TID Radiation Effects on Flash memories

Leif Scheick

Electronic Parts Engineering Office

Radiation Effects on Floating Gate Memories

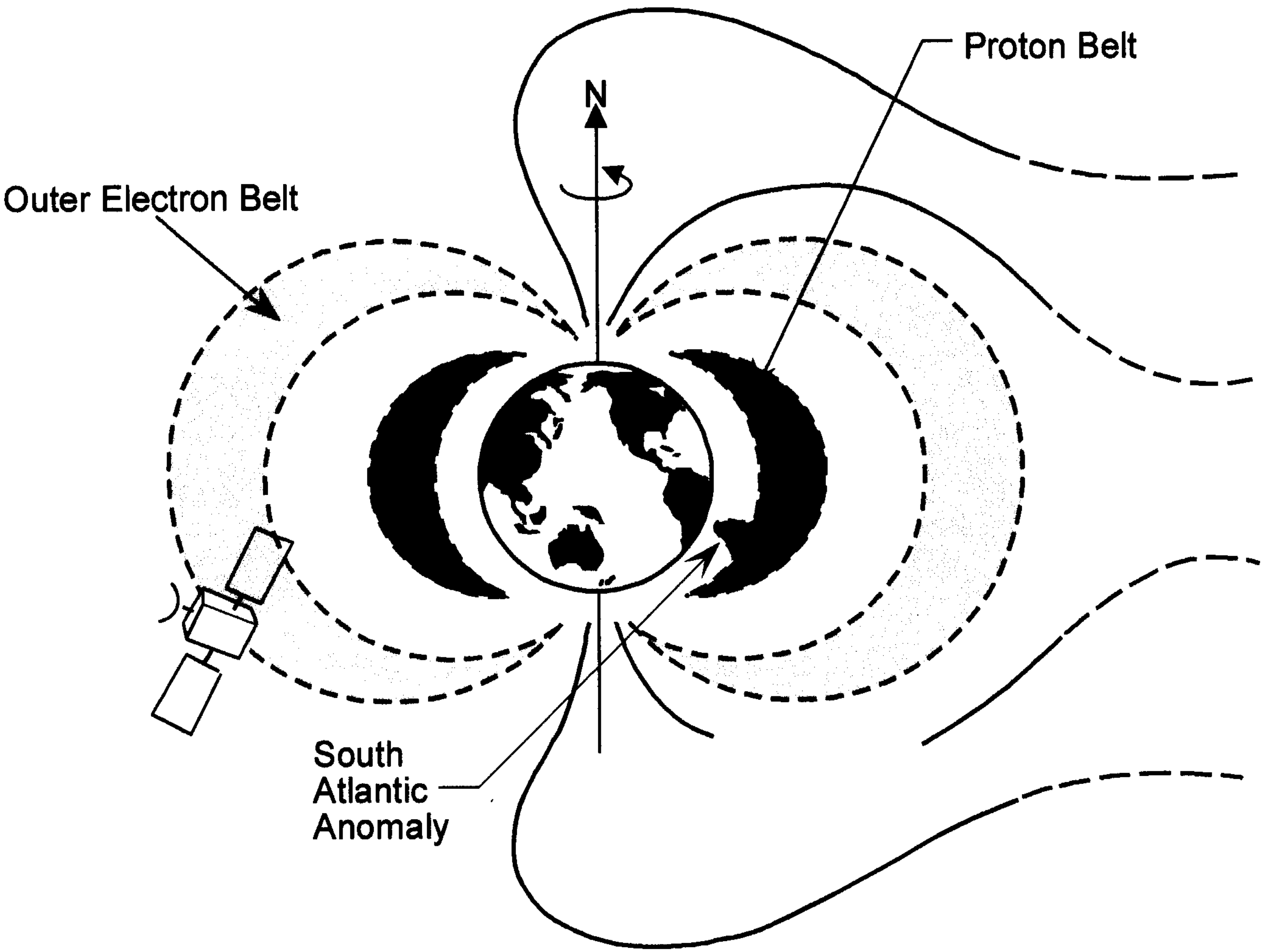
- Flash Is very Important to Any Mission Where Power Is Likely to Be Turned Off
  - Data storage, Shutdown information
- Flash is becoming an important component in space missions
  - Mars missions, Jupiter missions, Solar missions
- Flash used in extreme manner
  - 100,000 cycles
  - Low temp
  - 2,000,000 times the radiation to kill a human

Dose Issues for Flash

- Total dose issues are the issue
  - Total ionizing dose (TID) is the average energy per unit mass for continuous radiation field
  - Typical sources are electrons, protons, gamma and x-rays
- All sub-parts of the Flash are suscpetible
  - CMOS
  - Oxide
  - Floating gate

SP susceptible

NASA Radiation Challenges



- Total accumulated dose depends on orbit altitude, orientation, and time.

Standard Dose rates for various orbits and Missions [per year surface dose]

- Earth
  - LEO (ISS - Shuttle) ~ 100rad (protons)
  - MEO ~ 100krad (protons and electrons)
  - GEO (GOES) ~ 1krad (electrons)
  - Transfer (CRRES) ~ 10krad (protons and electrons)
- Mars
  - Surface ~ 2krad (electrons)
  - Orbit ~ 5krad (protons)
  - Transit ~ 5krad (protons)
- Jovian
  - Transfer ~ 10krad -100Mrad (protons/electrons)

General rules about radiation - Time, Shielding, Distance

- Maximize:
  - Distance
    - Source farthest point away from part
    - Not generally possible
  - Shielding
    - Most shielding between source and part
    - Shielding marginally effective
- Minimize:
  - Time
    - Least amount of time with part exposed to source
    - Not practical
- USPS will not obey any of these

What Is a "Rad?"

$$Dose = \frac{Energy}{Mass}$$

1 rad = 100 erg / gram

$$Dose = Dose(material)$$

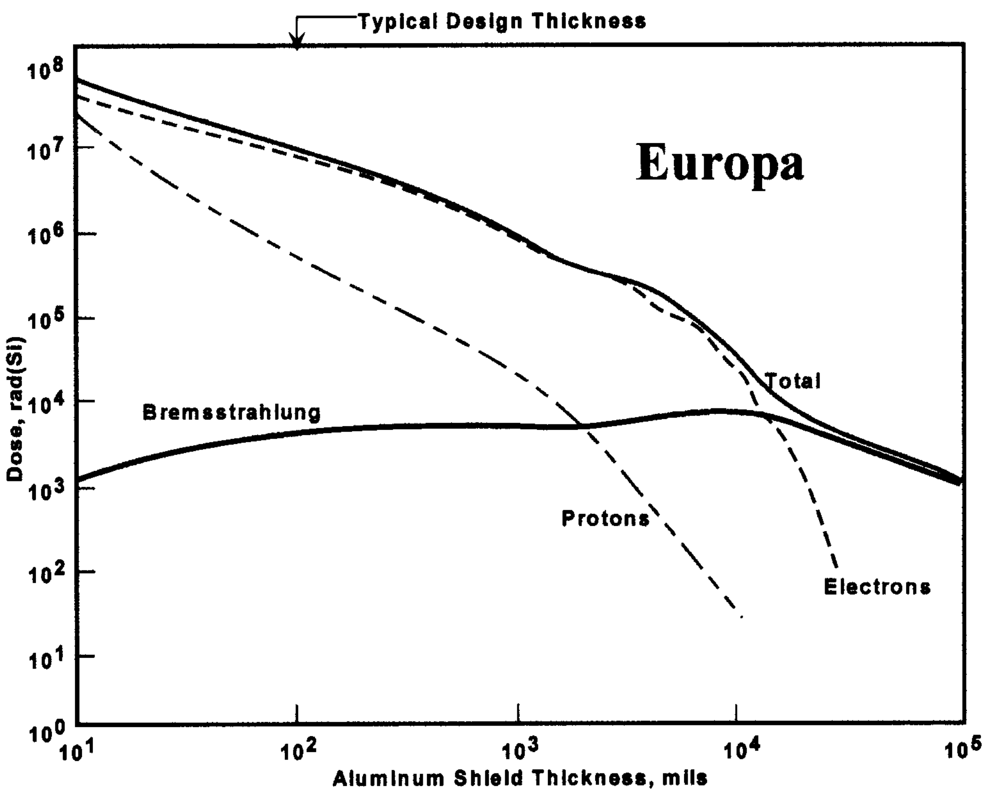
1 rad => 1 rad(Si)

