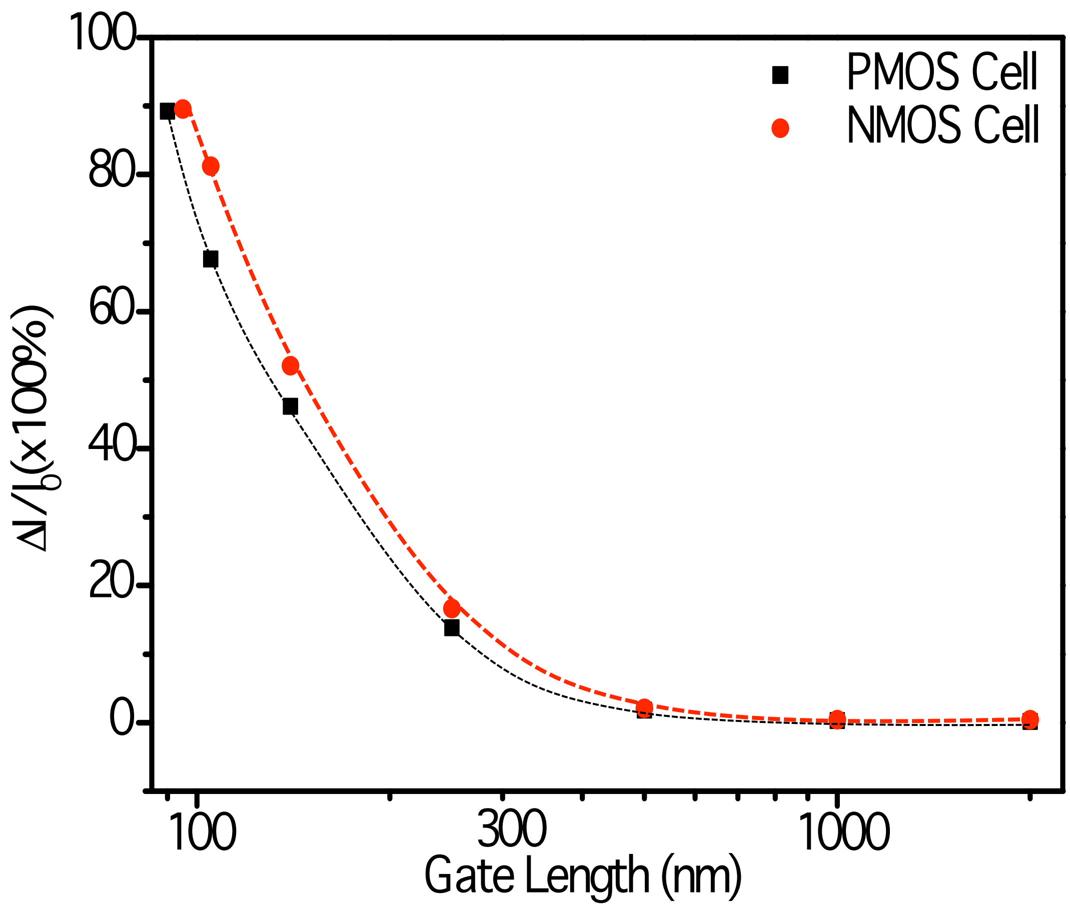
GIDL Programming of FinFETs





- Memory window is larger for GIDL than for back-gate pulse.
- Charge storage occurs primarily near the drain.

