Electronic Radiation Hardening
-
Technology Demonstration Activities (TDAs)

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ESA/ESTEC, TEC-QEC

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Outline

- Radiation effects and technology hardening
  - **TID**
  - TNID, SEE
- Technology Demonstration Activities
  - T222-019QC – Critical components for power systems
  - T222-020QC – Radiation characterisation of Laplace critical RH optocouplers, sensors and detectors
  - T222-016QC – Radiation Hard memory; Radiation testing of candidate memory devices for Laplace Mission

Specific constraints of the JGO radiation environment

JGO radiation environment

- Trapped Particles
  - **electrons**
  - protons
  - heavy ions
- Transient Particles
  - solar event protons and heavy ions
  - galactic cosmic rays

Radiation effects at the device level

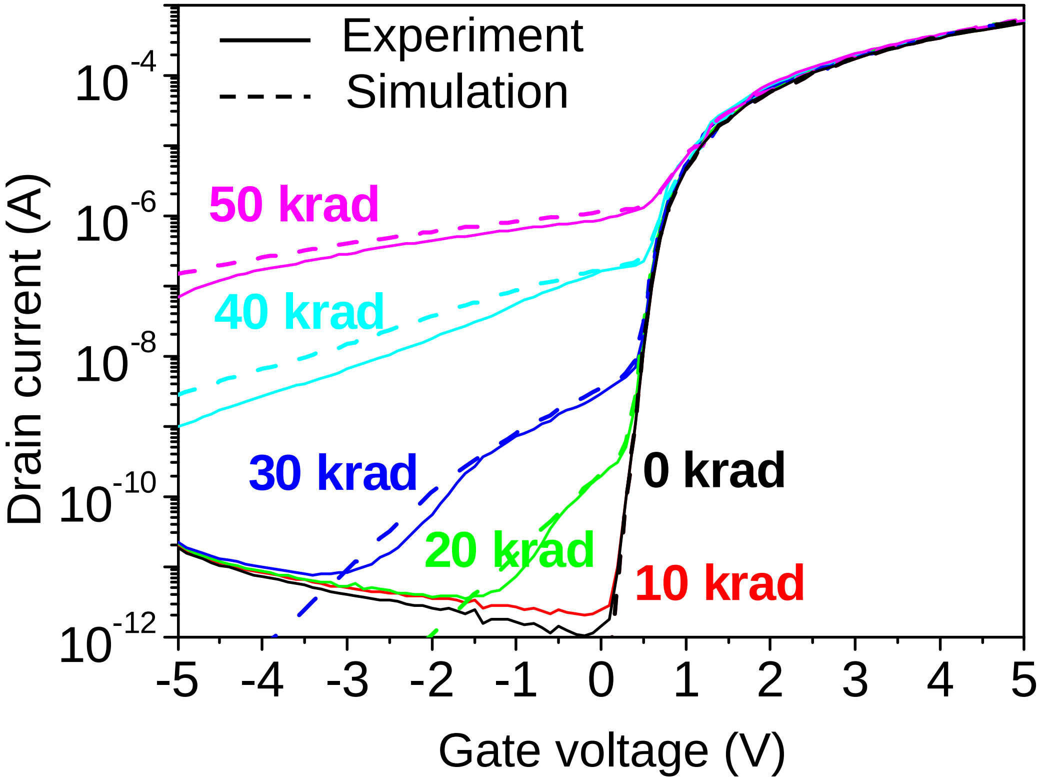
Total dose effects

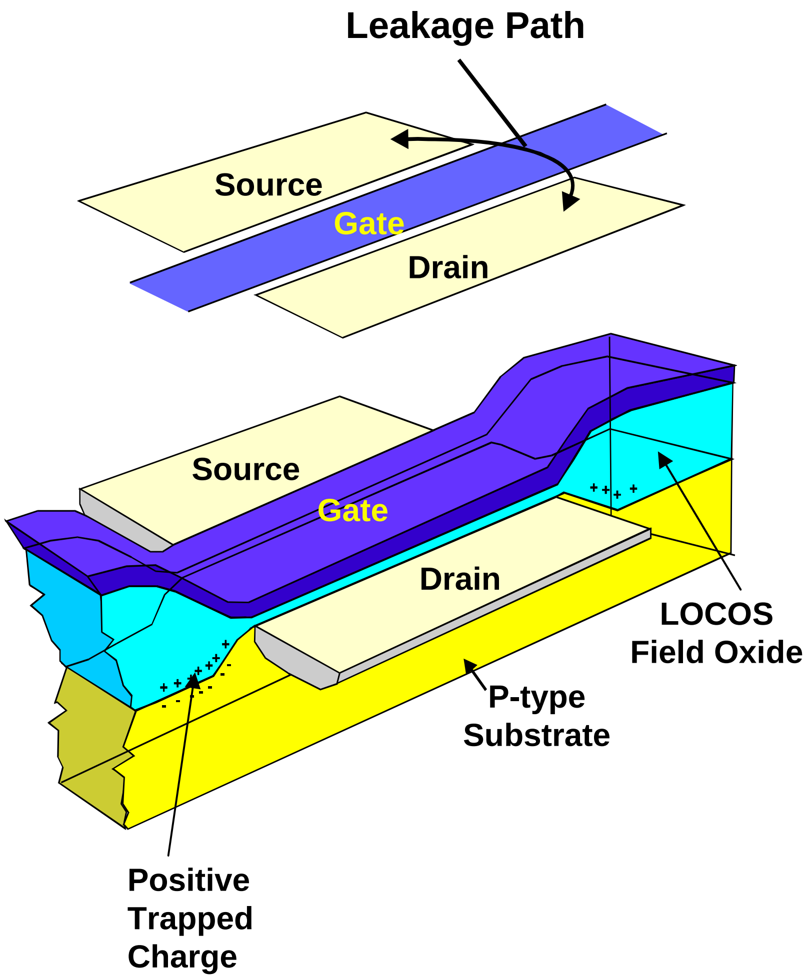
Displacement Damage effects

Single Event Effects (SEE)

Charge buildup in field oxides can cause large increase of the leakage current because of the lateral parasitic transistor