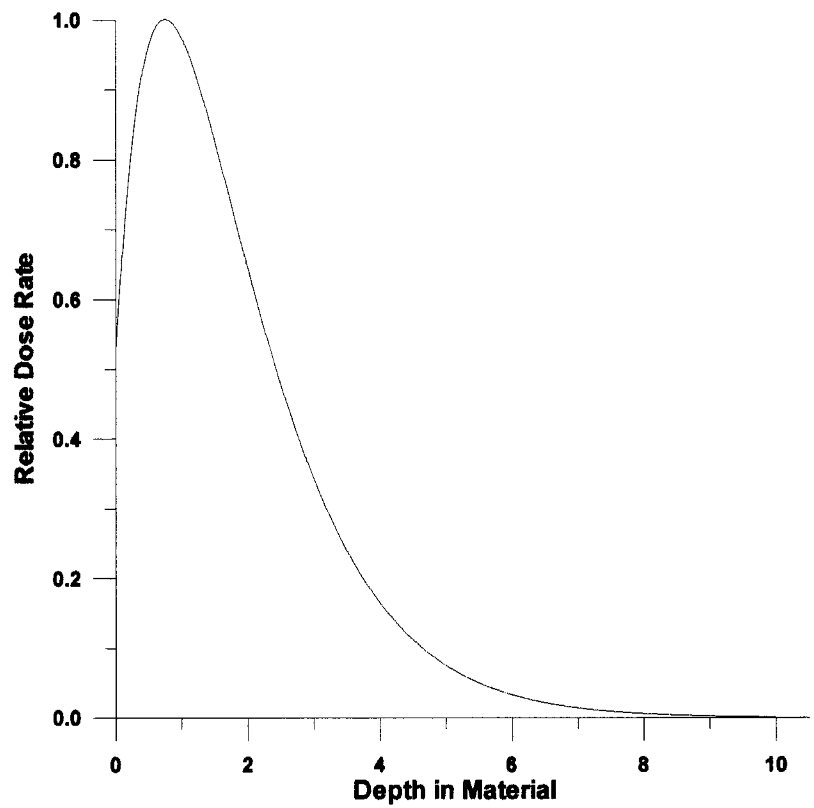
1 rad ~ 8.1×10^{12} /cm^3 # electron-hole pairs (SiO_2)

TID Shielding:

Diminishing returns

- Electrons more effectively shielded than protons
- Incremental shielding gives diminished returns





- Adding shielding gives limited options

Mechanisms for Global Permanent Damage

- Electrons and Protons Produce Ionization in Semiconductors
  - Ionization excites carriers from conduction to valence band
  - Charge is trapped at interface regions and oxides
  - Depends on bias conditions and device technology
    - Unbiased devices experience only marginally reduce effects
  - Typical effect: threshold shift in MOS transistors
    - Nmos and pmos do not switch properly
    - Leakage occurs, Isd

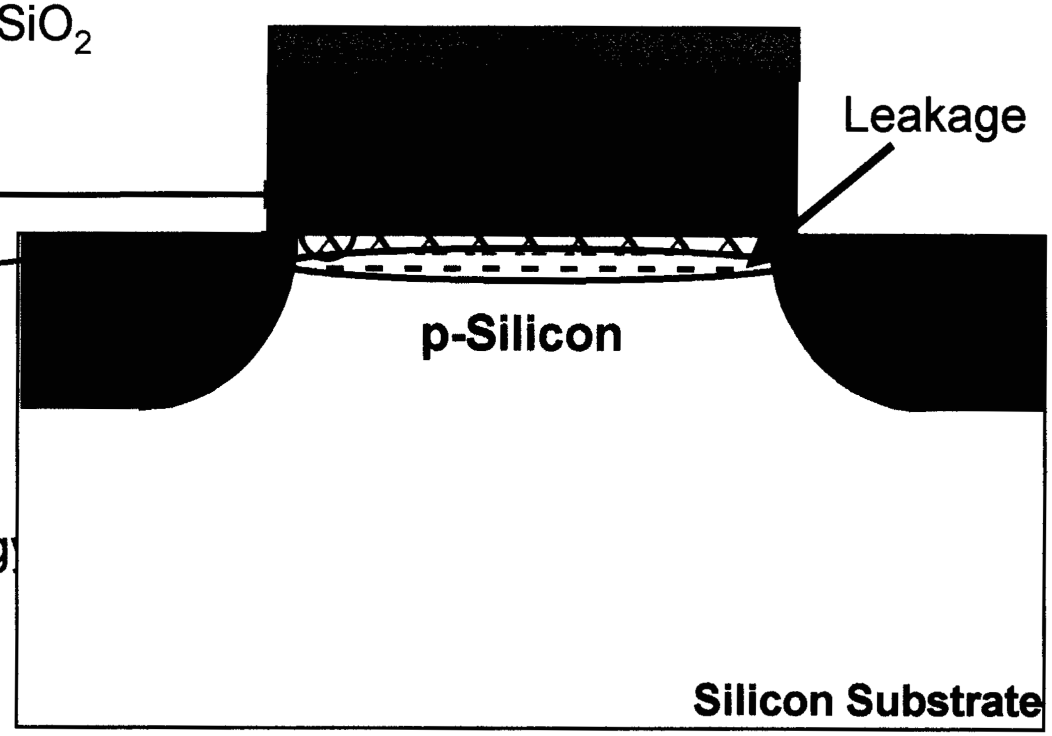
Total Dose Effects in MOS Devices

Charge trapping in SiO_2 and at Silicon/SiO_2 interface.

