# Effetti di radiazione in celle di memoria non volatile di tipo Flash

Scuola Nazionale di Legnaro, 06.04.2005


**Angelo Visconti**

**STMicroelectronics**

Central R&D - Non Volatile Memory Technology Development

Agrate Brianza (Milano), Italy

# Activity developed within a collaboration with

UNIVERSITA' DEGLI STUDI DI PADOVA
DEI, Department of Information Engineering

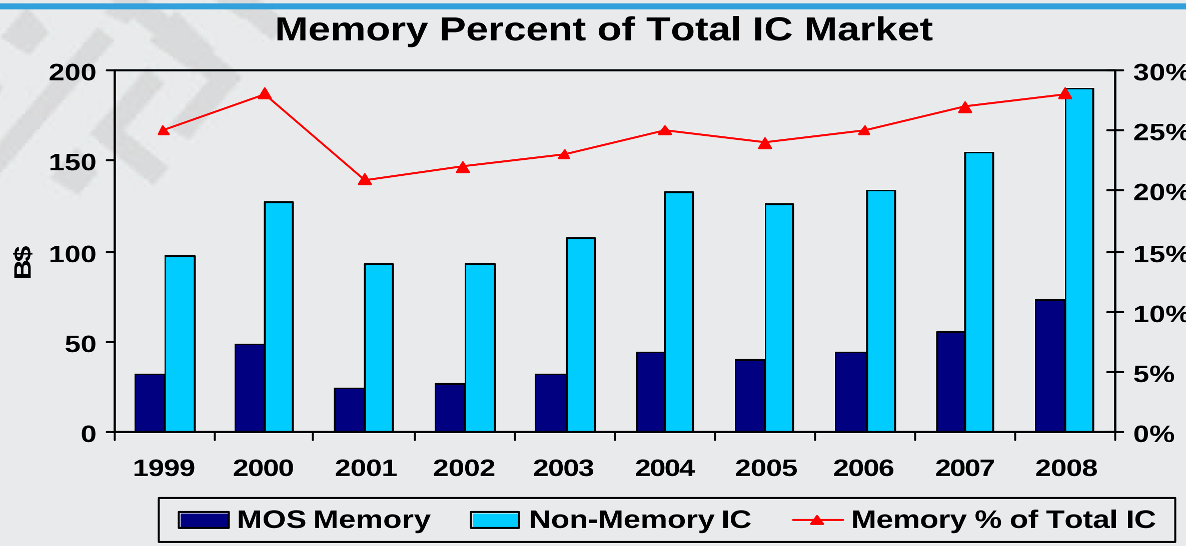
DEPARTMENT OF INFORMATION ENGINEERING
UNIVERSITY OF PADOVA

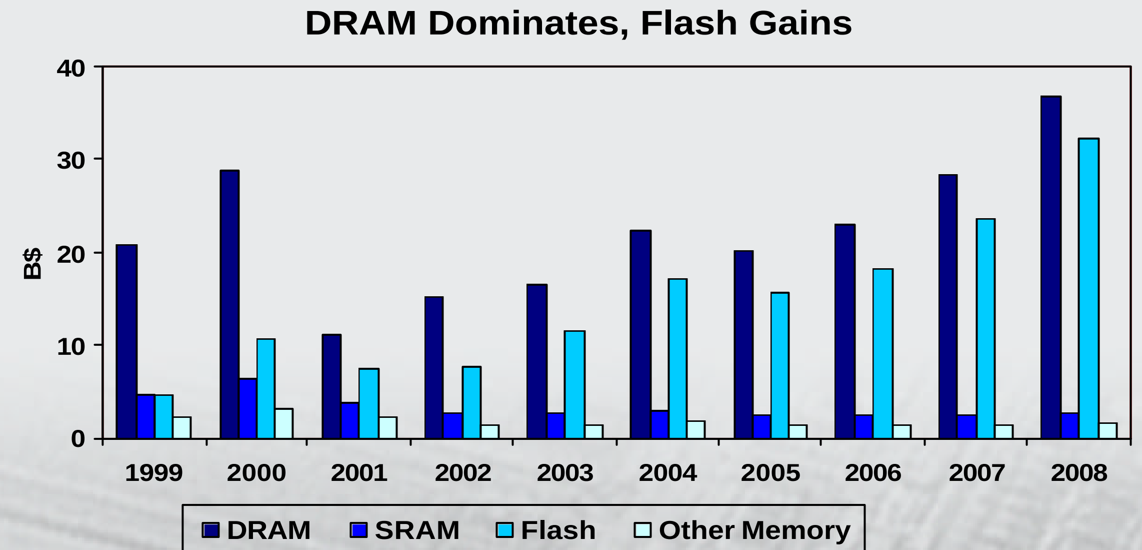
**Prof. Alessandro Paccagnella**
**Dr. Giorgio Cellere**