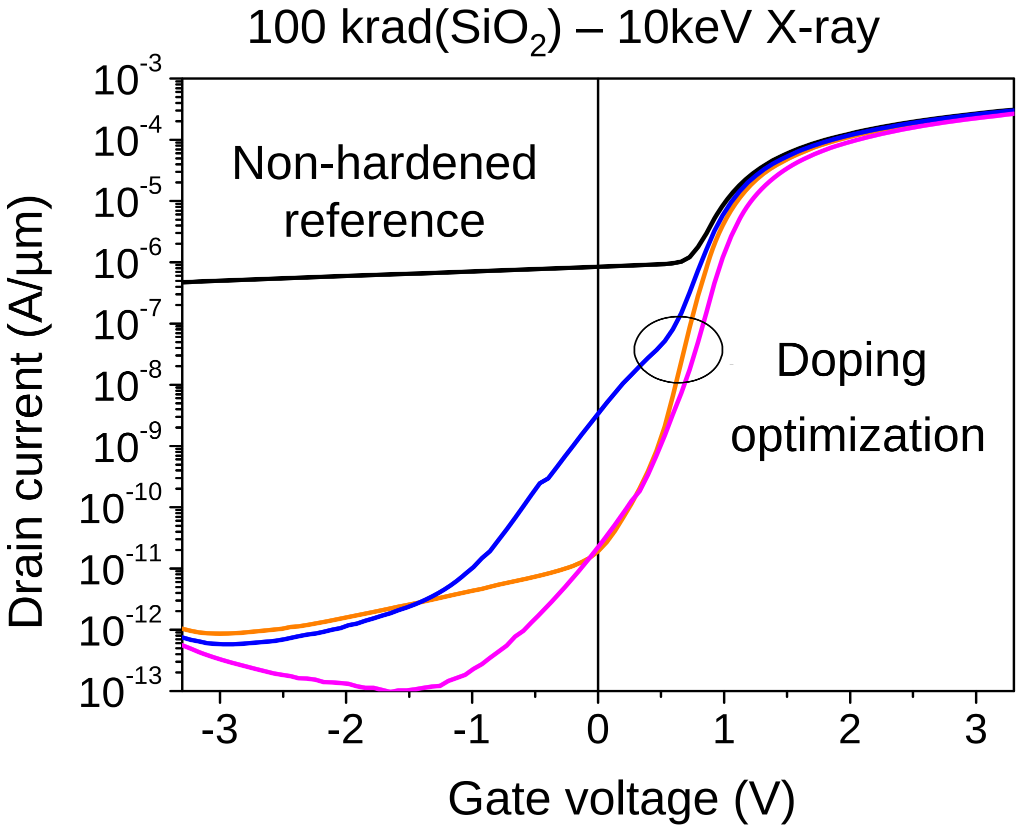
CMOS technology 0.8um,
LOCOS isolation



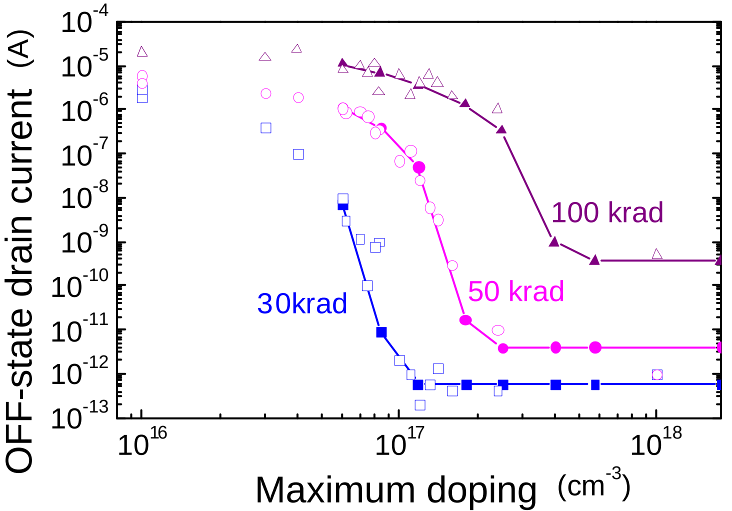


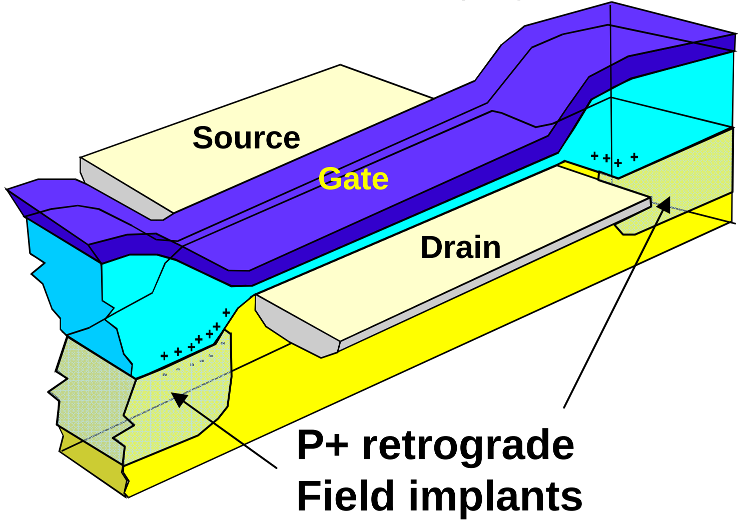
[Ferlet HDR05]

Technology hardening is possible, for example by doping under the field oxide; but it is often a trade-off against electrical performances