1. Oxide Trapping (N_{ot})
2. Interface Trapping (N_{it})

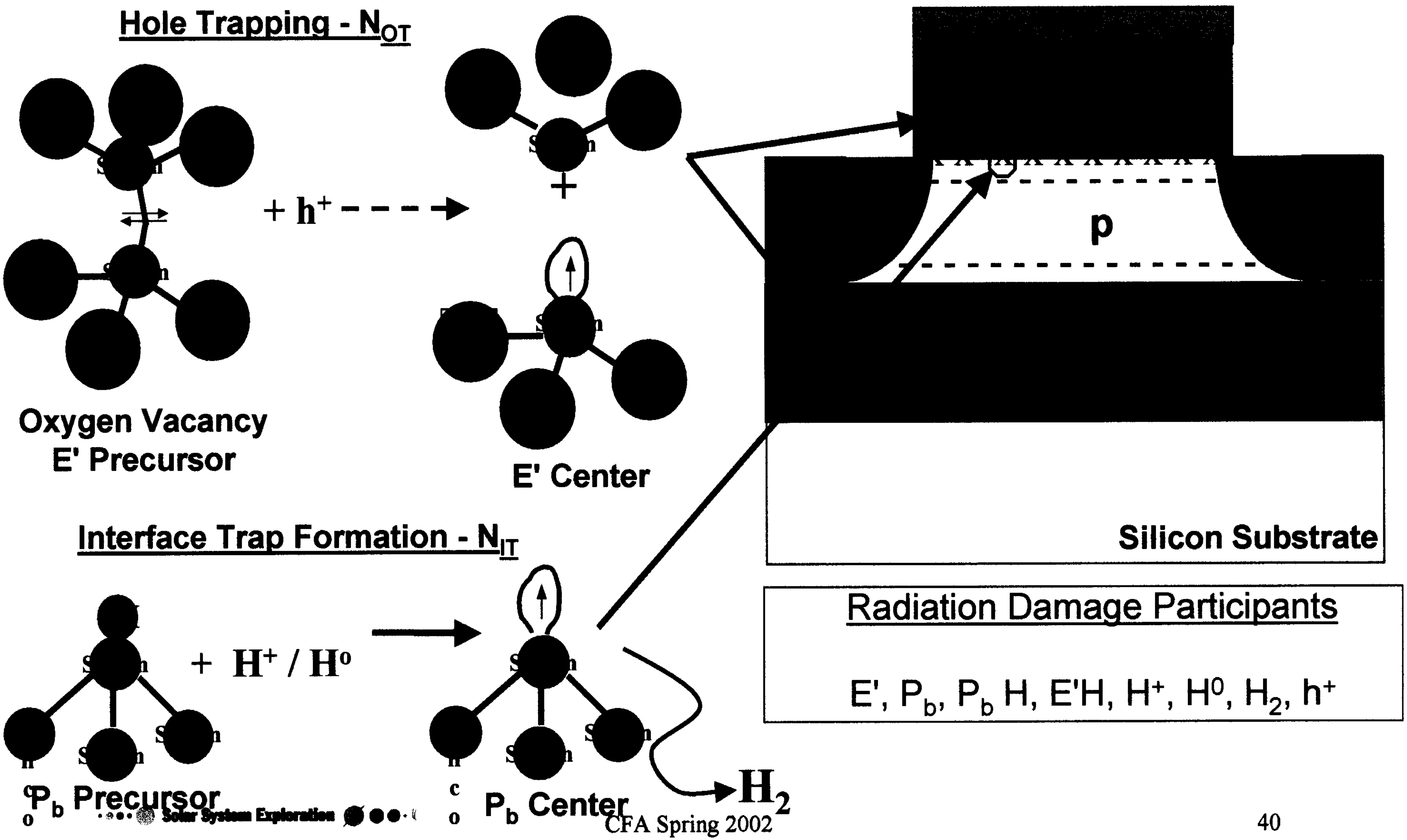
- Dominated by point defects

Will affect CMOS and FAMOS technolgy

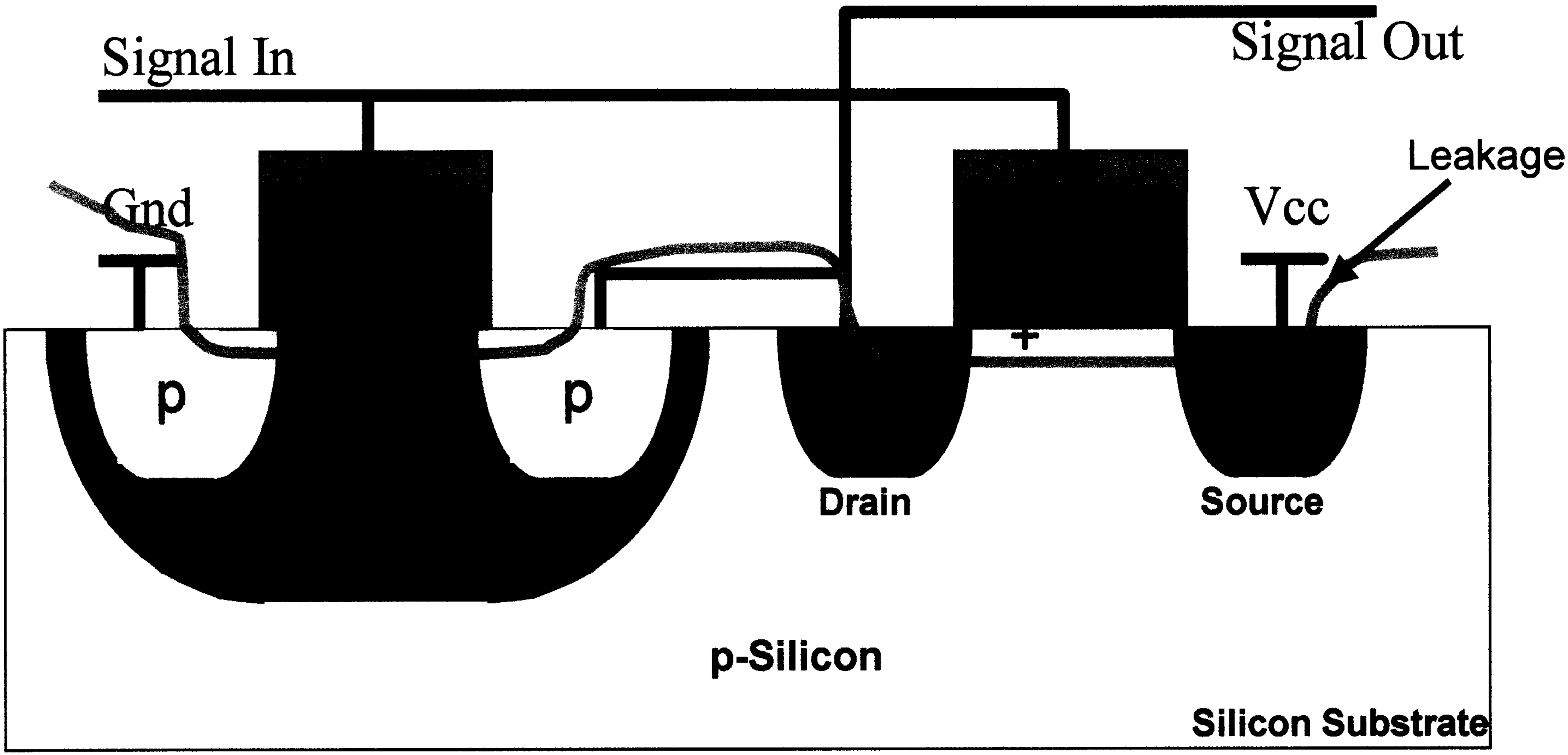


$$\Delta Vth = V(InterfaceTraps) + V(OxideTraps)$$

Total Dose Defects in MOS Devices



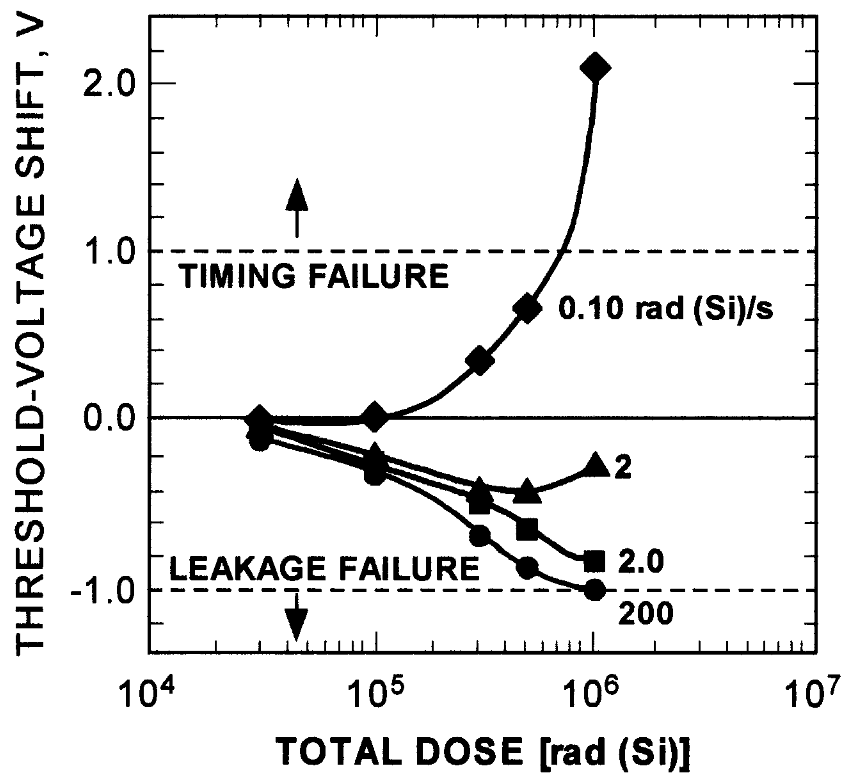
CMOS leakage: CMOS inverter



Dose Rate Effects in CMOS

- Hole traps and interface traps build-up on different time scales.
- Irradiation at different dose rates can produce different failure mechanisms and total dose hardness.

ΔV_{th} vs. Dose

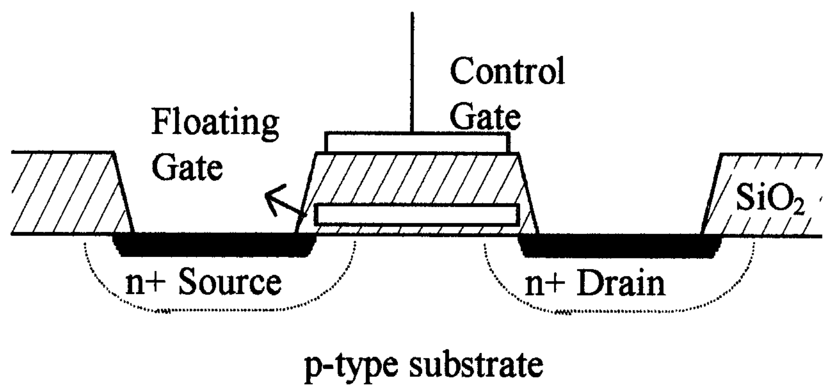


Important Operating Modes in Flash

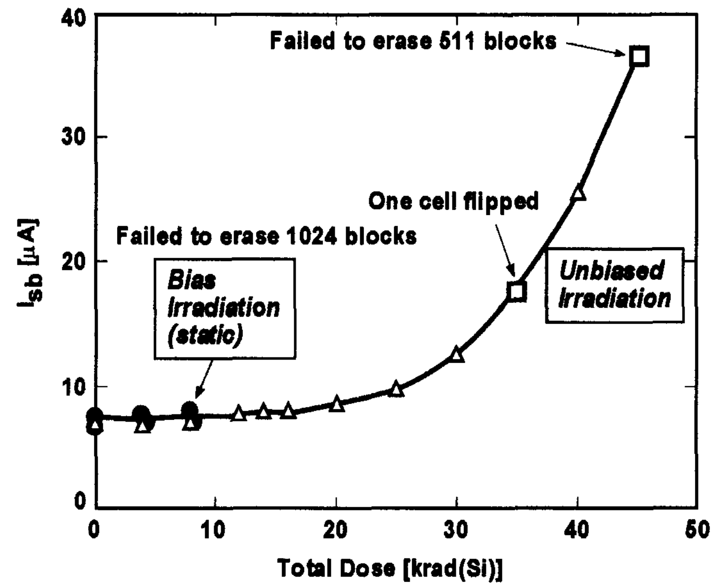
Description	Dominant Bias Condition	Sensitive to Charge Pump	Sensitive to Wear Out
Read-only	Off	No	No
Read-only	On	No	No
Read mostly	Off	Slight	Slight
Read mostly	On	Yes	Slight
Intensive R/W	On	Yes	High

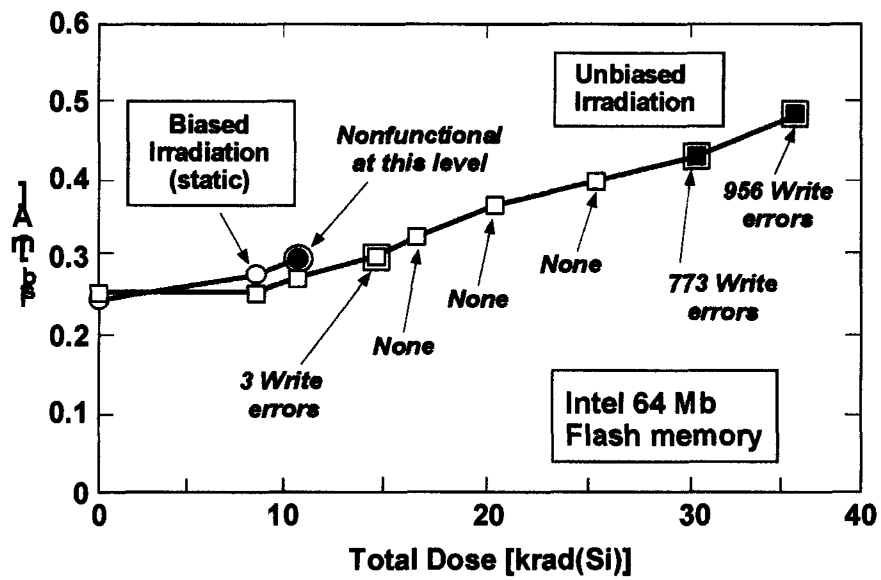
Flash Reliability issues

- Floating Gate Reliability
- Trap-up
  - Increase in voltage required to program/erase due to cycling
  - Can be enhanced due to radiation damage
- Charge pump degradation
  - Increase in leakage current and timing failure
- Time dependant dielectric breakdown
- Retention
  - 10 yr. retention at 25C
  - 135C retention down to 1 year

