Total dose effects in Ge and SiC MOS devices

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Outline

1. **Ge-pMOSFET devices**
   - Irradiation and annealing response of I_{on}/I_{off}
   - Transmission gate configuration vs. positive bias
   - 1/f noise analysis

3. **SiC MOS devices**
   - NBTI/PBTI on p/n-type MOS capacitors
   - Total dose effects on MOS capacitors
   - Post-irradiation NBTI/PBTI on p/n-type MOS capacitors

Experimental details

- Radiation

  $V_D = V_S = -1V$

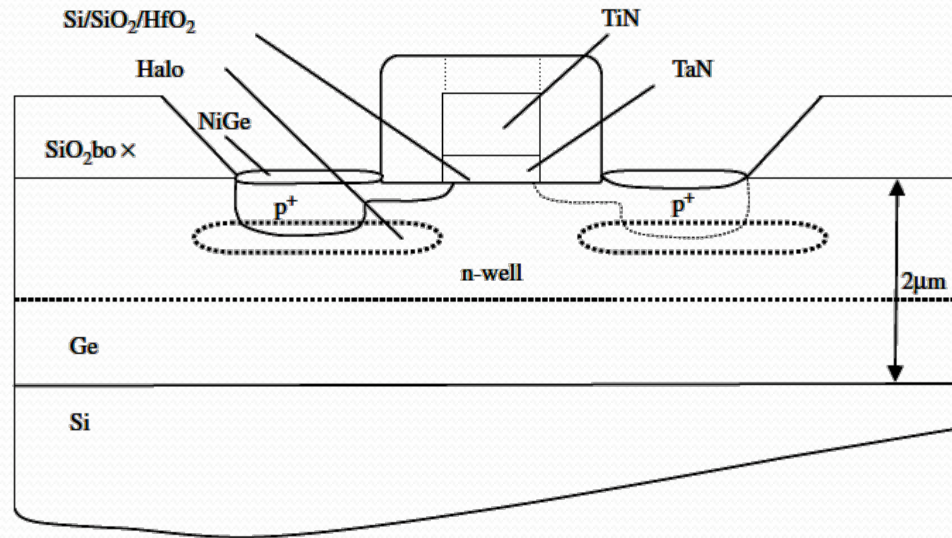
  V_G&V_B GND

- Annealing

  $V_D = V_S = -1V$

  V_G&V_B GND

Ge pMOS (from imec)



D04	D09	D10	D05 With FOX
5 Si Monolayer	8 Si Monolayer	8 Si Monolayer	5 Si Monolayer
As: 80 keV 5×10^{13} cm^{-2}	As: 80 keV 3.5×10^{13}cm^{-2}	As: 80 keV 6.5×10^{13}cm^{-2}	As: 80 keV 5×10^{13} cm^{-2}

I_{on}/I_{off}

Irradiation

Annealing

I_{on}/I_{off}

10^5

10^4

10^3

10^2

8 Si monolayers (Halo = 3.5×10^{13} cm^{-2})

8 Si monolayers (Halo = 6.5×10^{13} cm^{-2})

W/L = 9.8μm/0.8μm

0 200 400 600 800 1000

Total Dose (krad(SiO_2))