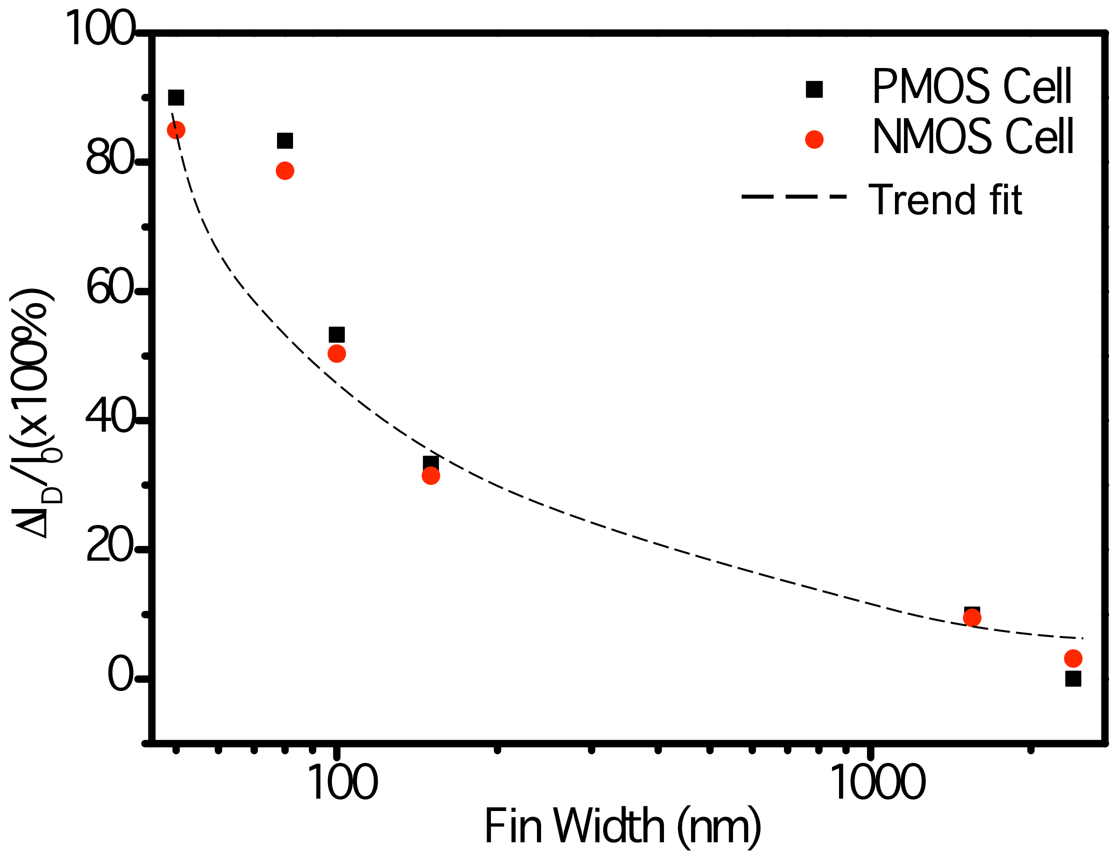
Gate Length Dependence



- The memory windows for small gate lengths are very promising for potential future ZRAM technology insertion.

[E. X. Zhang, et al., Solid-State Electron., 2010, accepted]