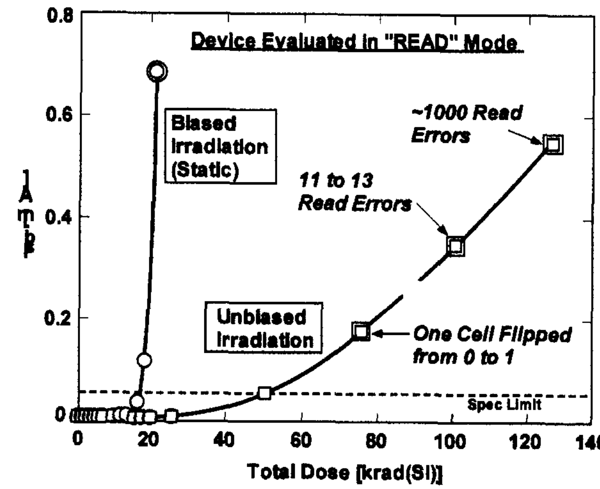


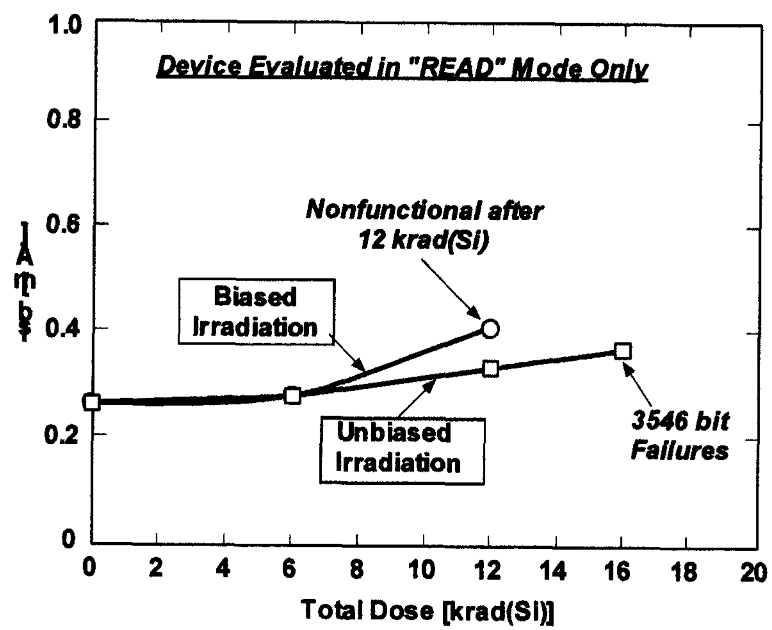
Write/Erase Errors



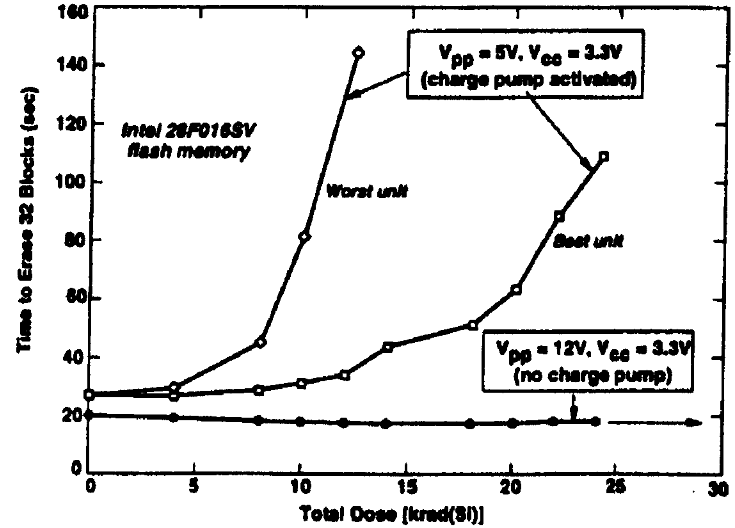


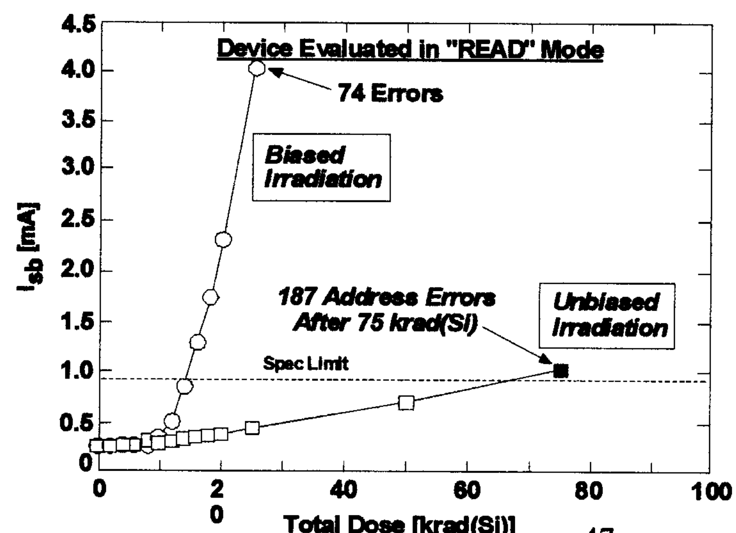
Read Errors


Device Evaluated in "READ" Mode
Biased Irradiation (Static)
~1000 Read Errors
11 to 13 Read Errors
Unbiased Irradiation
One Cell Flipped from 0 to 1
Spec Limit
0
0.2
0.4
0.6
0.8
0
20
40
60
80
100
120
140
Total Dose [krad(Si)]

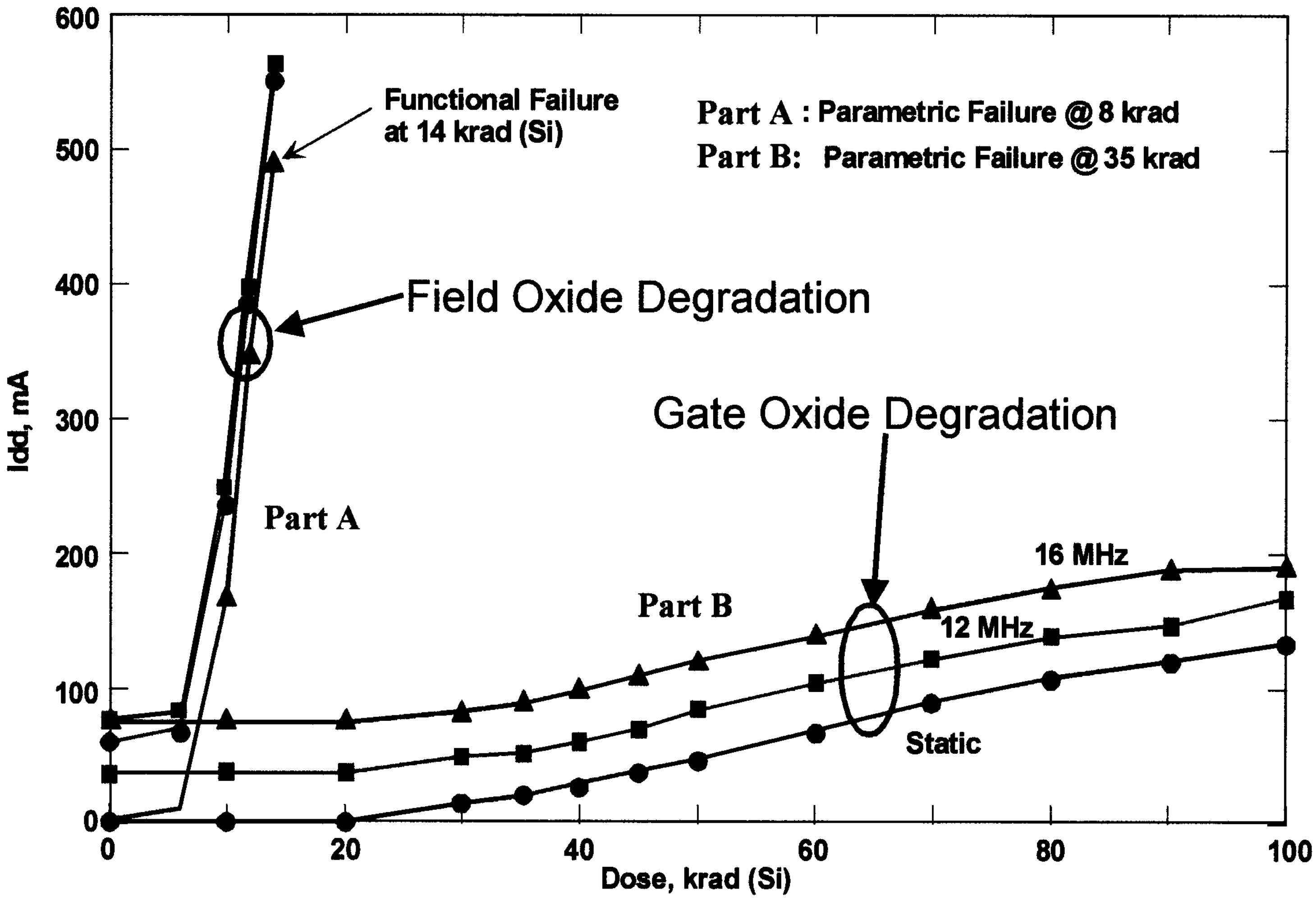

Device Evaluated in "READ" Mode Only
Nonfunctional after 12 krad(Si)
Biased Irradiation
Unbiased Irradiation
3546 bit Failures
0
0.2
0.4
0.6
0.8
1.0
0
2
4
6
8
10
12
14
16
18
20
Total Dose [krad(Si)]