5 Si monolayers (Halo = 5×10^{13} cm^{-2})

5 Si monolayers (Halo = 5×10^{13} cm^{-2})
with buried field oxide isolation

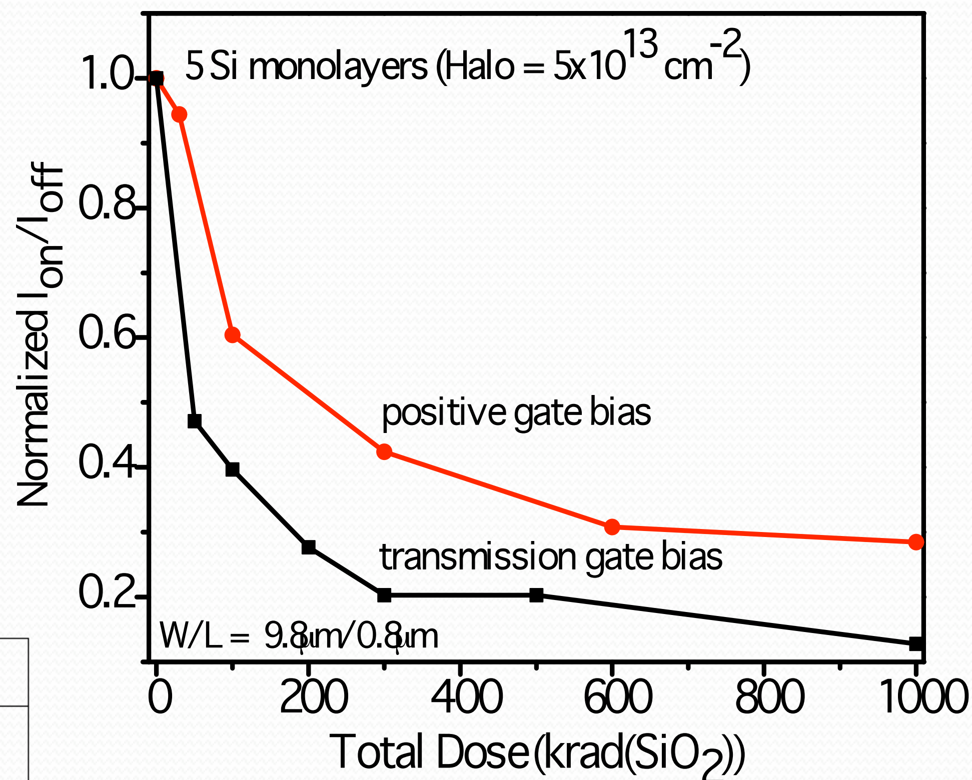
10 100 1000 10000 100000

Annealing time (s)

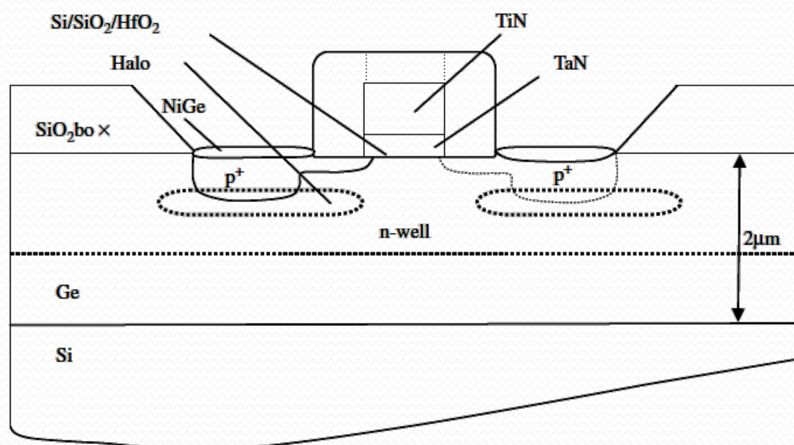
- On-state current shrinks because of mobility degradation.
- Off-state current increases as a result of increase in radiation-induced leakage.