# Outline

- **Semiconductor memory**
  - **Market**
  - **Flash applications**
- The NOR Flash stacked gate memory cell
  - Structure
  - Reading operation
  - Writing mechanism
  - Reliability basic
- Radiation effects on Flash cell data retention
  - TID: X and $\gamma$ Rays
  - TID: Alpha particles
  - TID: Neutrons
  - SEE: Heavy ions
  - Technology Scaling effects
- Summary

# Memory Regaining Momentum

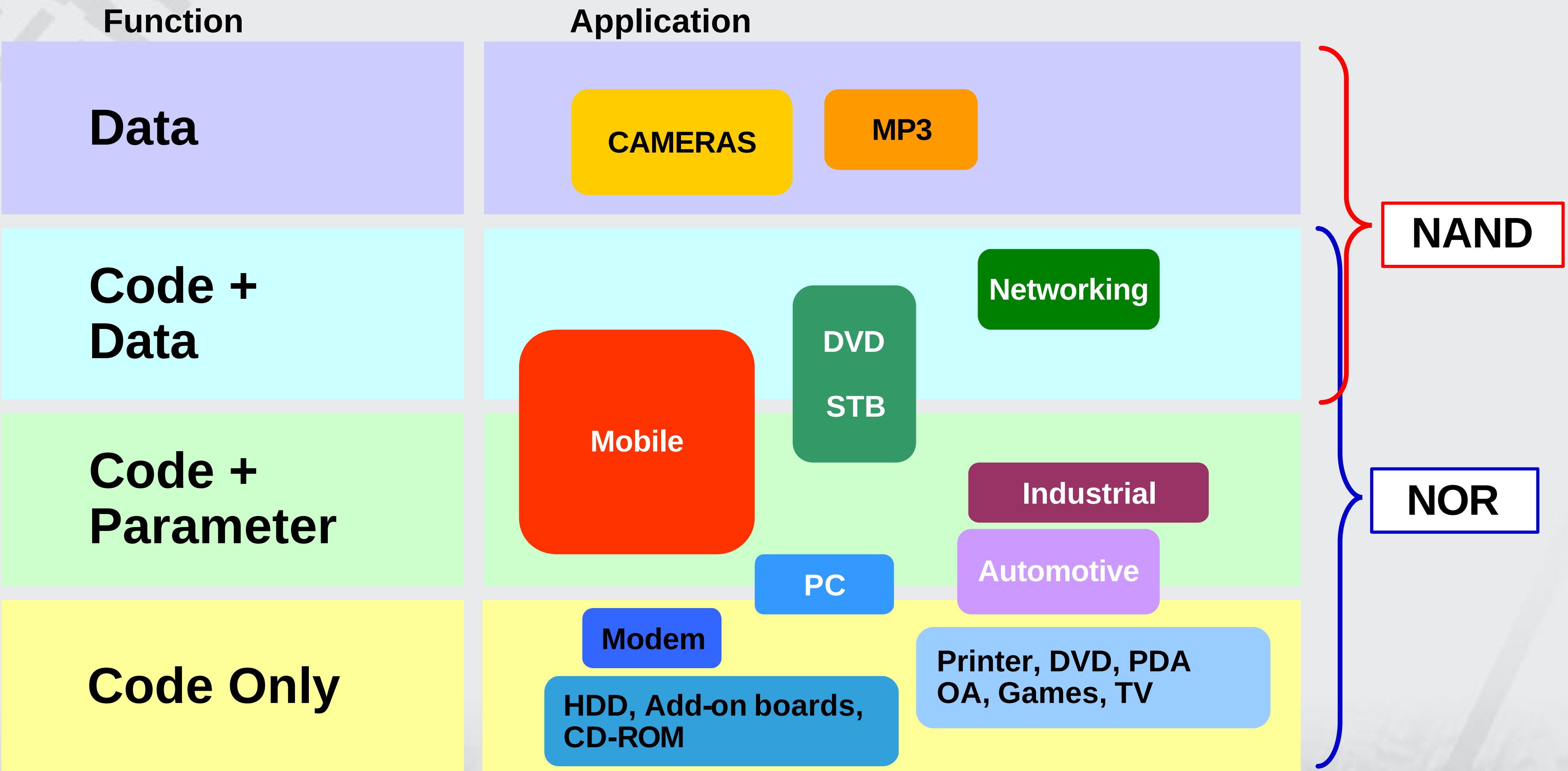