Biased vs Unbiased

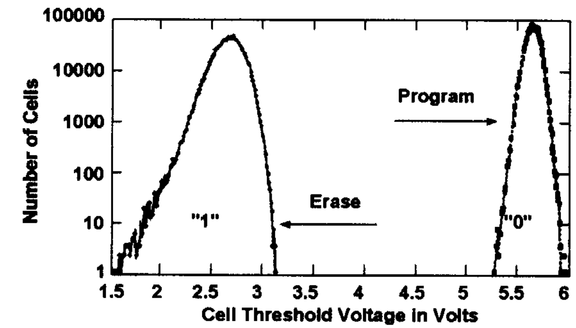




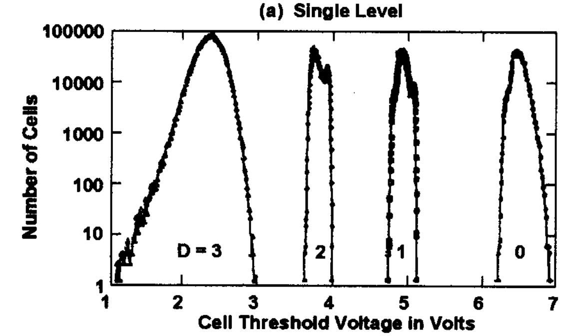
COTS: Same Part, Different Failure Mechanism



Multi level

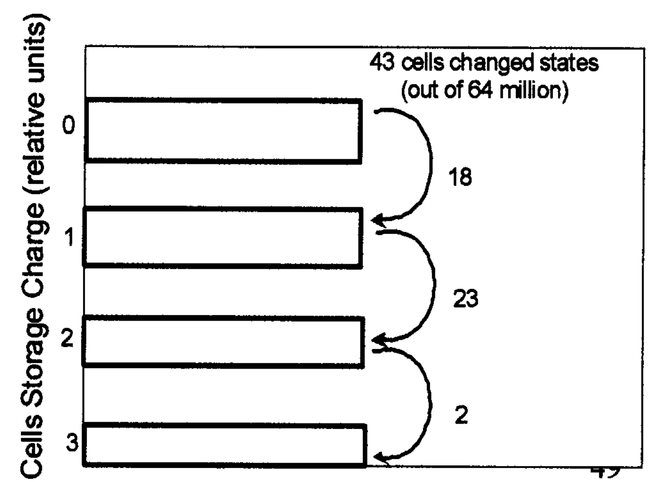


(a) Single Level

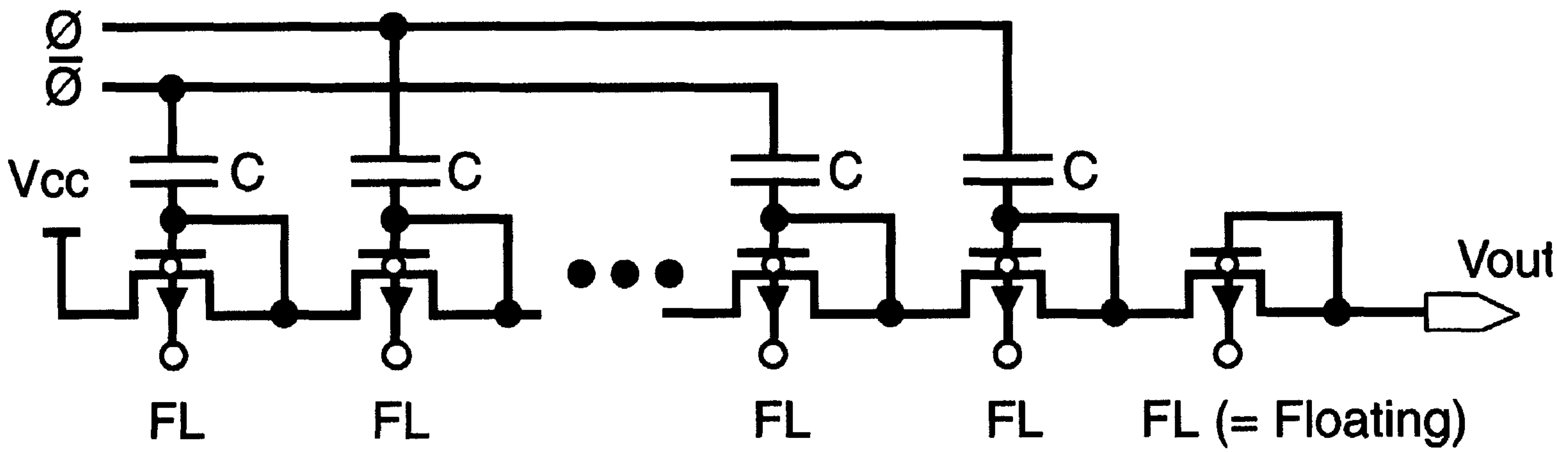


(b) Multiple Level

Device irradiated with Iodine (LET = 60 MeV-cm2/mg)