Transmission gate configuration vs. positive bias

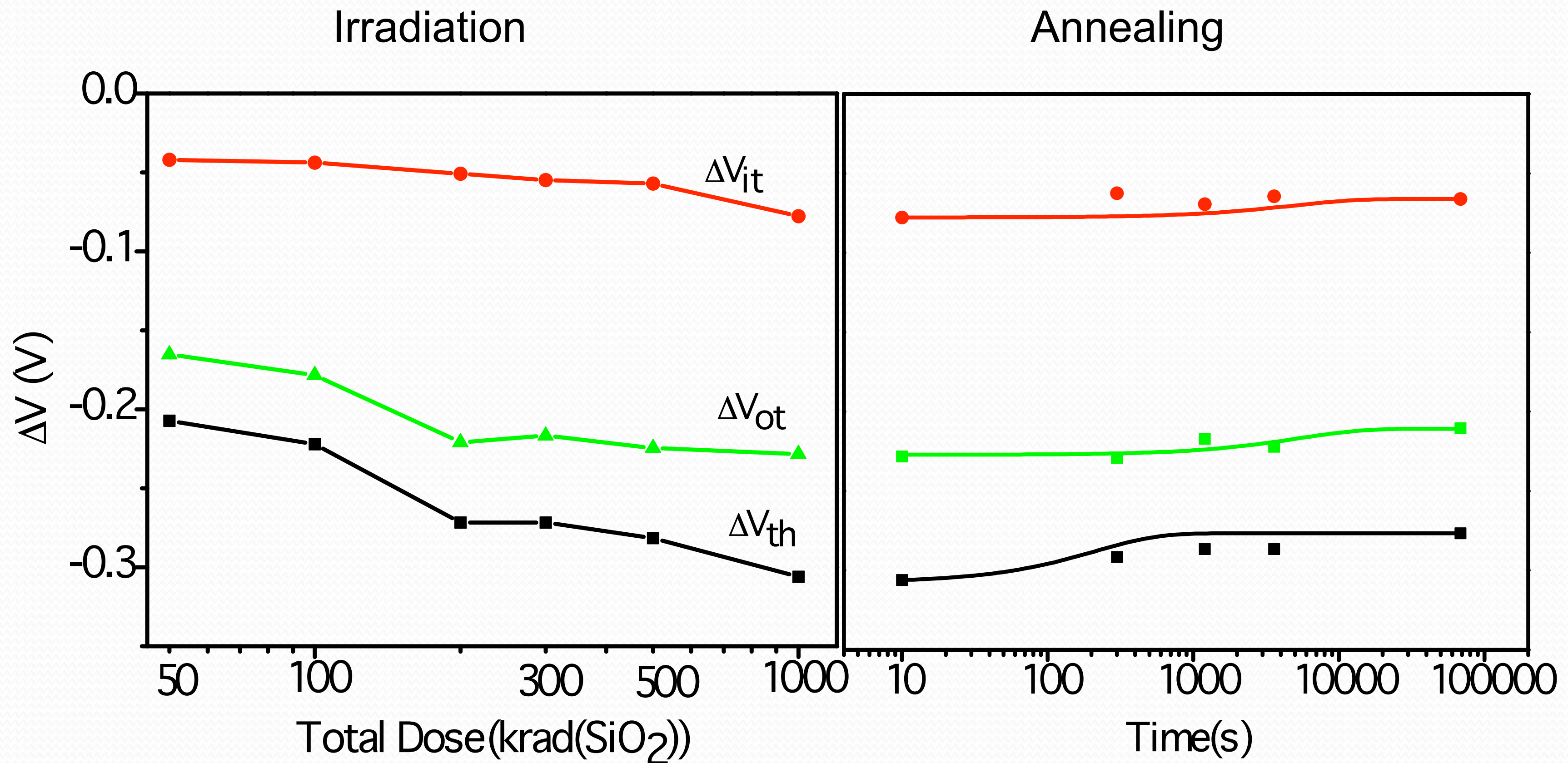
Worst-case leakage in irradiated Ge pMOS devices occurs under transmission gate bias conditions.



Electric field at the source and drain affects the halo.