- Memories going to climb back to 30% of IC Market
  - DRAM $ growth 17%
  - Flash $ growth 23%

Source: WSTS, IC Insights

# Flash Applications




Today in mass production

NOR: 128Mb, 130nm tech. NAND: 1Gb, 90nm tech

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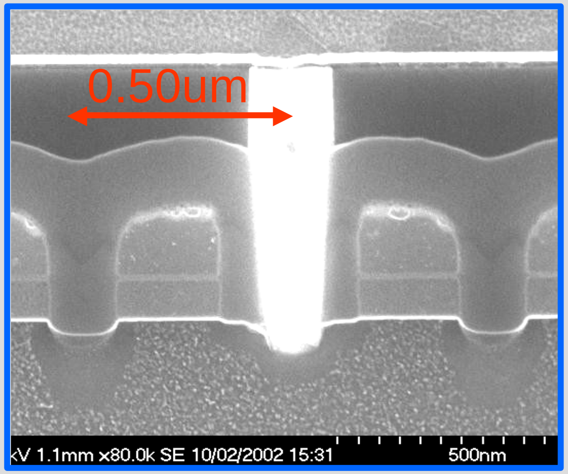
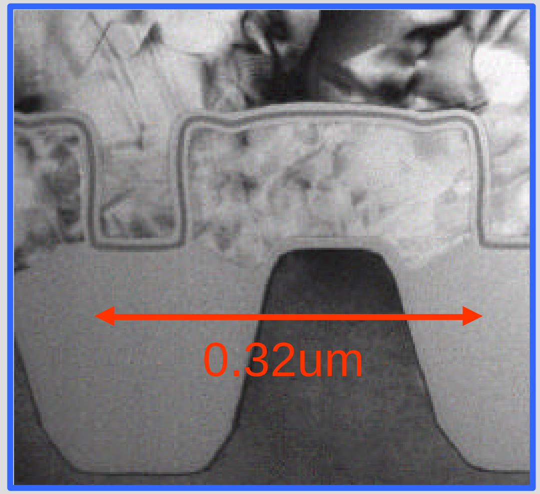
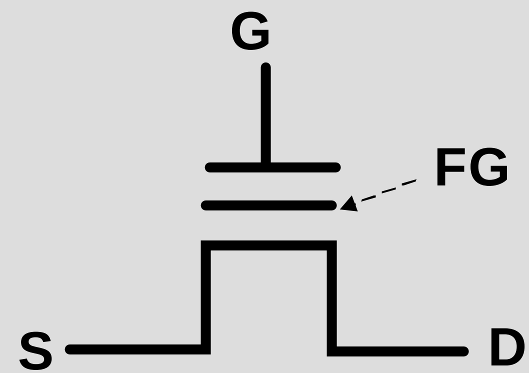
# NOR Stacked Gate Flash Cell