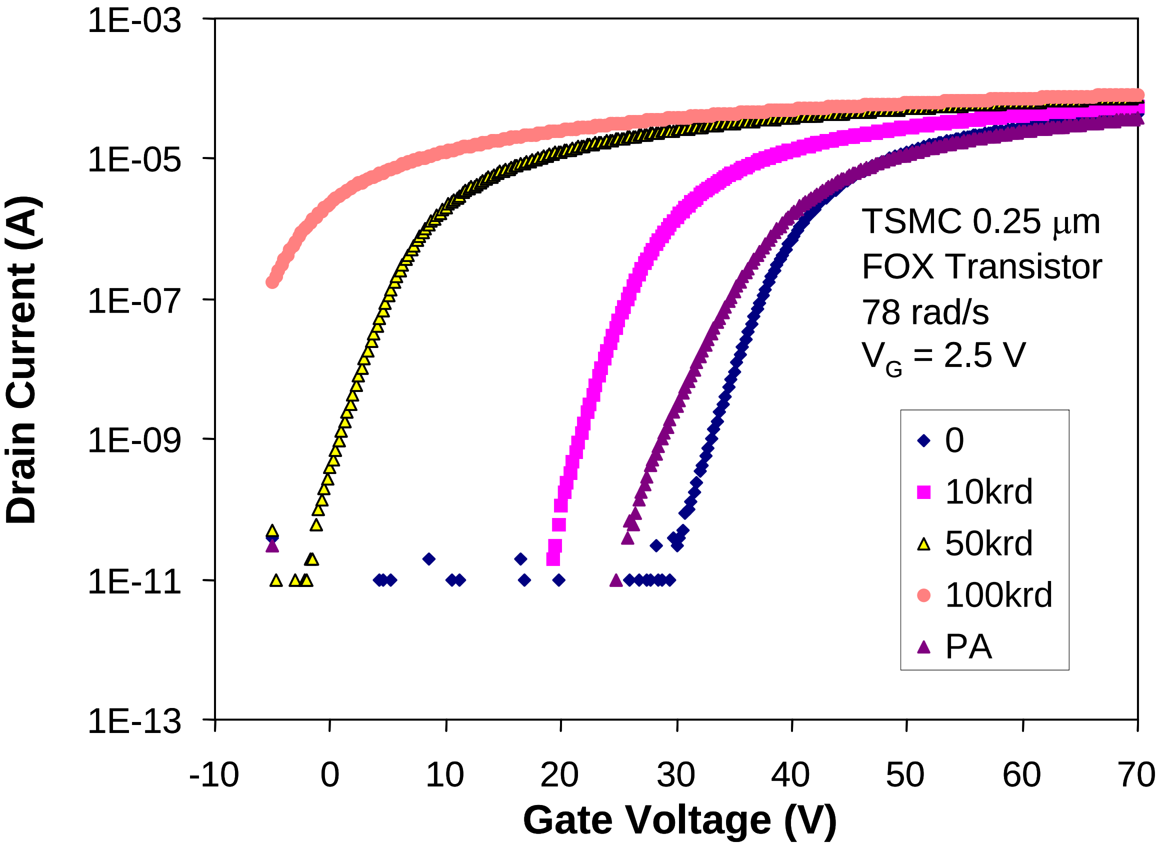

100 krad(SiO_2) – 10keV X-ray

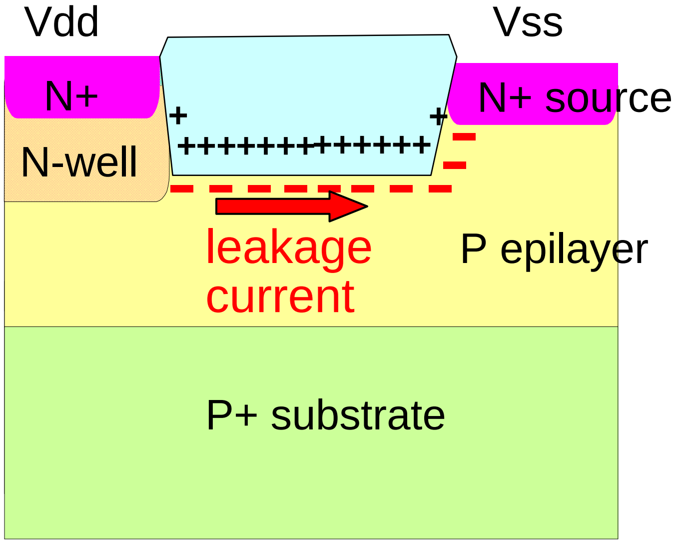
[Ferlet HDR05]





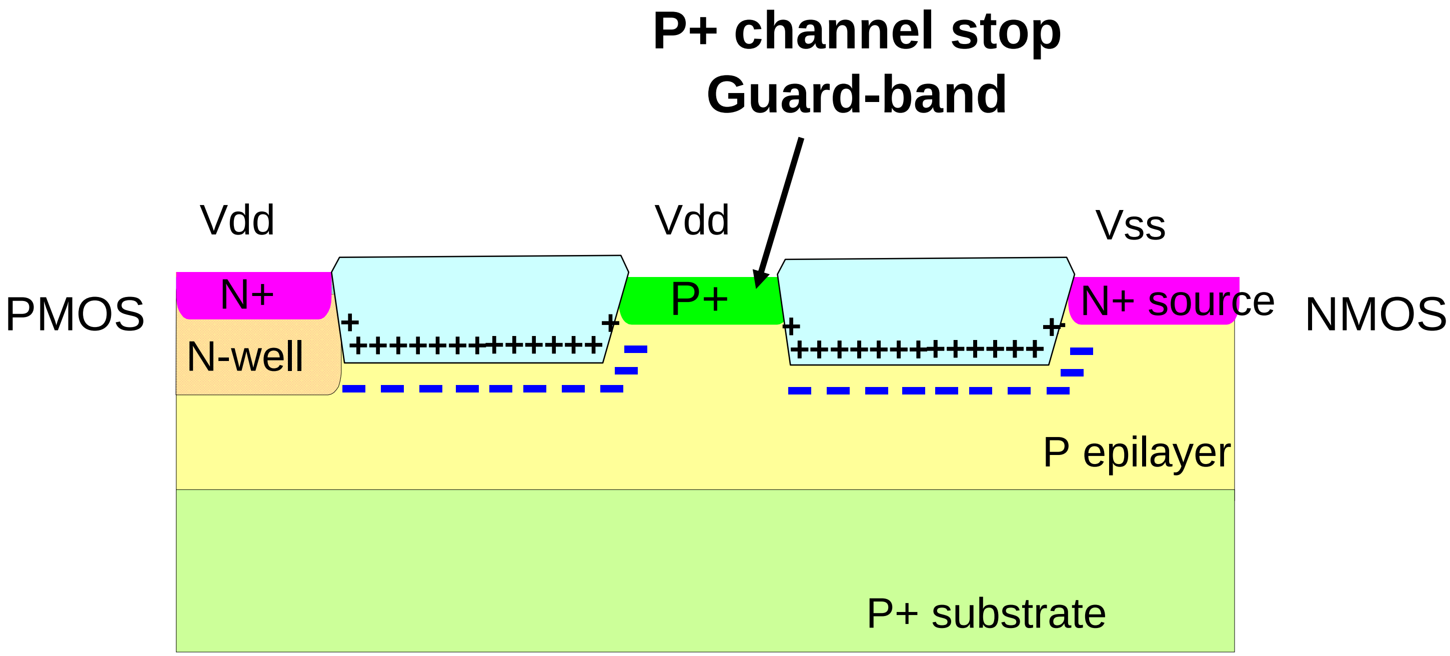
Another source of radiation-induced leakage current is the parasitic “inter-device” transistor



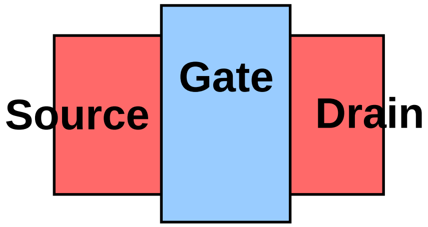


[R. C. Lacoe, et. al. TNS Dec. 2000]

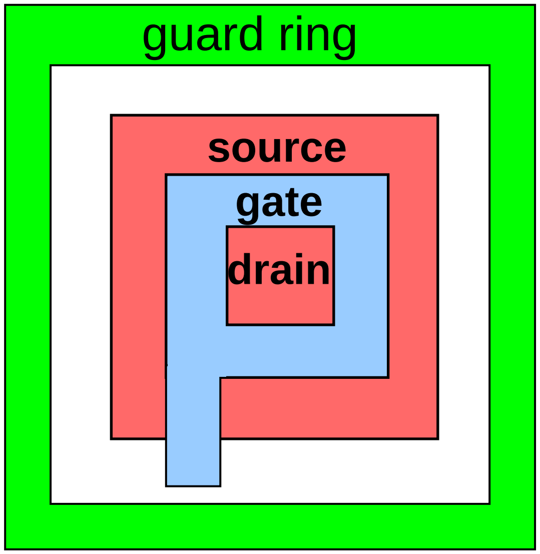
Inter-device leakage is efficiently mitigated with P+ guard ring, but at the expense of area penalty