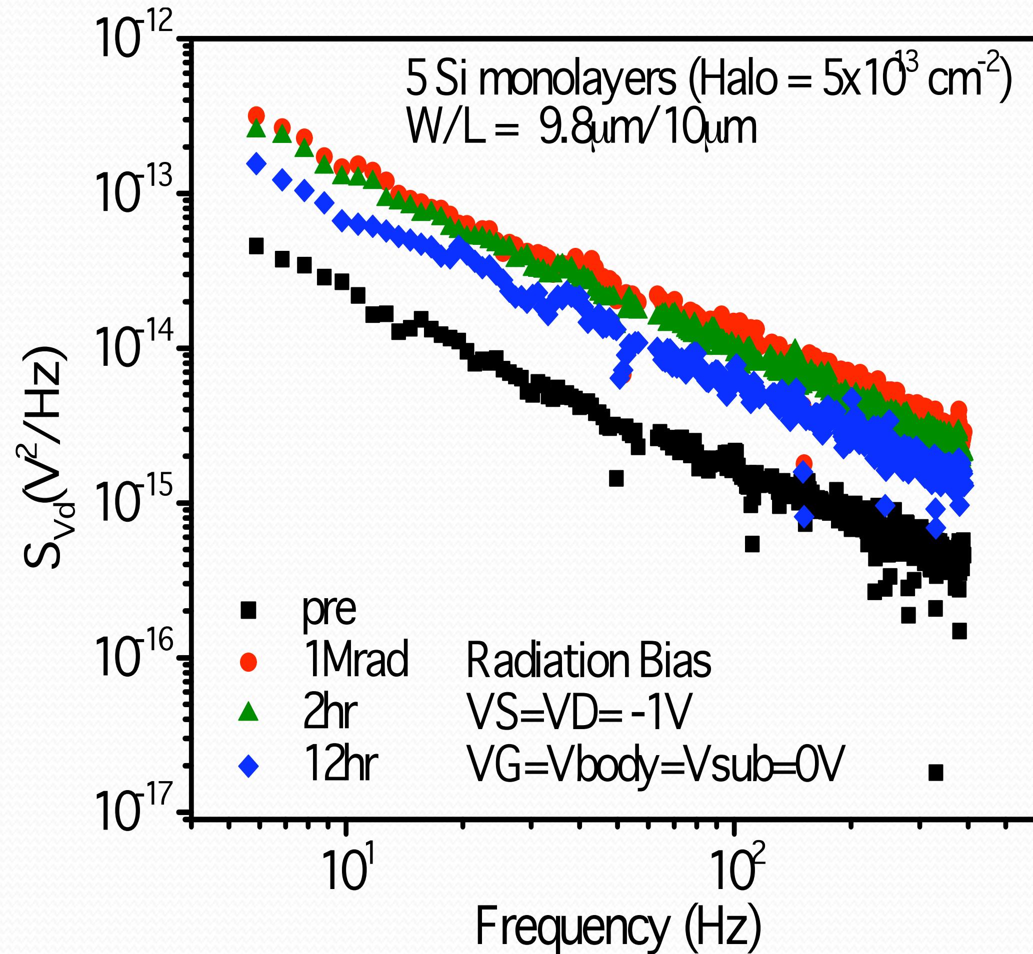


Voltage shift vs. total dose and annealing time



1/f noise analysis

- Noise increases with total dose
- Noise decreases with annealing
- Consistent with traps observed via I-V characterization
  - Interface traps
  - Border traps



SiC MOS devices

Experimental details

- **Oxide thickness of devices:**

  n-type: 67.5 nm

  p-type: 55 nm

- **Positive Bias Temperature Instability (PBTI)/Negative Bias Temperature Instability (NBTI)**