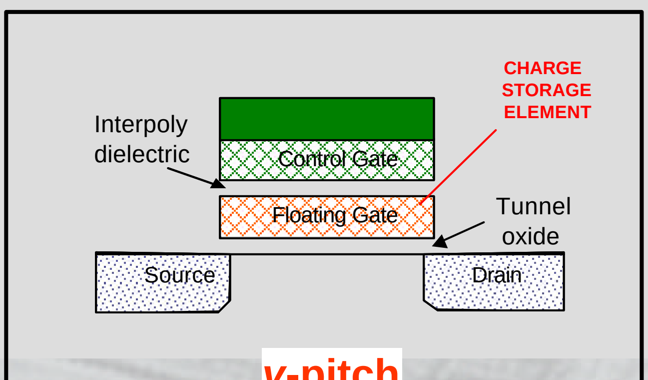



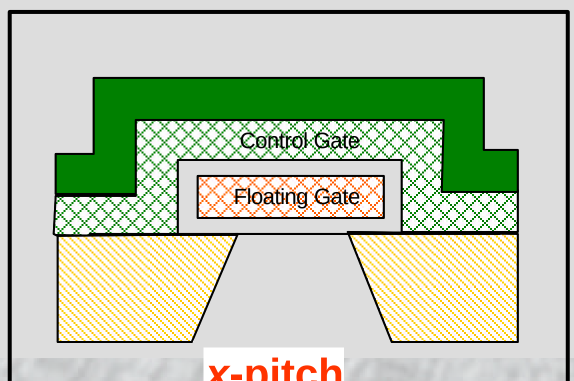

## NOR cell

- ➢Tunnel oxide th.: 9-10nm
- ➢ONO EOT: 14-15nm
- ➢Cell gate length: 200nm

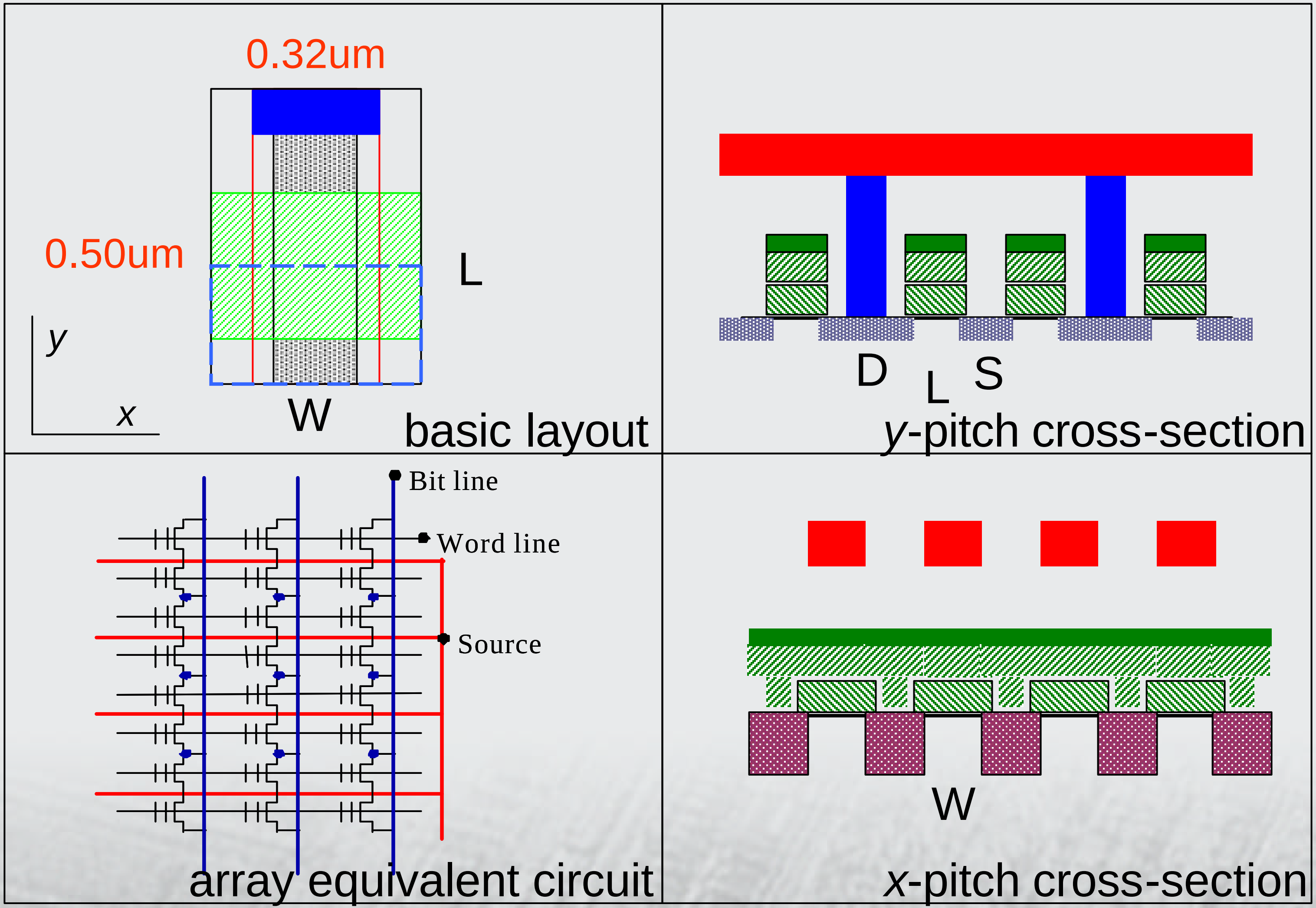