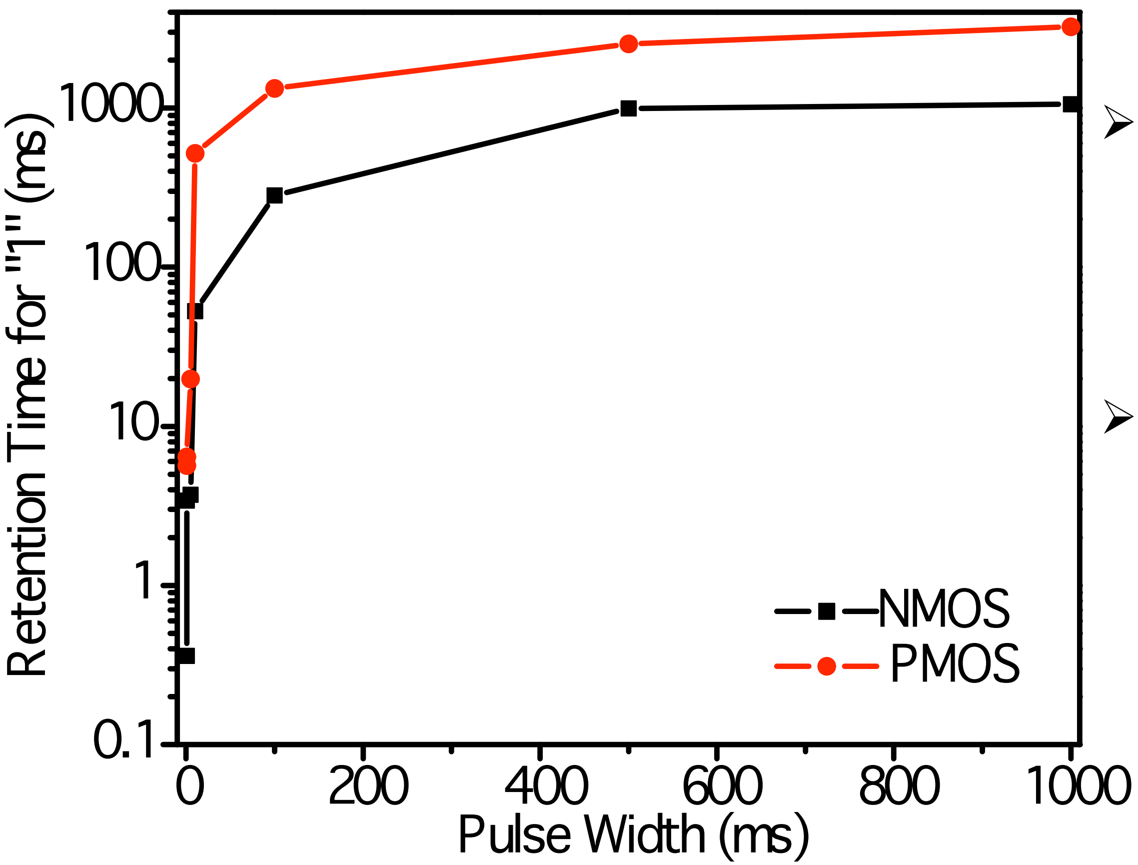
Memory Window vs. Fin Width



- The memory window also increases significantly with decreasing fin width.