  Electric Field: $\pm$1.5 MV/cm & $\pm$3 MV/cm

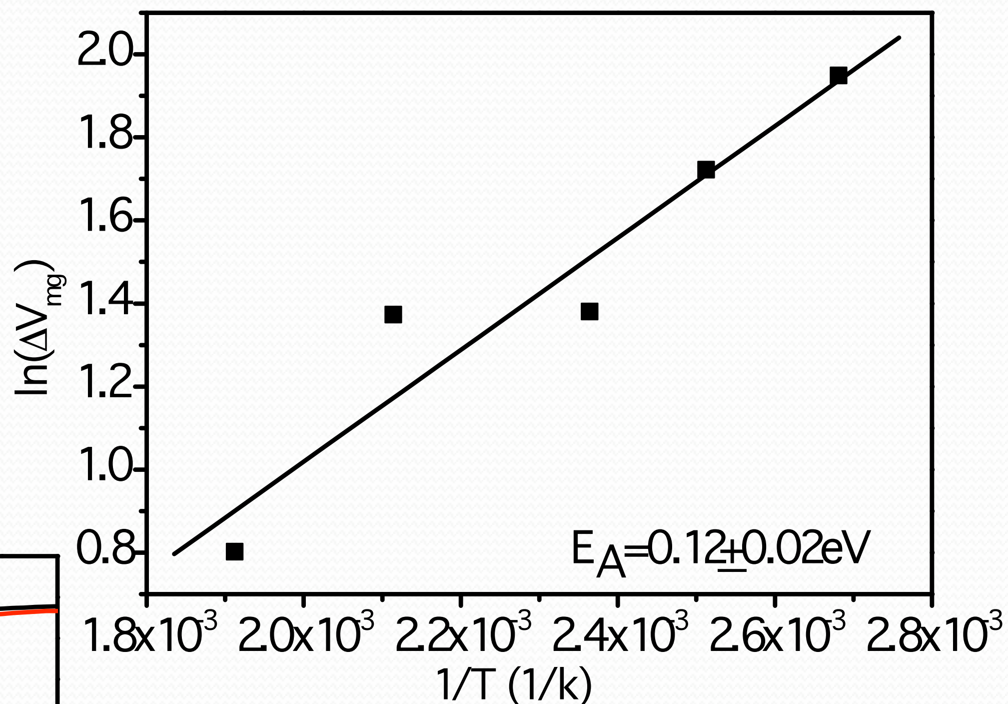
  Temperature: 100 ^{o}C to 250 ^{o}C

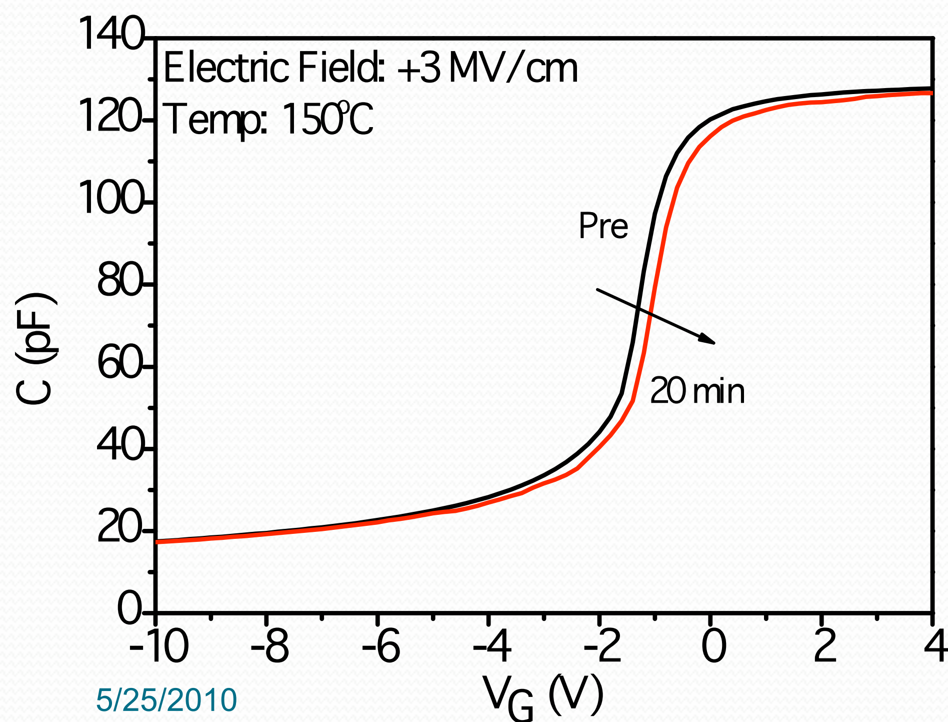
- **Irradiation & Post-rad NBTI/PBTI**

  Electric Field: $\pm$1.5 MV/cm & $\pm$3 MV/cm, GND