**130nm Technology Node**

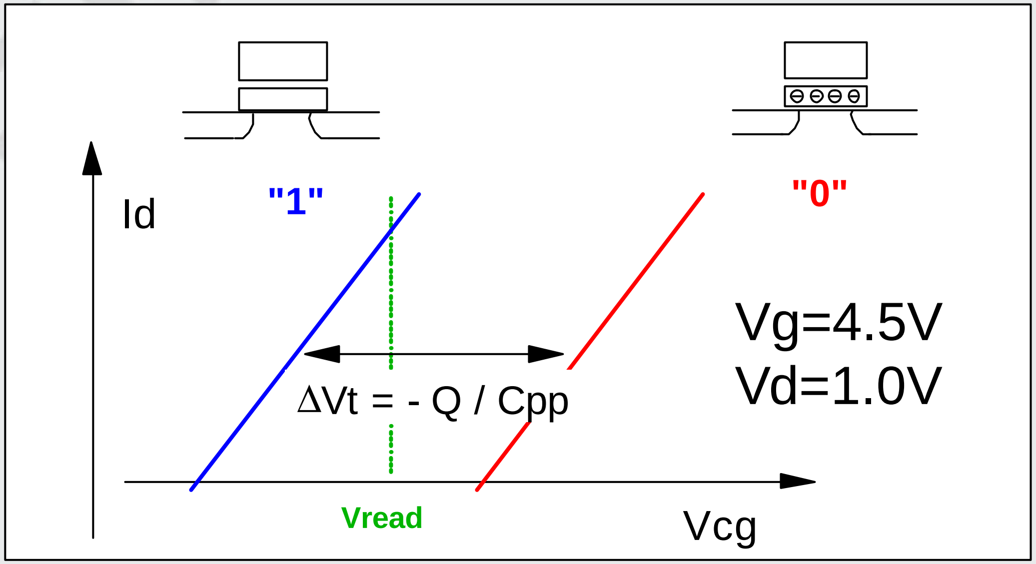


# NOR Flash Array

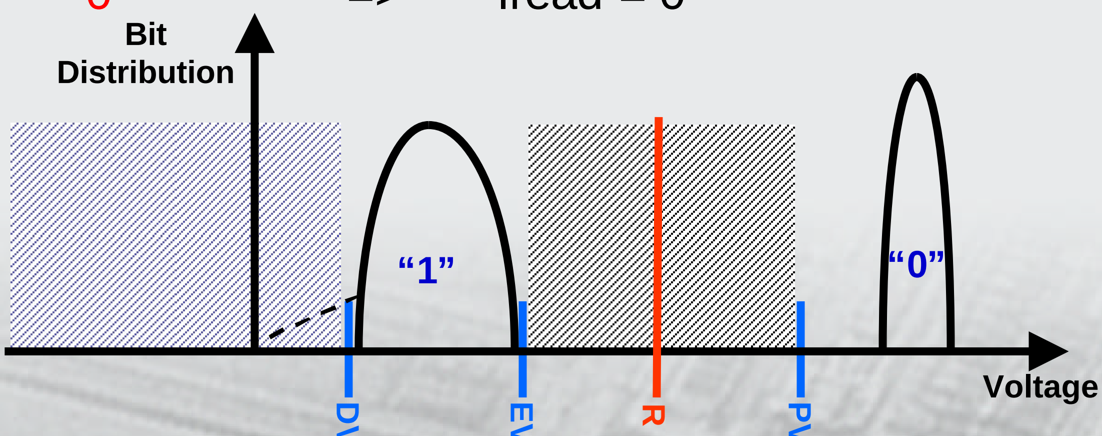


# Reading Operation, Distributions and Working