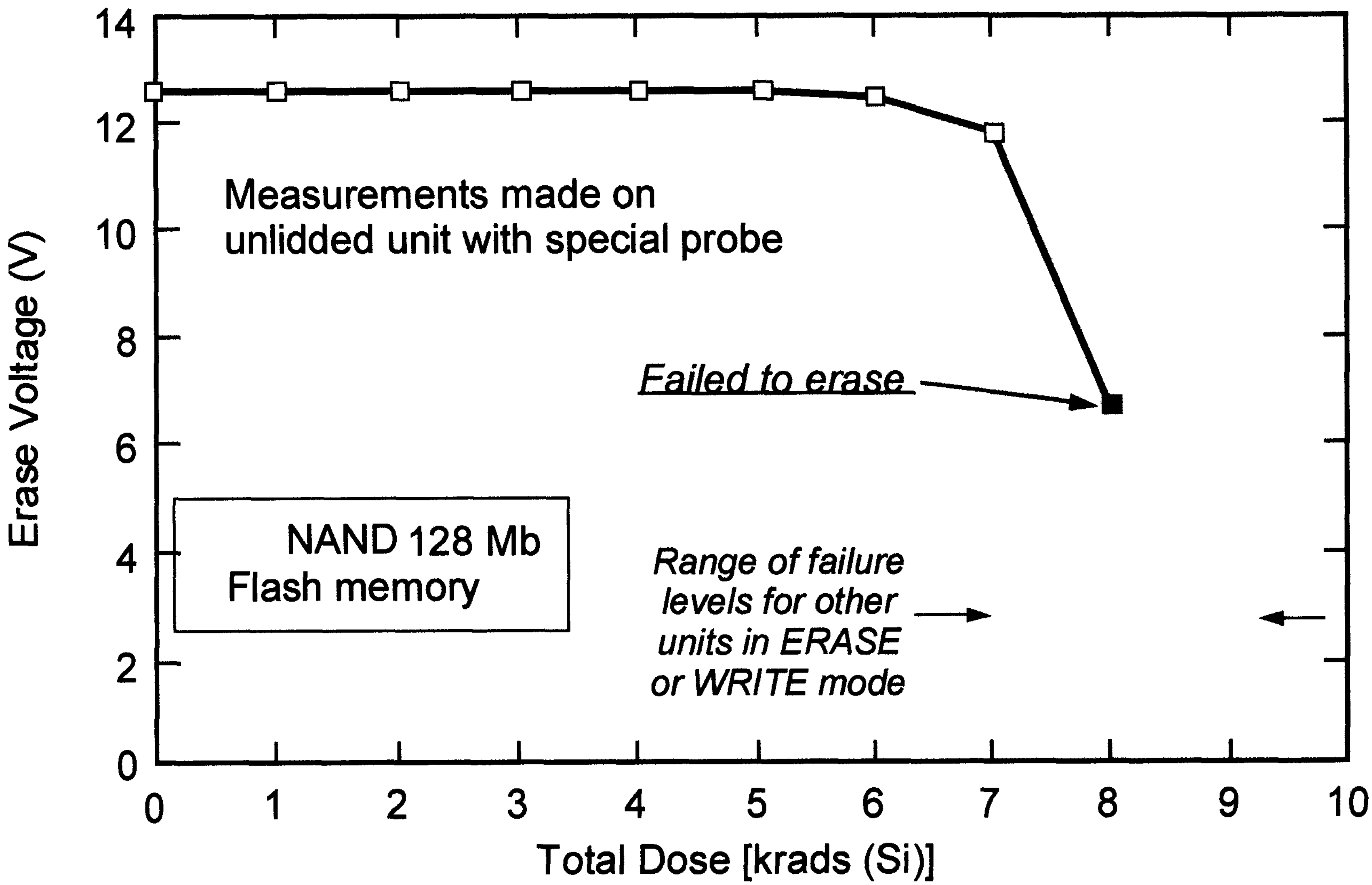


Charge Pump



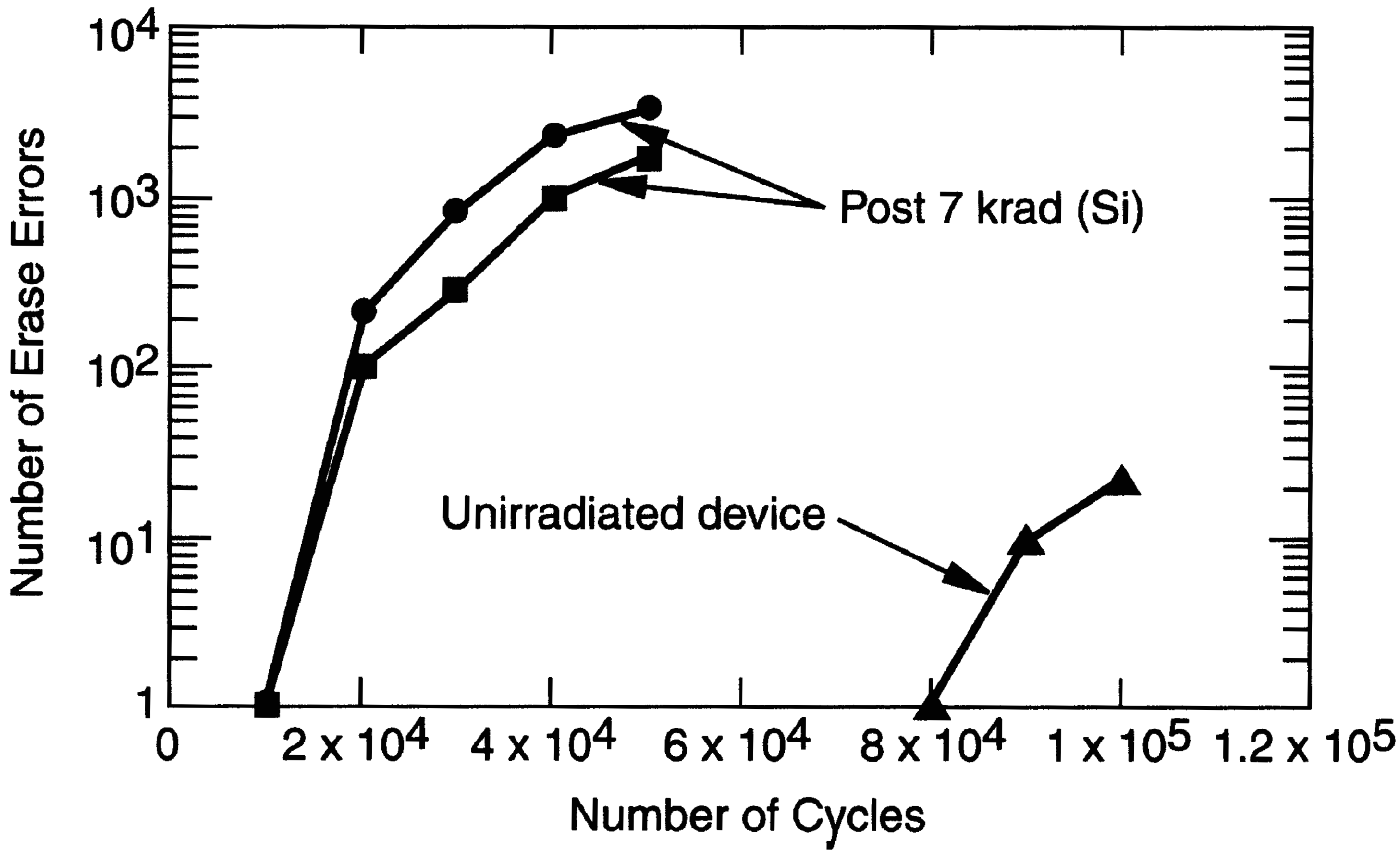
$$V_{out} = V_{cc} - |V_{te}| + N(V_{cc} - |V_{te}|) \quad (1)$$

Flash Memories



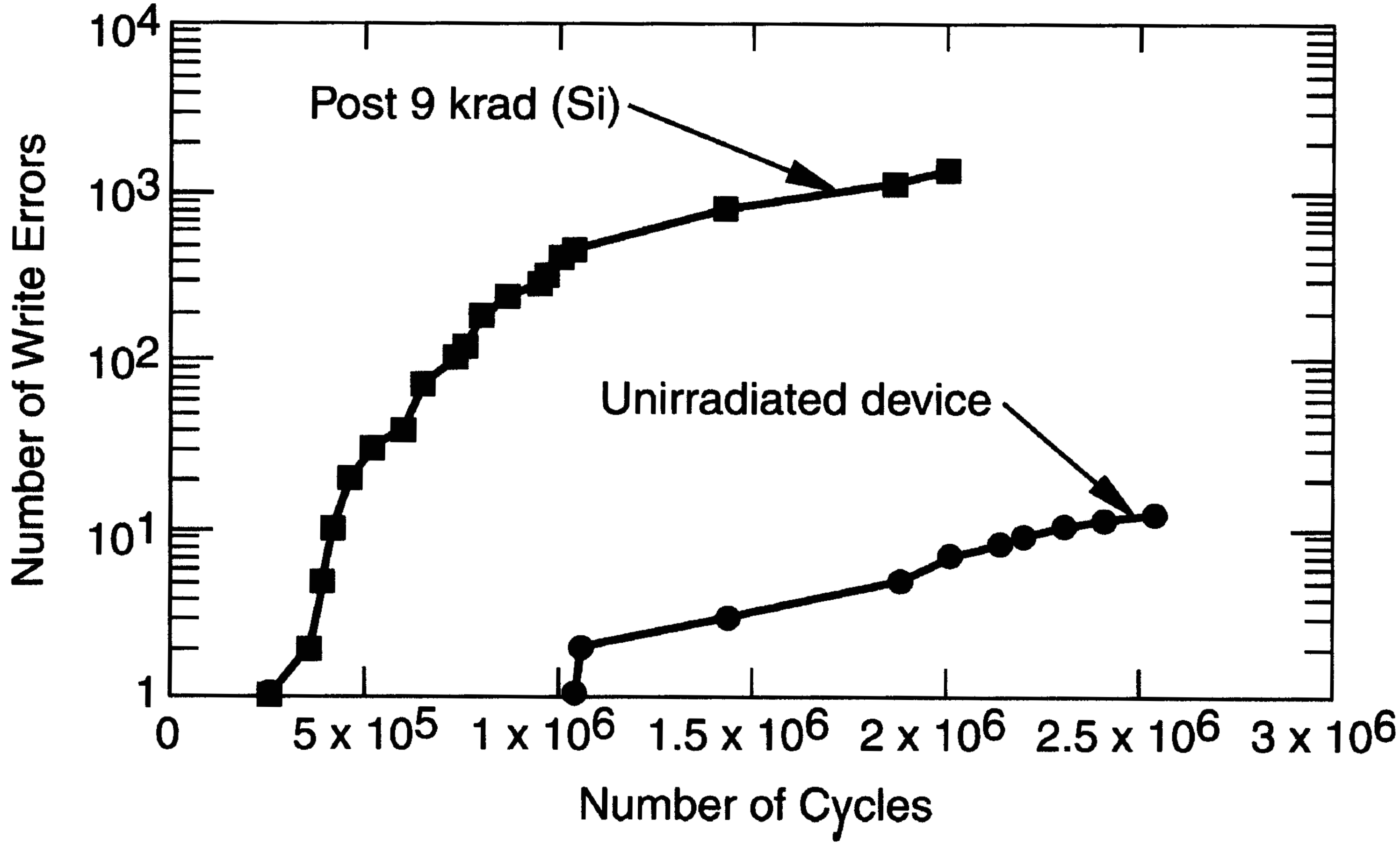
Wear-out

NOR 64 Mb Flash



Wear-out

NAND 64 Mb Flash



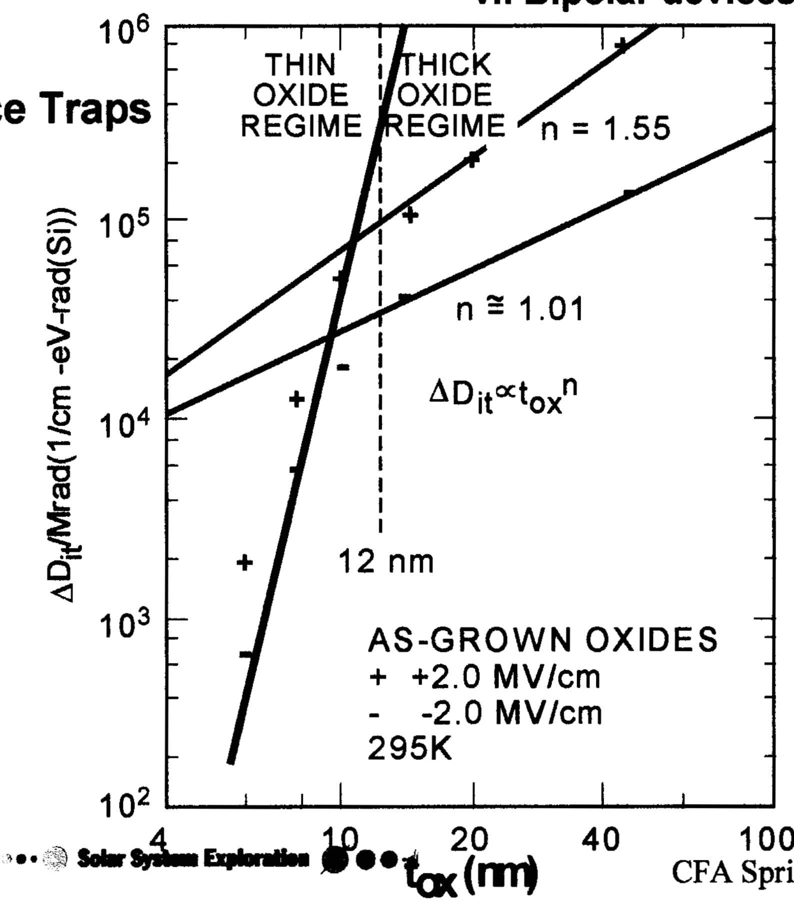
Oxide Thickness

Trapping drops off steeply in thin oxides but there are still problems:

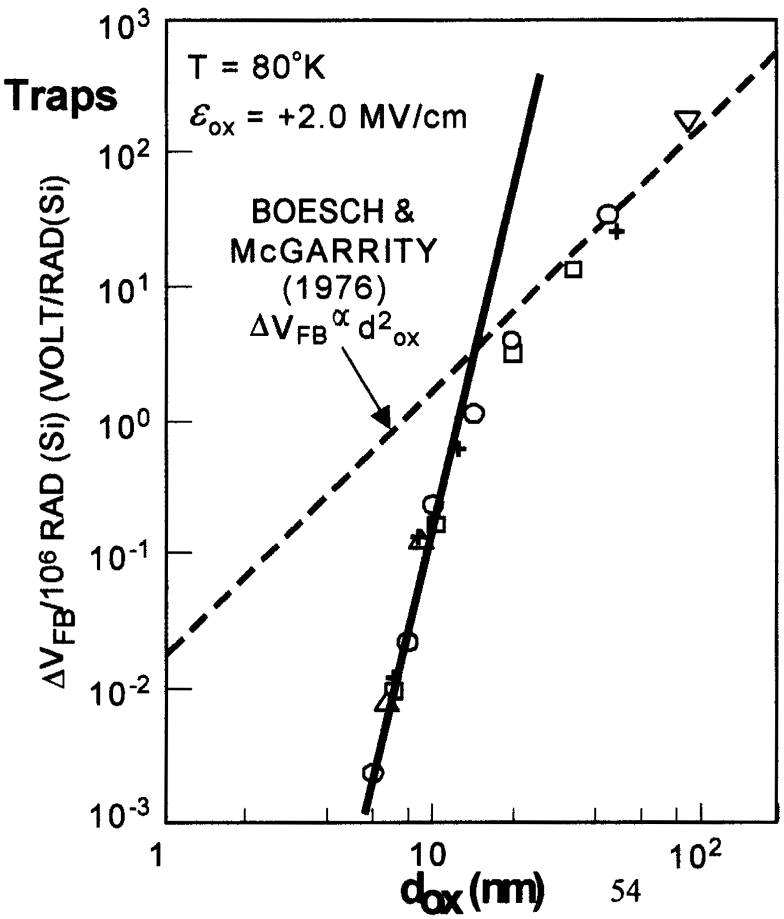
1) **Radiation Induced Leakage Currents (RILC) in ultrathin oxides**

2) **Thick oxides:**
   - i. Power MOSFETs
   - ii. Field oxides
   - iii. Silicon-on-insulator (SOI) buried oxides
   - vi. Bipolar devices.

Interface Traps



Hole Traps



Thin Oxide Issue

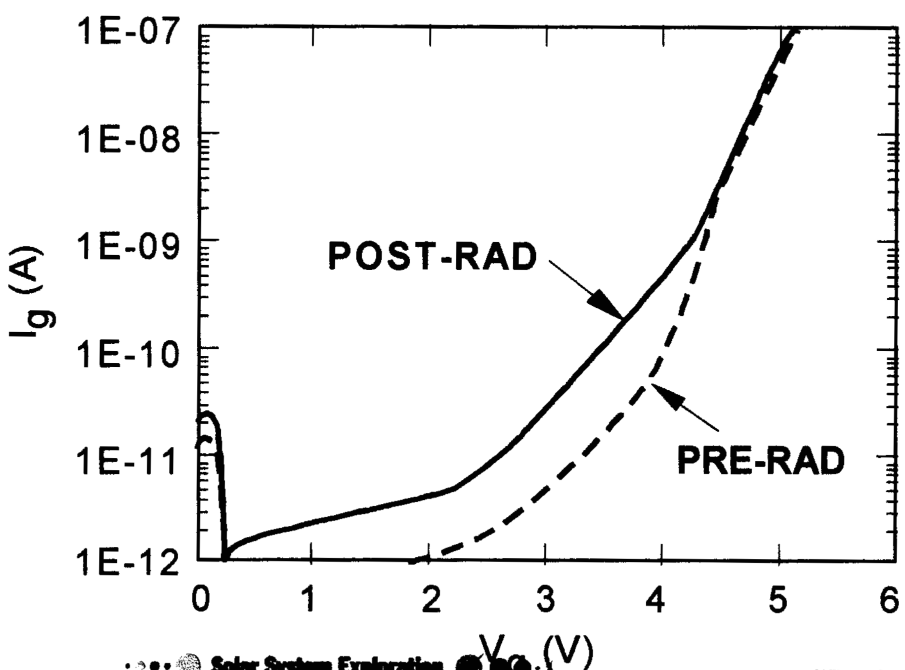
-Radiation Induced Leakage Current (RILC)

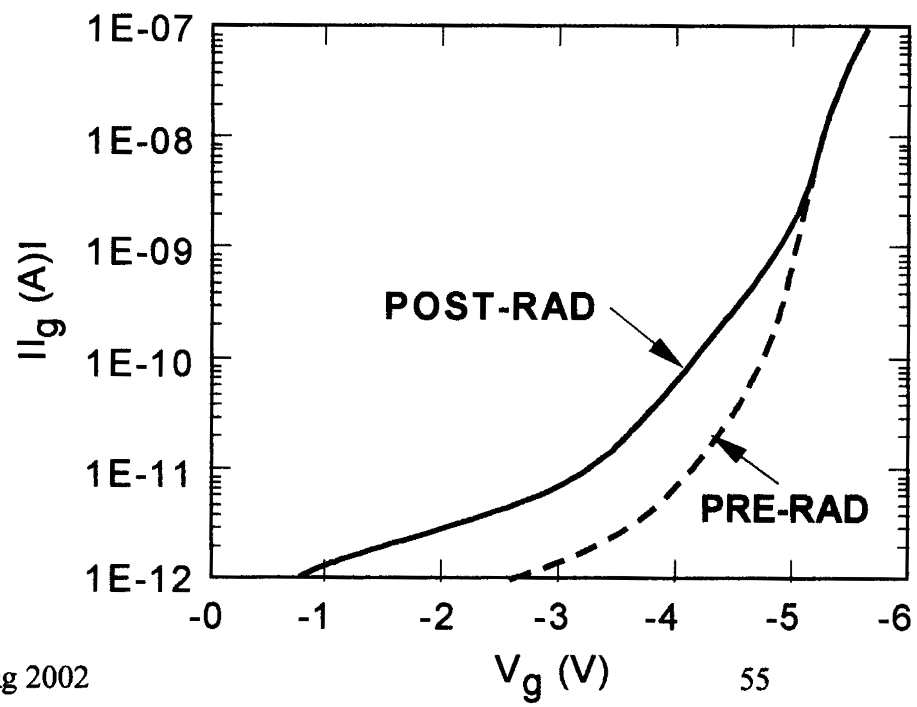
-Reported in thin oxides (<10 nm) at high doses (>1Mrad).

- Similar to stress induced leakage current (SILC).

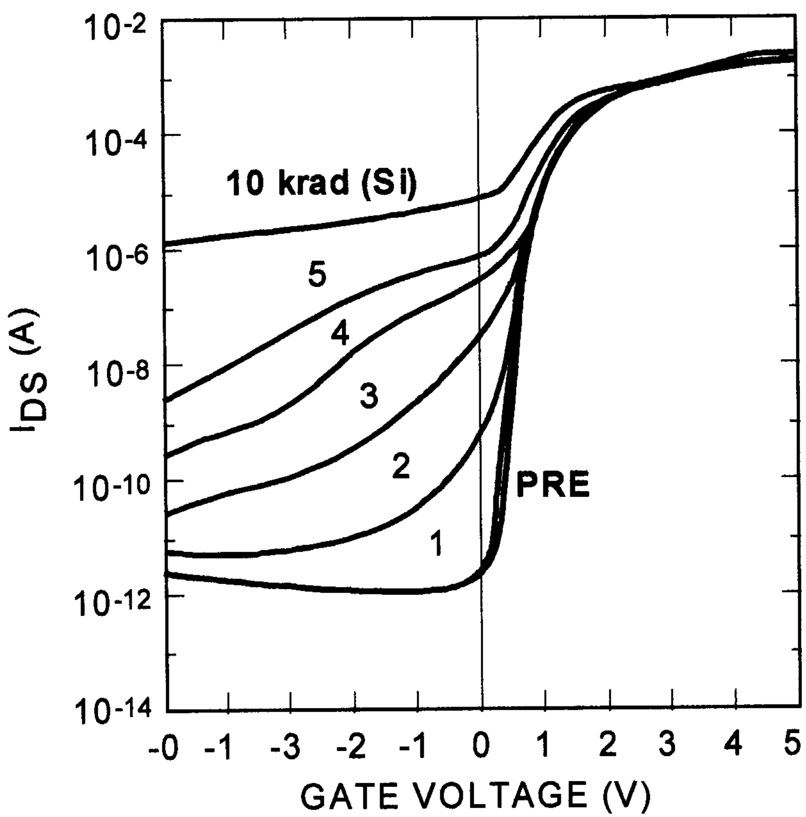
- Thought to be due to trap assisted tunneling.