  Temperature: 100 ^{o}C to 250 ^{o}C

PBTI on n-type 4H-SiC capacitors



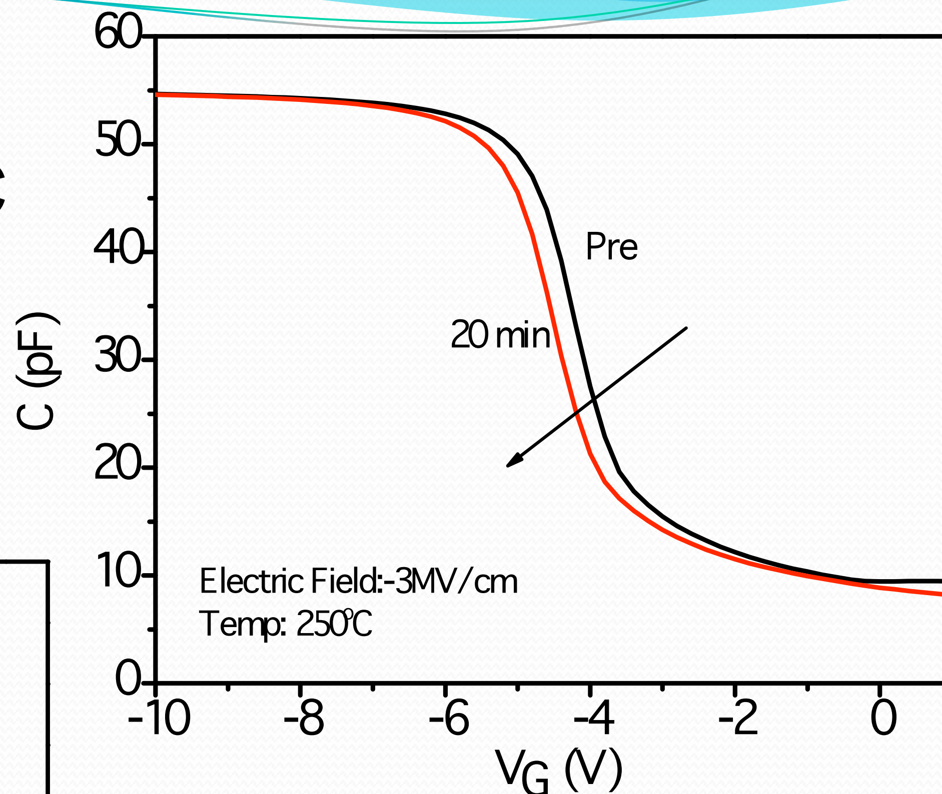


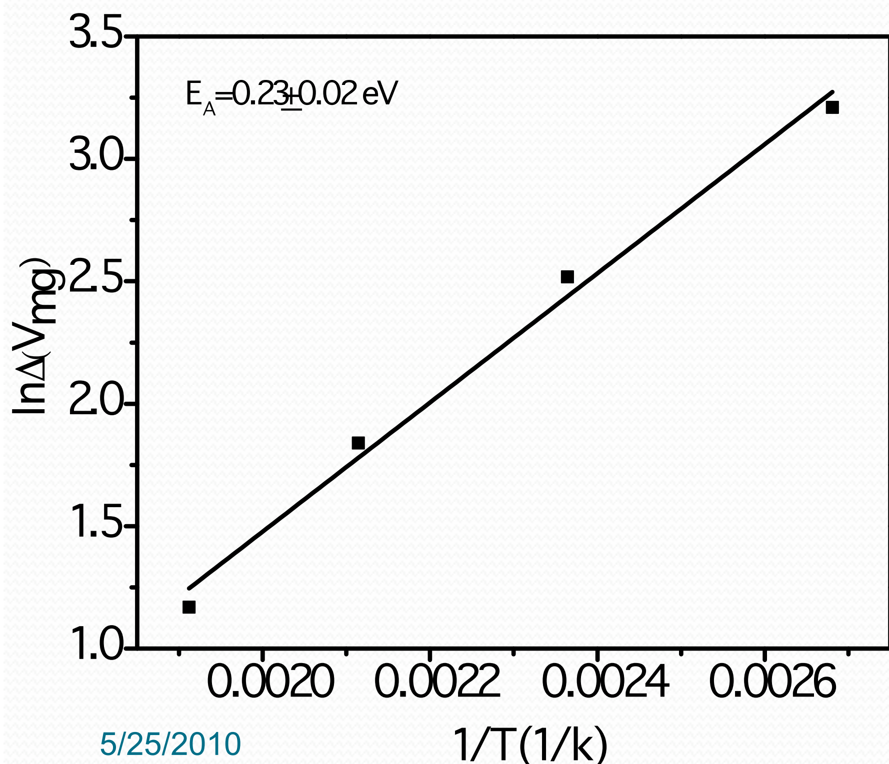
Activation energy was extracted from Arrhenius plot.