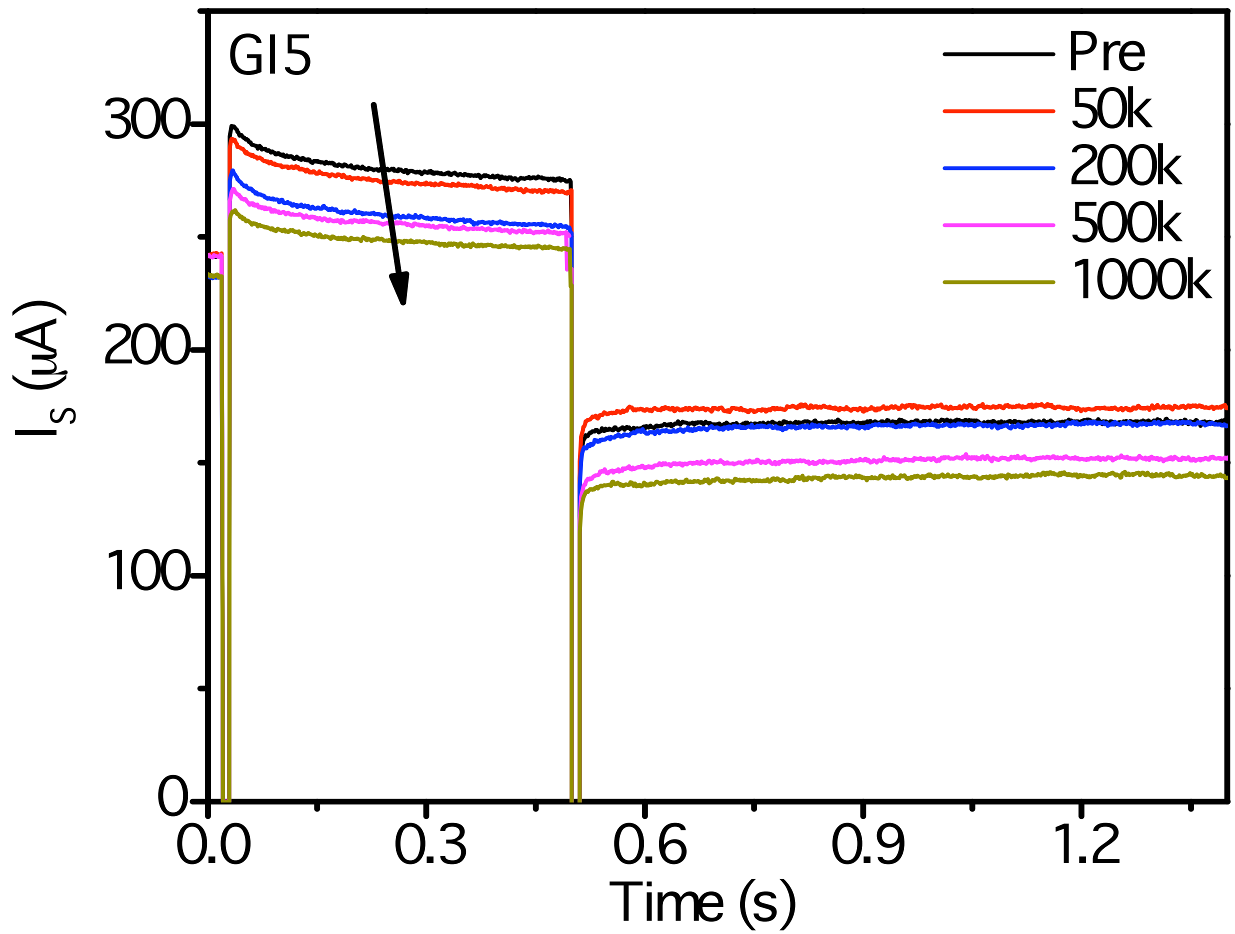
Retention vs. Pulse Width

Retention defined here as time to 50% loss of excess current



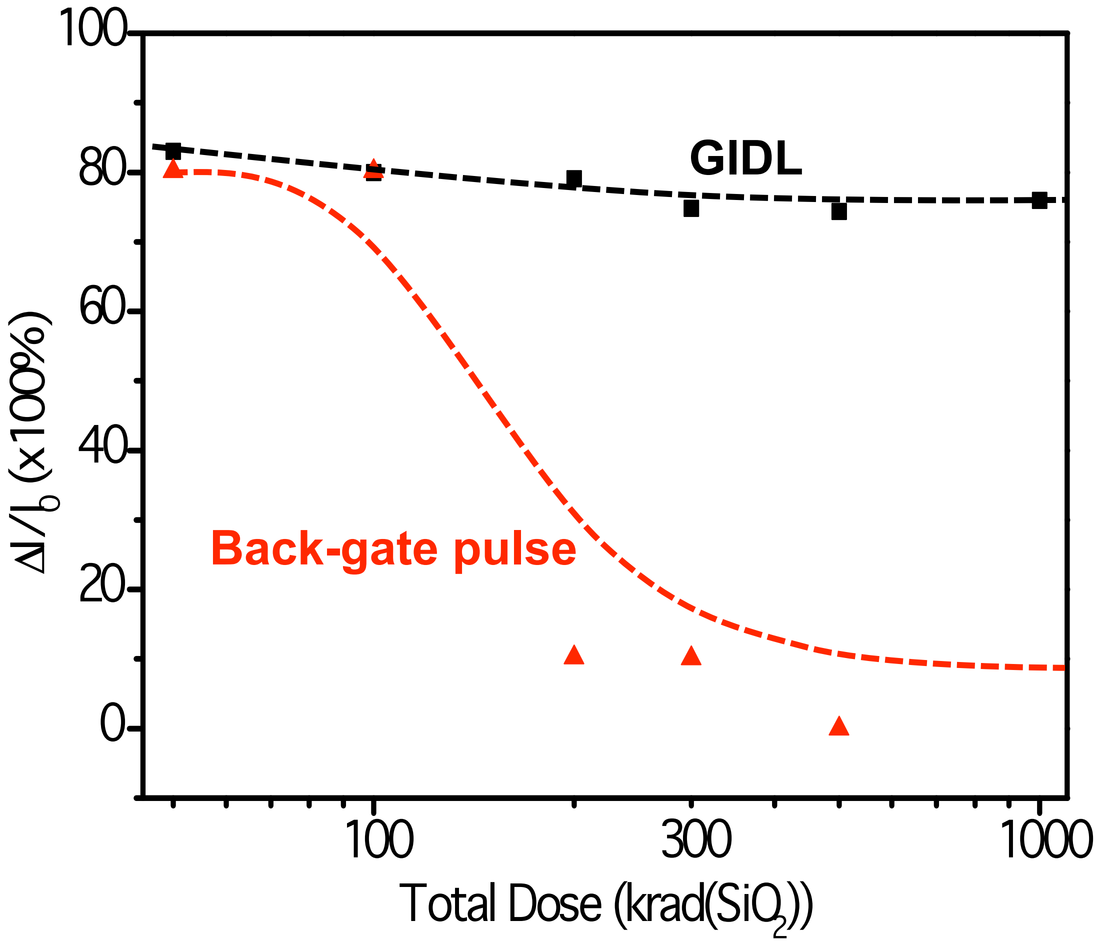
- **Retention time increases with increasing pulse width, much more than expected for excess charge in the transistor body.**
- **Shallow trapped charge in BOX can significantly enhance retention times.**

Radiation Effects on ZRAMs Programmed by GIDL



Experimentally measured transient I_D for pMOS FinFET vs. time and dose, programmed via GIDL.

Comparison of GIDL and Back-Gate Programming: TID Effects



- ✓ For this technology, ZRAM programmed by GIDL is more tolerant to total-dose irradiation than ZRAM programmed by back-gate pulse.

Conclusions

- ✓ ZRAMs programmed by GIDL are more tolerant to total-dose irradiation than ZRAMs programmed by back-gate pulse.
- ✓ Charge trapping in BOX during the write pulse can enhance ZRAM memory window size and retention.
- ✓ Memory window scaling and total dose response are very promising for ZRAMs programmed by GIDL.

Thanks