- Possible failure mechanism for flash memories.

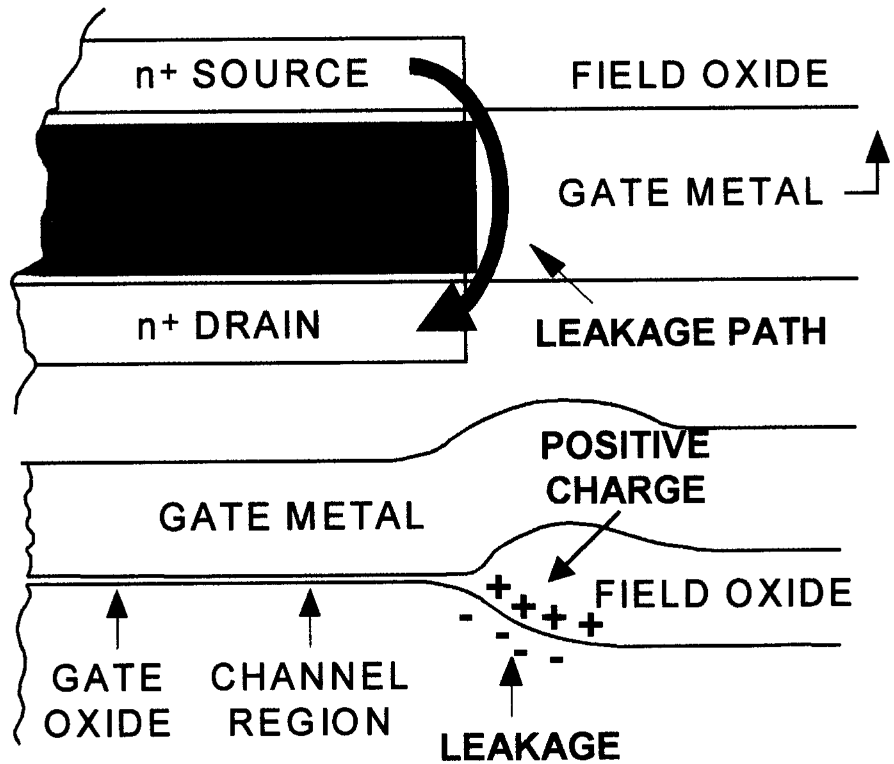




Field Oxide Leakage

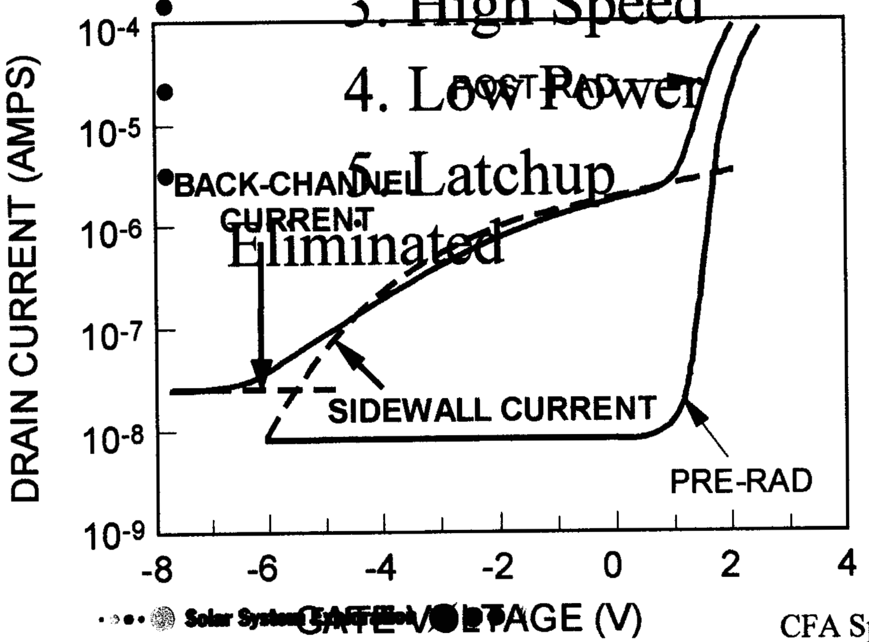


- Field oxides thick and poorly controlled.
- Dominant failure mechanism for commercial processes.
- Geometry is critical.

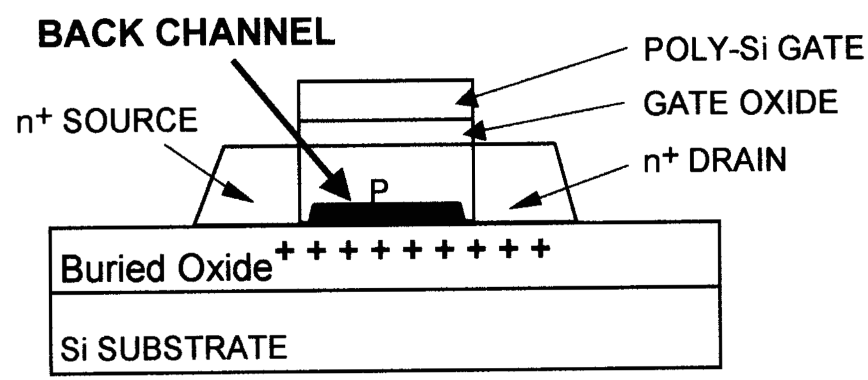


Rad Hard Option:
Silicon-on-Insulator (SOI)

- SOI Advantages:
- 1. Total Isolation
- 2. SEU Immune
- 3. High Speed
- 4. Low Power
- 5. Latchup Eliminated



- New SOI Total Dose Leakage Paths:
- 1. Back Channel Leakage
- 2. Sidewall Leakage



Current Mitigation Strategies

- Costs rise and performance suffers
- Shielding
- Thermally assisted annealing
- Design
- Screening

Current Mitigation Strategies

- Design
  - Charge pump
  - Hardened CMOS
- Possible Rad-hard vendors
  - UTMC
  - SEI

Radiation Test and Support Capabilities

JPL Radiation Effects Group

- Provides radiation test and analysis support for NASA programs
- Maintains radiation effects database available to outside users - device and systems manufacturers
- Perform radiation effects research in support of NASA objectives
- Technical assistance and data available to outside organizations in support of outreach objectives

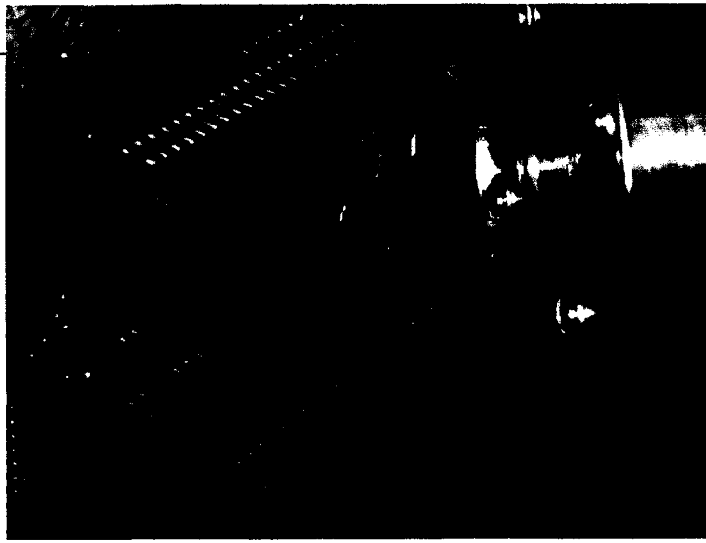
Simulated Environments

- Total Ionizing Dose (TID)
  - protons and electrons
  - secondary x-rays
- Displacement Damage (DD)
  - protons and electrons
- Proton Single Event
  - solar protons

JPL Co-60 Gamma Facility

- Total Ionizing Dose Source
- Co-60, 1.17 and 1.33 MeV gamma photons
- Up to 8000 curies, three sources available
- Dose Rates - 0.002 to 100 Rad/s
- No size limitation, 400 sq. feet chamber

Heavy Ion Facilities



- Simulation of the cosmic ray environment
- Commonly used accelerator facilities
  - UC Berkeley Cyclotron
  - Texas A&M Cyclotron
  - Brookhaven Linear Accelerator

Contact Information

- Karl Strauss
  - M/S 303-310
  - 818-354-4973
- Leif Scheick
  - M/S 303-220
  - 818-354-3272
- Steve McClure
  - M/S 303-220
  - 818-354-0482

Jet Propulsion Laboratory
4800 Oak Grove Drive
Pasadena, CA 91109

Attn: Name and Mail Stop

Parts Data and Information Links

- http://radnet.jpl.nasa.gov/
  JPL radiation effects database
- http://nepp.nasa.gov/
  NASA Electronic Parts Program, reliability and radiation data
- http://erric.dasiac.com/
  Defense Threat Reduction Agency Database
- http://www.nsrec.com/
  Nuclear and Space Radiation Effects Conference
- http://www.comrad-uk.net/
  Component Radiation Database, UK