Range

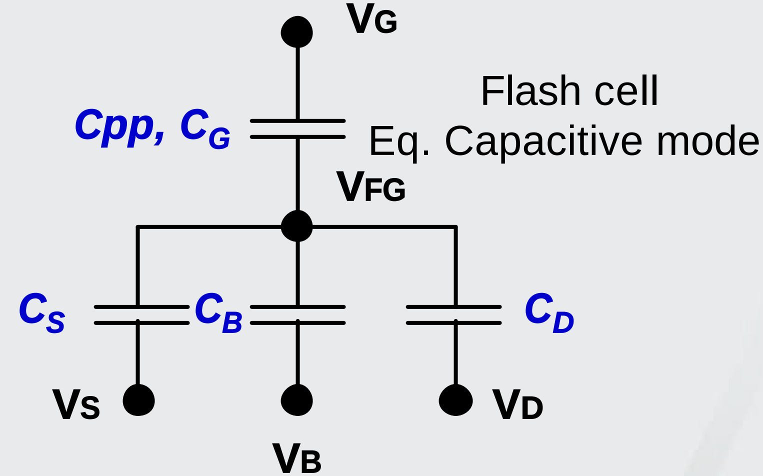



"1" => Iread > 0

"0" => Iread = 0




- **NOR Flash**
  - Read current: I=20-40uA
  - Random access: t=70-100ns
  - Serial throughput: 50MB/s