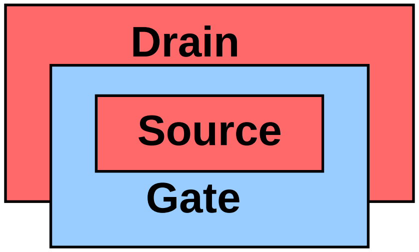
Hardness by design methodology: rad-tolerant design rules for IC design



Standard-edged transistor



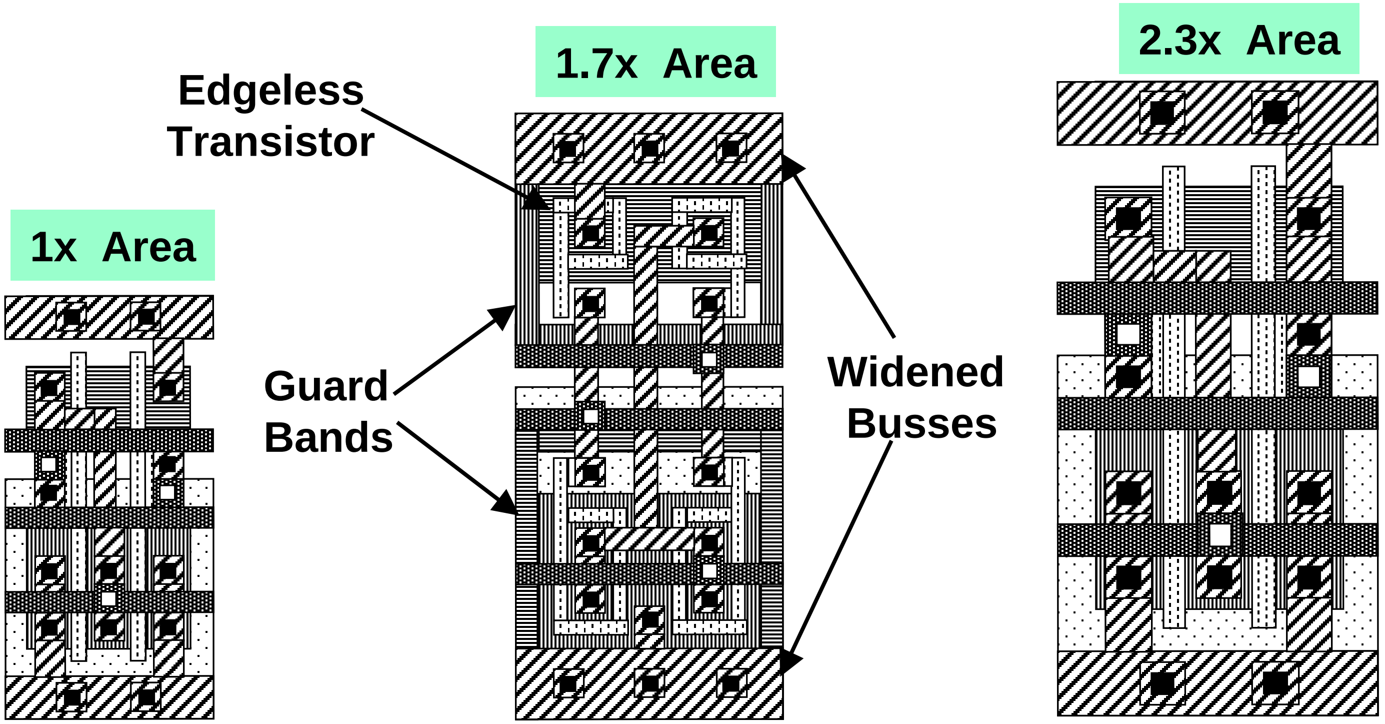
Edgeless transistor
+ guard ring



Ringed-source transistor

[Nowlin, 2005]

Area Comparison – 2NAND Logic Gate



1x Area

1.7x Area

2.3x Area

Edgeless Transistor

Guard Bands

Widened Busses

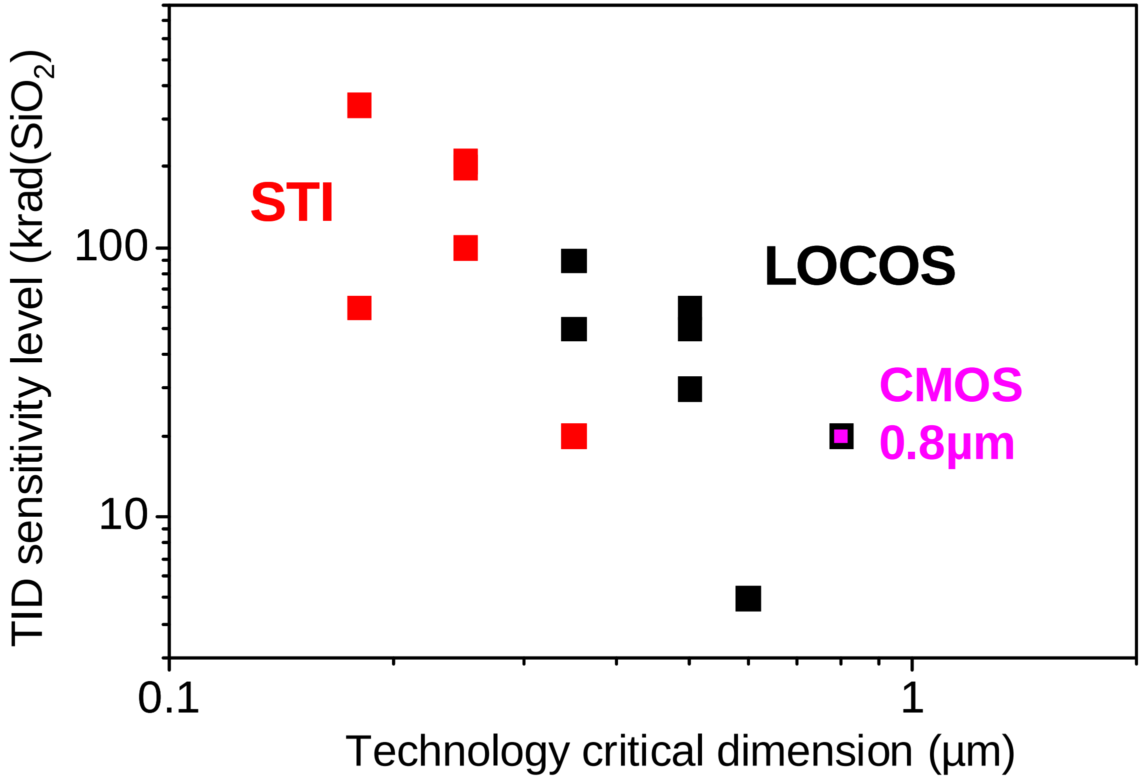
Std. Design
0.35-µm Comm.