Calculated Activation Energy

E_A = 0.12 ± 0.02 eV

NBTI on p-type 4H-SiC capacitors



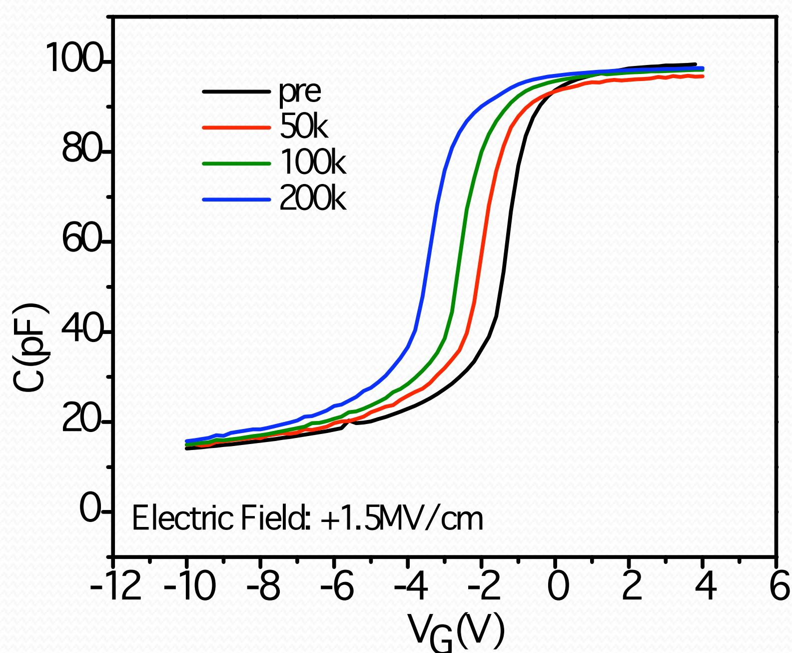


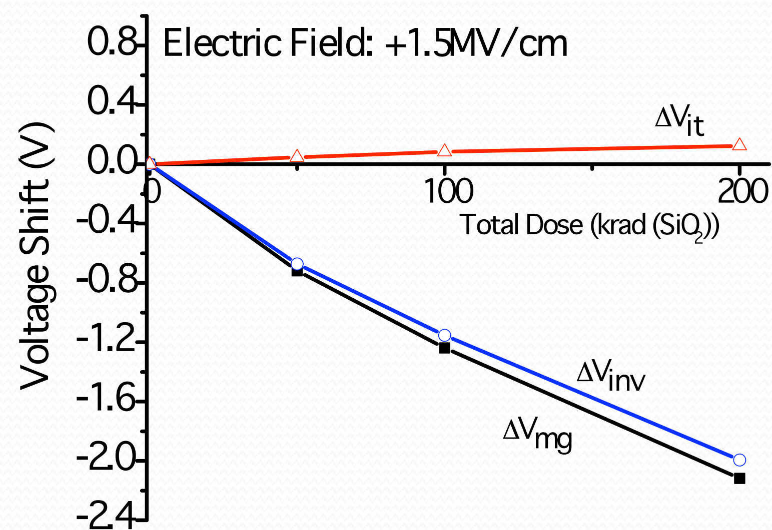
E_A = 0.23 ± 0.02 eV

Compared to SiO_2 on Si: estimated E_A (for interface and oxide-trap charge densities) lie in the range 0.2–0.4 eV*

*X. J. Zhou, *et al.*, Appl. Phys. Lett., vol. 84, no. 33, pp. 4394-4396, 2004.