**Working range (V): $V_t$ > 1.5**

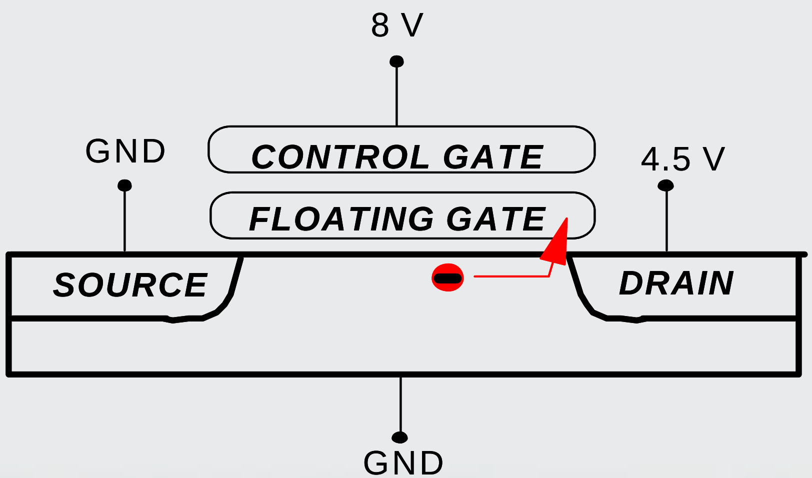
**$V_t$ shift (V): $DV_t>3$**

# NOR Flash Writing Mechanism

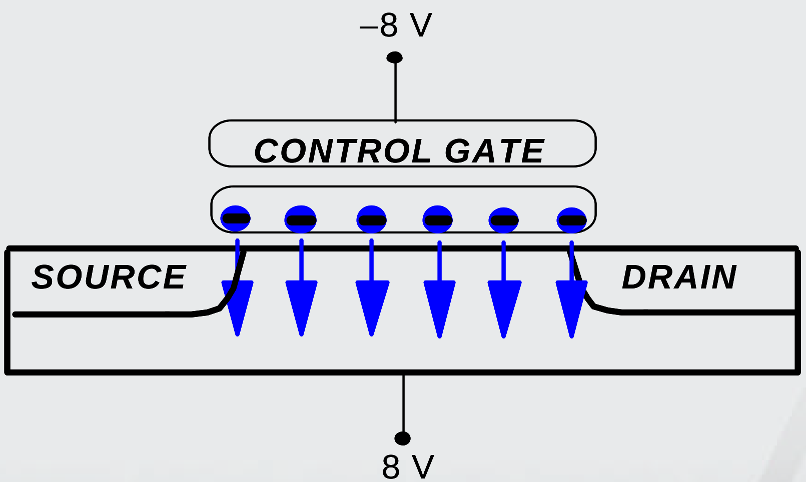
- **Programming**:
channel hot electron (CHE) injection in the floating gate at the drain side

- **Erasing**:
Fowler-Nordheim (FN) electron tunneling current through the tunnel oxide from the floating gate to the silicon surface