Rad-Hard-By-Design
0.35-µm Comm.

Std. Design
0.50-µm 1 Gen Behind

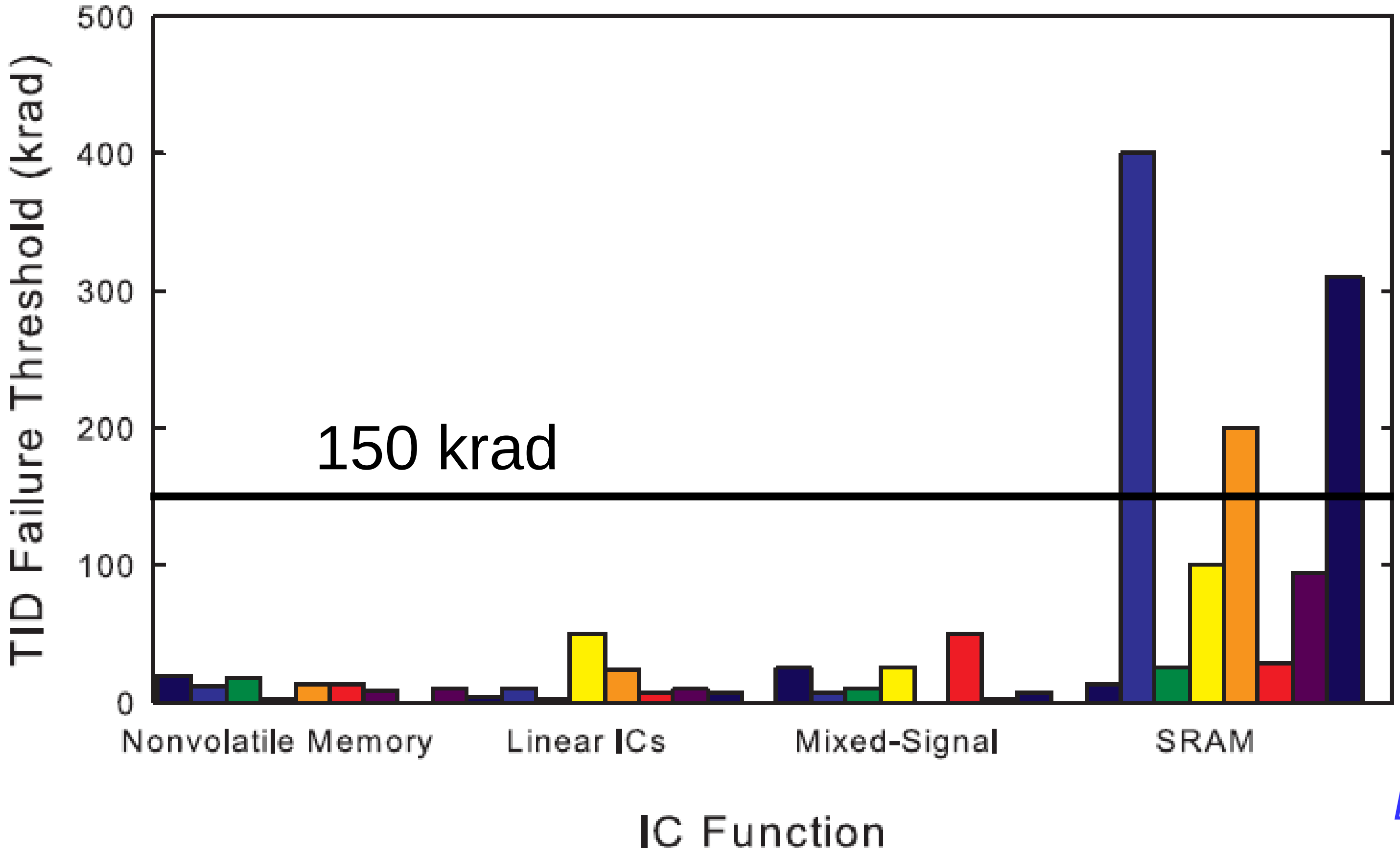
[R.C. Lacoe et. al., TNS Dec. 2000]

Highly scaled CMOS technologies, with standard design, are less sensitive to TID



Compilation from [Lacoe03, Anel97, Kerwin98, Shaneyfelt98, Brady99, Lacoe99, Lacoe00, Lacoe01, Nowlin04]

However, real systems use a wide variety of IC technology generations, for which TID hardening is not granted

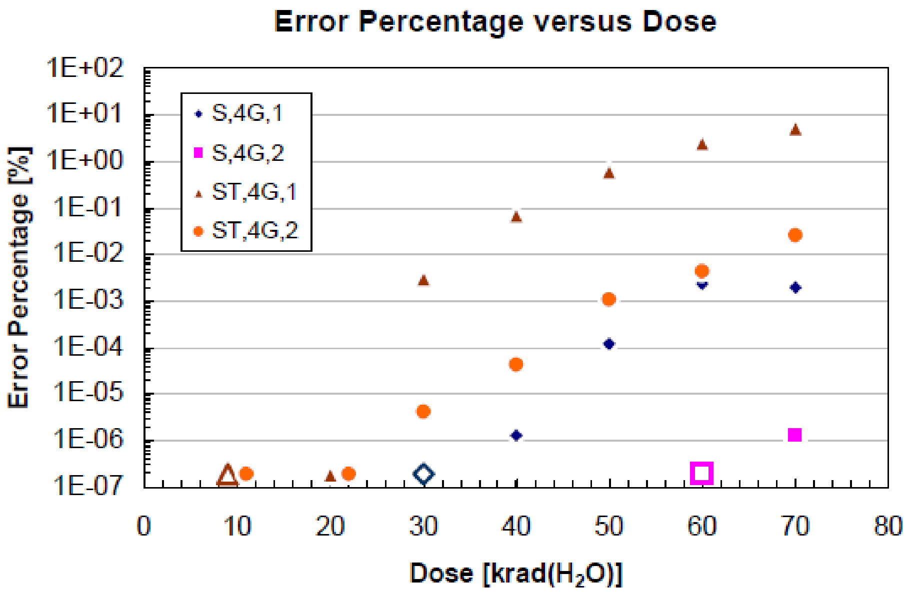


[Dodd09]