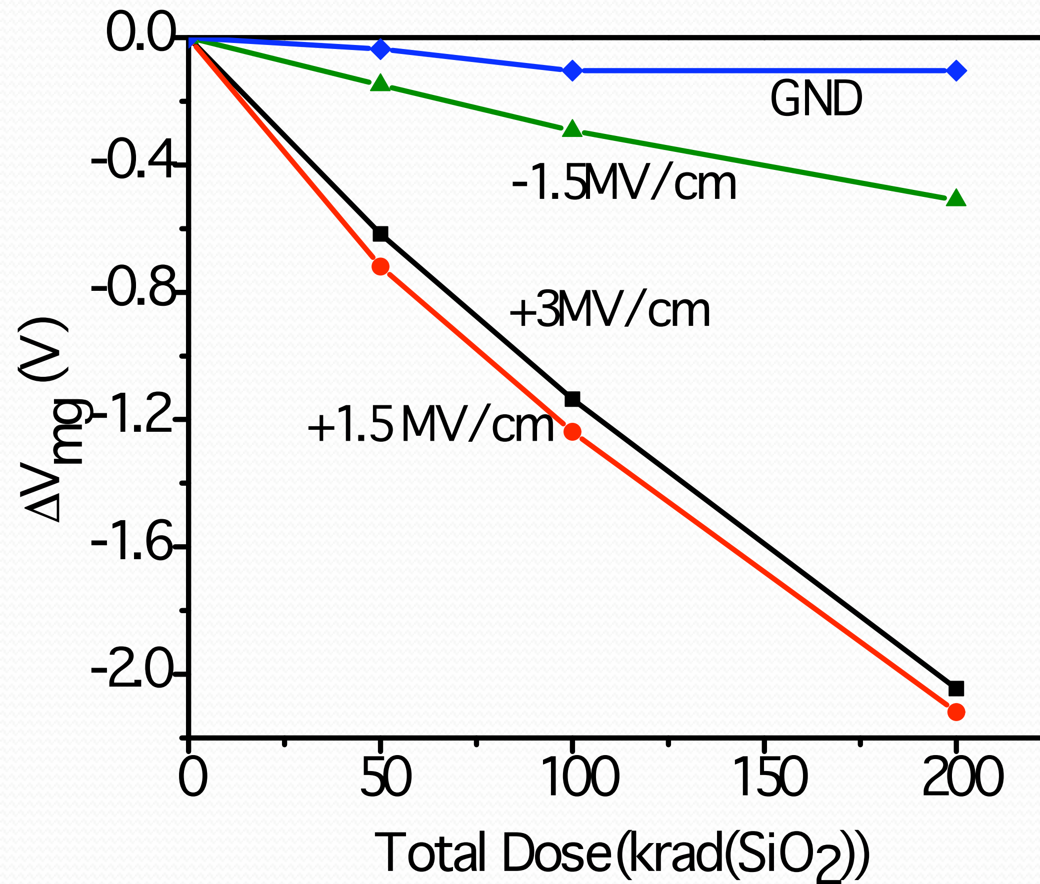
Total dose effects on n-type capacitors





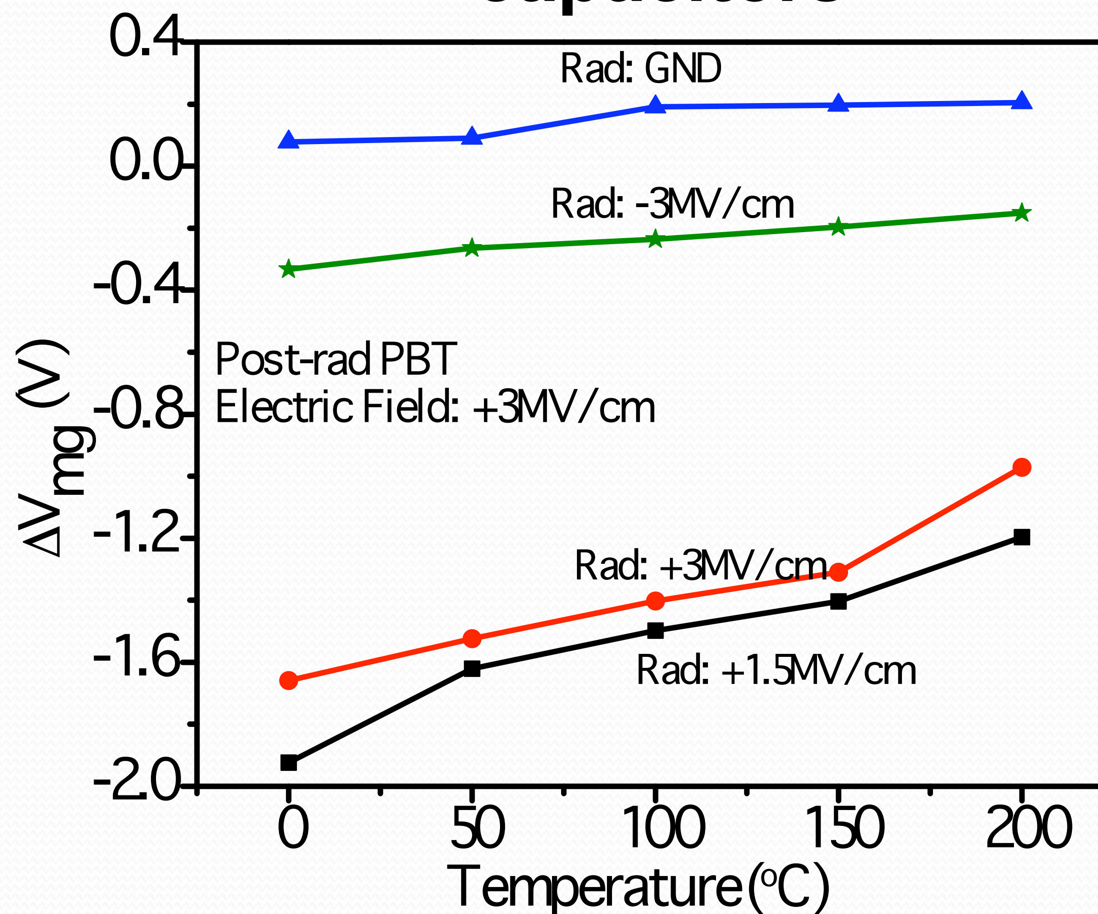
Due to the wide band gap of SiC, interface traps that build up during radiation can contribute to the mid-gap voltage shift, in addition to contributing to stretchout.

Total dose effects on n-type capacitors



Positive bias irradiation gives the largest degradation among all the other bias irradiations.

Post-irradiation PBTI on n-type capacitors



Post-irradiation NBTI on p-type capacitors

NBTI
Electric Field: -3MV/cm

Irradiation
Electric Field: +1.5MV/cm

Irradiation releases some hydrogen, which helps to create more interface traps during the NBTI.

Temp: 150°C
NBTI
sum of (separate)NBTI+(separate)200k irradiation
NBTI after 200k irradiation
ΔV_{mg} (V)
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
1
10
100
1000
10000
100000
Time (s)

Conclusions

- **Ge-pMOSFETs :**
  - **Worst-case leakage in irradiated Ge pMOS devices occurs under transmission gate bias conditions.**
  - **Noise and I-V measurements show interface and border traps decrease during post-rad annealing.**

- **SiC MOS devices:**
  - **NBTI and PBTI activation energies measured and found to be generally consistent with results for SiO_2 on Si.**
  - **More difficult to separate effects of interface and oxide traps for SiC than Si, due to wide band gap.**
  - **Buildup of additional interface and/or oxide trap charge during post-rad NBTI adds to radiation-induced midgap shifts, leading to worst-case response.**

Thanks!