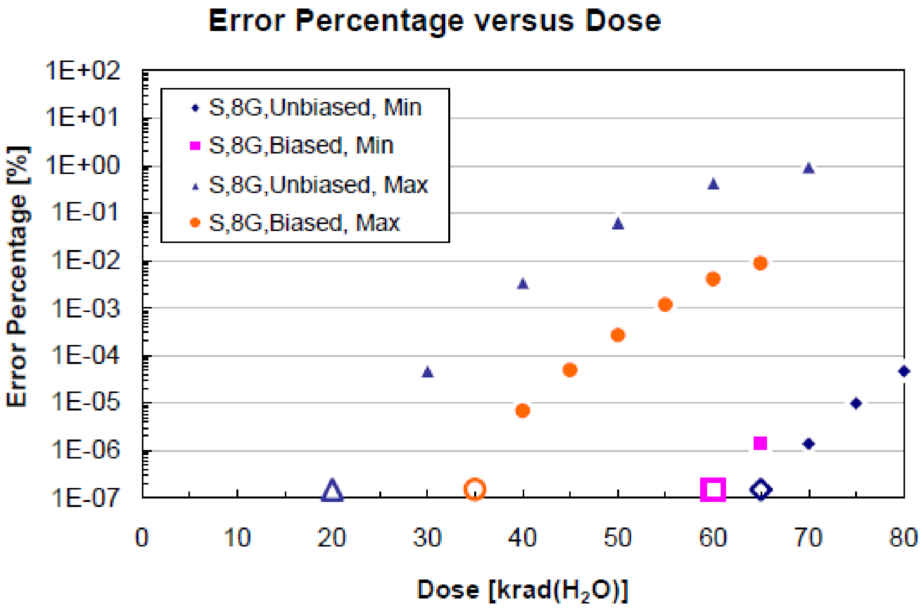
Compilation from Radiation Effect data workshops between 2002 and 2004

Significant variation is observed on the TID sensitivity, even for same “date code” parts

8-Gbits NAND-Flash, Samsung & ST



8-Gbits NAND-Flash, Samsung

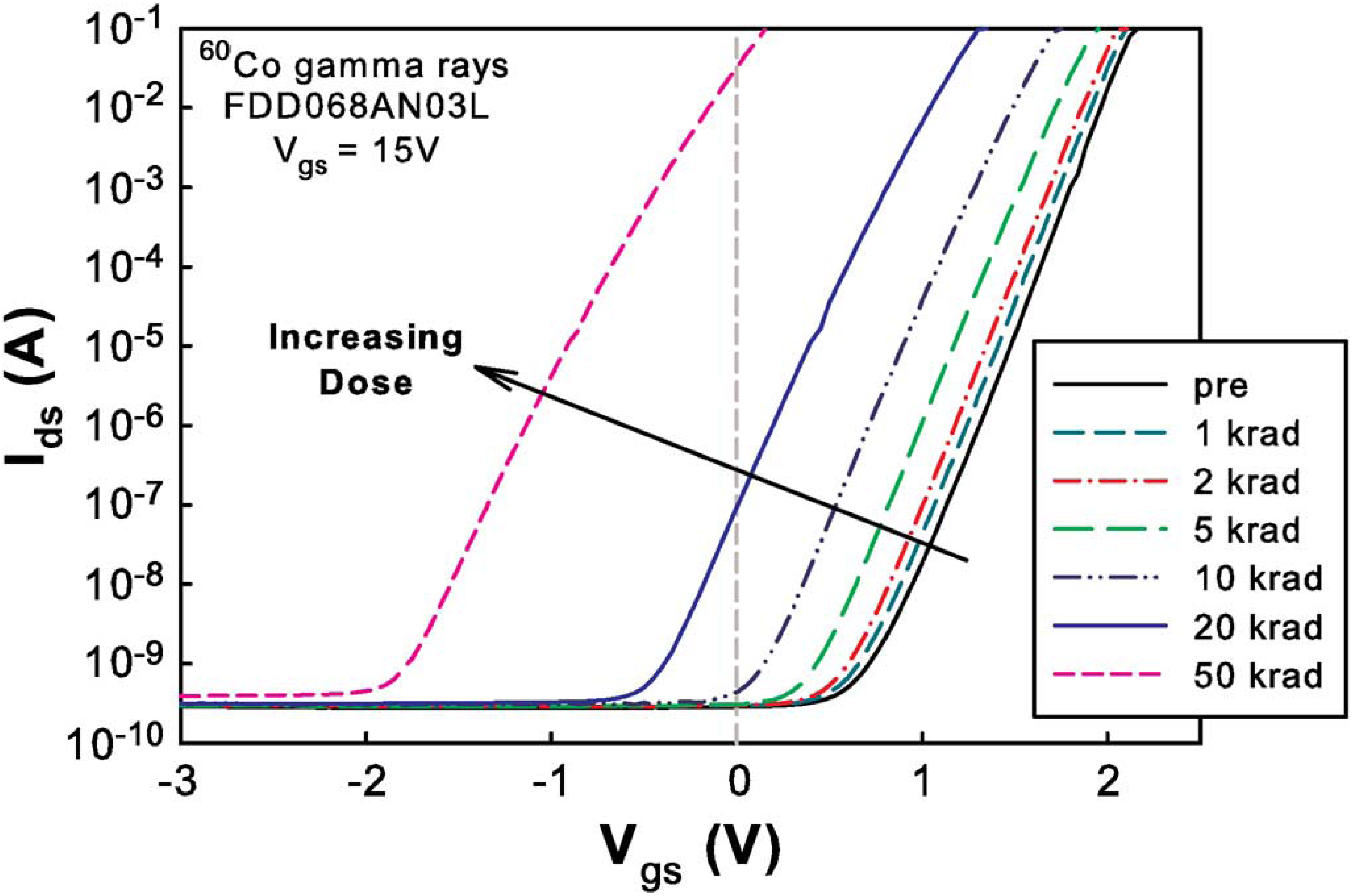


Example of COTS mass memory

Biased vs unbiased tests:
10 + 8 samples

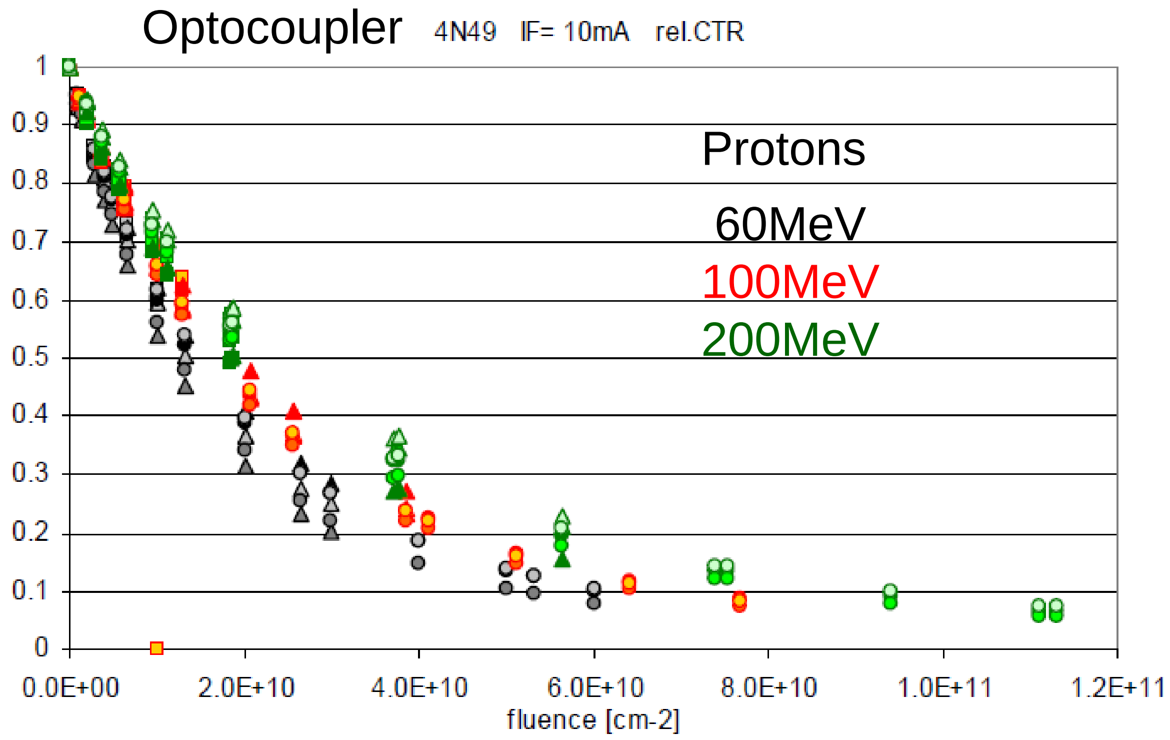
[Schmidt, IDA, 2008] under ESA contract

TID in power MOSFET



[Shaneyfelt et. al., TNS 2008]

Optoelectronics is highly sensitive to TNID - degradation of the minority carrier lifetime



4N49 optocoupler: relative CTR with respect to fluence

[D. Peyre, et. al. 2009] under ESA contract

TID / TNID Mitigation

- Reduce the dose levels
  - Improve the accuracy of the dose level calculation
  - Change the electronic board, electronic box layout
  - Add Box and/or Spot shielding

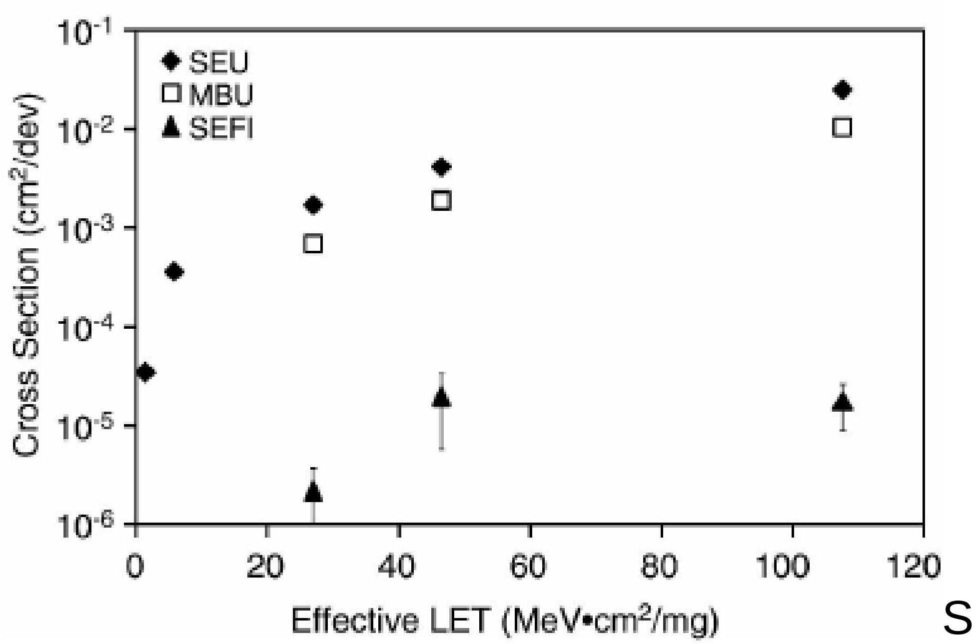
- Increase the failure level
  - Tolerant library => **DARE library**
  - Tolerant designs (cold redundancies, etc.)
  - Test of the flight lot, with significant sampling
  - Test in the application conditions
    - Duty cycle (biased-unbiased devices)
    - Temperature
  - Test at low dose rate (CMOS only)
  - Relax the functional requirements

} Specific IC design

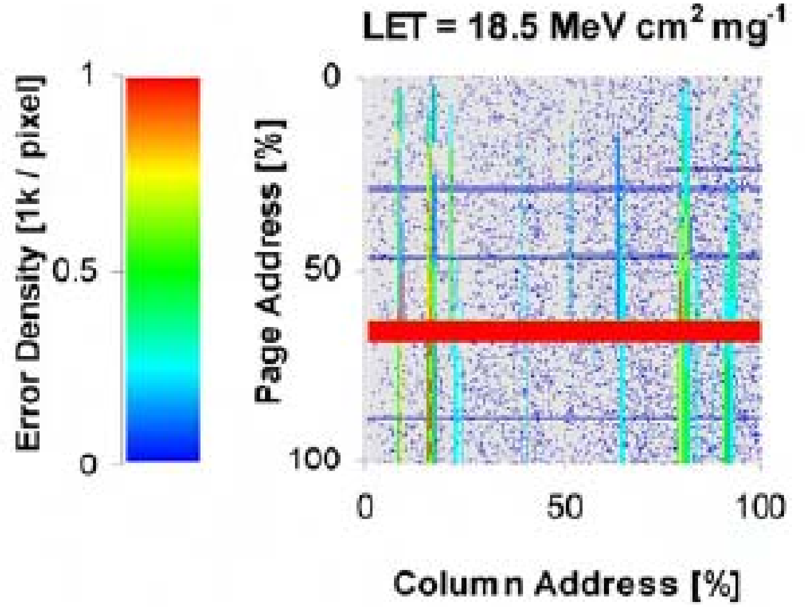
[C. Poivey, RADECS 2003]

SEE characterization

Samsung 1Gbits DDR1 SDRAM



8-Gbits NAND-Flash, Samsung



SEU-MBU-SEFI-SEL:
Effect of die revision: x10^2 SEU rate
Lot-to-lot variations

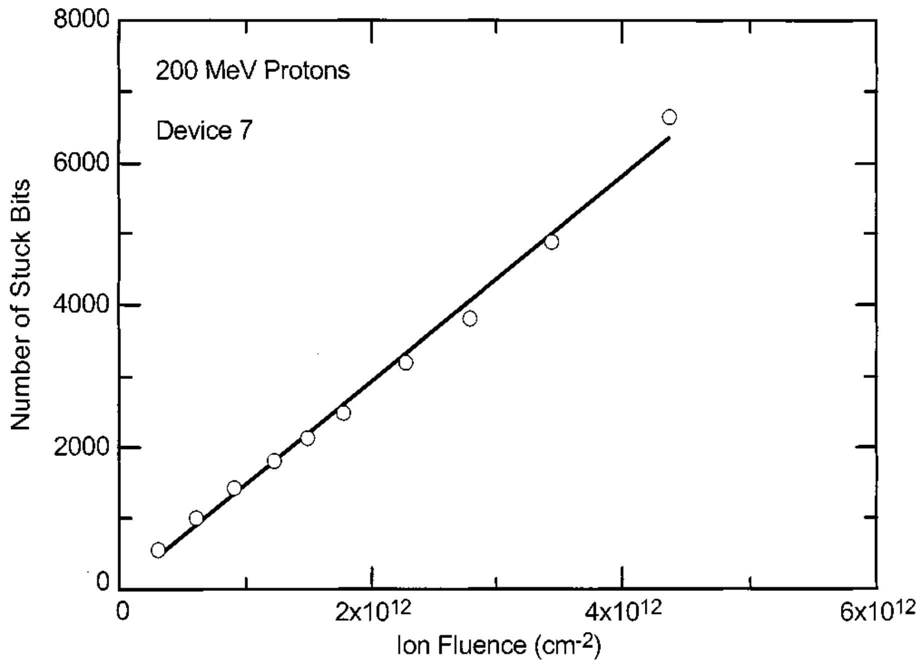
[Ladbury 2006]

SEFI:
- Rows, columns, blocks are in error;
- Need reset or power cycling
- Mitigated by decreasing the refresh time
- Must be taken into account by the system

[Hagen Schmidt, IDA, 2008]

End of Life reliability: stuck bits

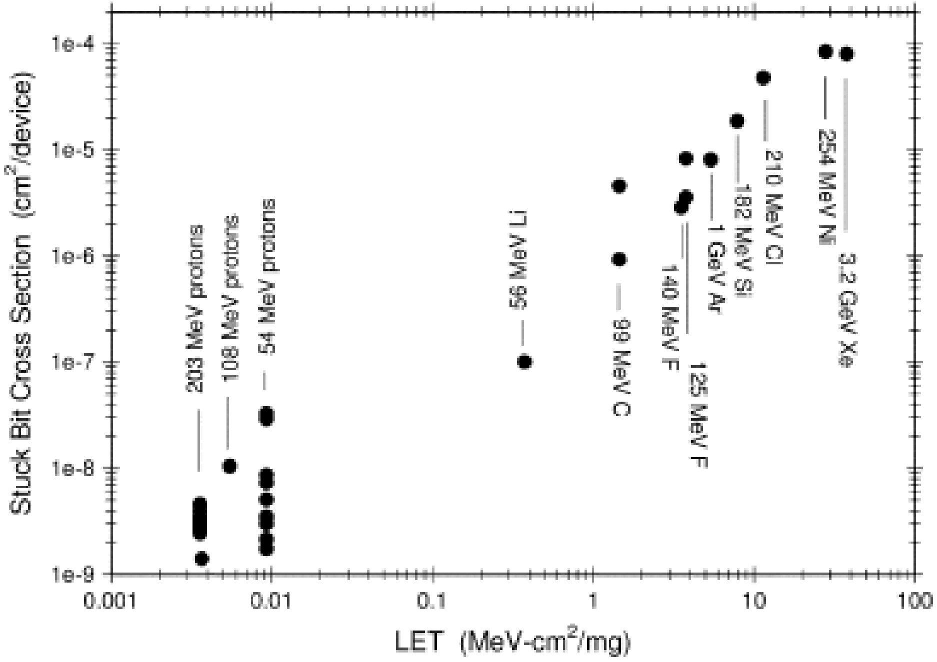
Samsung 1Gbits DDR1 SDRAM



Large part to part variations

[Edmonds 2001]

Hyundai 64-Mb SDRAM



Micro-dose or -displacement damage

[Edmonds 2008]

SEE Mitigation

- Devices sensitive to destructive failures **must be discarded**
  - SEGR / SEB in Power MOS
  - Latch-up in CMOS

- Implies careful design and/or part selection
  - ASICs designed with a rad-tol or rad-hard technology and/or library
    - ➢DARE Library
  - SEE rad-hard parts whenever possible
  - Test of the flight lot with significant sampling

Technology Demonstration Activities (TDAs)

- T222-019QC – Critical components for power systems
  - *Christian Poivey*
- T222-020QC – Radiation characterisation of Laplace critical RH optocouplers, sensors and detectors
  - *Marc Poisat*
- T222-016QC – Radiation Hard memory; Radiation testing of candidate memory devices for Laplace Mission
  - *Fredrick Sturesson*

T222-019QC

Survey of critical components for 150krad power systems

- Project scheduling
  - Duration 18 months
  - KO meeting in November 2009

- Components for Power systems
  - Power DC/DC converters 10-30W
  - PCDU – Power control and distribution – 500-1000W

- Radiation tests
  - Total ionizing dose: 150 krad(Si)
  - Displacement damage: about 10^{11} cm^{-2} equivalent 10MeV protons

Survey of critical components for 150krad power systems (2)

- Surveyed functions
  - Power MOSFETs
  - MOSFET drivers
  - Operational amplifiers
  - Voltage comparators
  - Optocouplers
  - Discrete bipolar transistors
  - Schottky diodes
  - Voltage references
  - Analog multiplexers
  - CMOS logic
  - Pulse Width Modulators

Pre-selection of Rad-hard parts whenever possible

Bipolar-based parts will be tested for ELDRS (Enhanced Low Dose Rate Sensitivity)

Combined effects Co60 and protons (TID-TNID)

Selected parts shall not be sensitive to destructive events

T222-020QC

Radiation characterization of optocouplers, sensors and detectors

- Project scheduling
  - KO meeting expected Q2 2010,
  - Project duration 18 months

- Tested Components:
  - Optocouplers and APSs (Active Pixel Sensors)
  - Selected from rad-tol or rad-hard devices
  - Complete the existing radiation data

- Radiation tests: TID, TNID and SEE
  - Total ionizing dose: 150 krad(Si)
  - Displacement damage: protons (about 10^{11} cm^{-2} eq. 10MeV) and neutrons
  - Combined TID and DD experiments
  - SEE: protons 100-175-250MeV

T222-020QC

Radiation hard memory; radiation testing of candidate memory devices for Laplace mission

- Project scheduling
  - KO meeting expected Q2-Q3 2010,
  - Project duration 36 months

- Selection of memories
  - Flash Memories
  - SDR SDRAM memories
  - DDR2 (or DDR3) memories
  - DDR2 memory interface devices
  - Phase Change Memory (PRAM), FeRAM, MRAM, any other memory type

- Radiation tests: TID, TNID and SEE
  - Total ionizing dose: 150 krad(Si)
  - SEE: protons and heavy ions
    - Latch-up, SEFIs