## CHE program



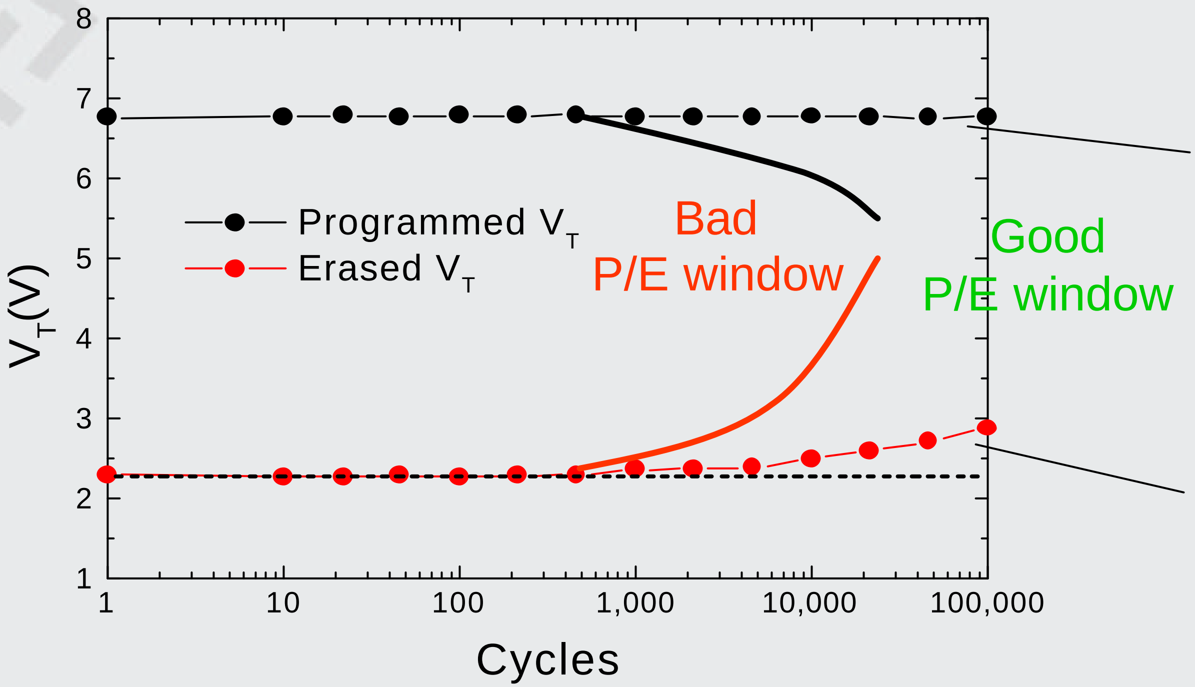

## Channel FN erase

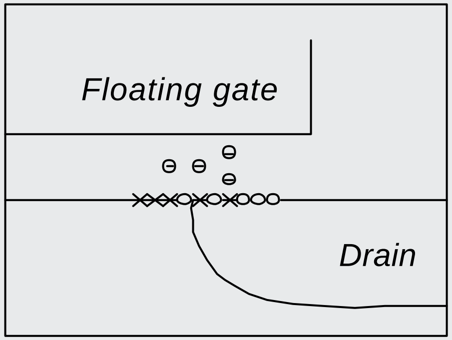


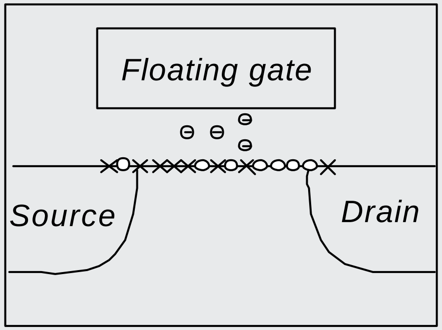

- Program is done at word level
- Program time ~5µs

- Erase is done at sector level (0.5 Mb)
- Erase time ~200ms

# Reliability basics: Flash Cell Endurance




- Interface states generation and charge trapping in the oxide occurs along the whole channel during Program/Erase
- Optimized cell design & operation are necessary to prevent Program/Erase window closure

# Reliability basics: data retention

**Flash Cell, 130nm Tech.**

X=0.32um T**ox**= 10nm

Y=0.50um T**ONO**= 145nm

**Cpp = 0.27 fF**

Q(0)= Cpp $\Delta$Vt =- 0.27 fF 4V = - 1fC = ~6700 $e^-$

**($1e^- \Leftrightarrow$ 0.6mV)**

Le's suppose that a memory cell losts its data if the threshold falls below 1V

Qleak= - 0.27 fQ = ~1600 $e^-$

The memory cell has to guarantee 10 years of data retention, then:

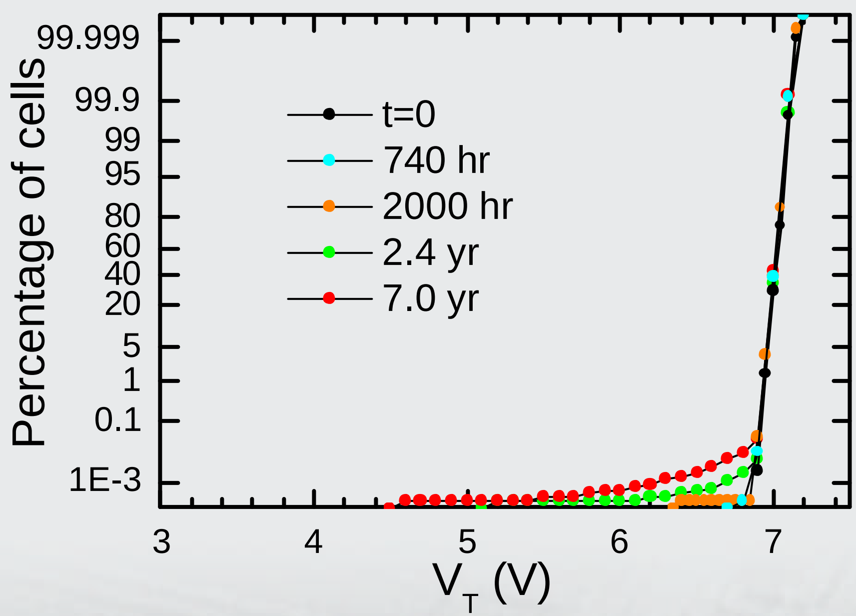
**I leak < $10^{-24}$ A ~ 3 $e^-$/week**

# Effect of Cycling on Data Retention

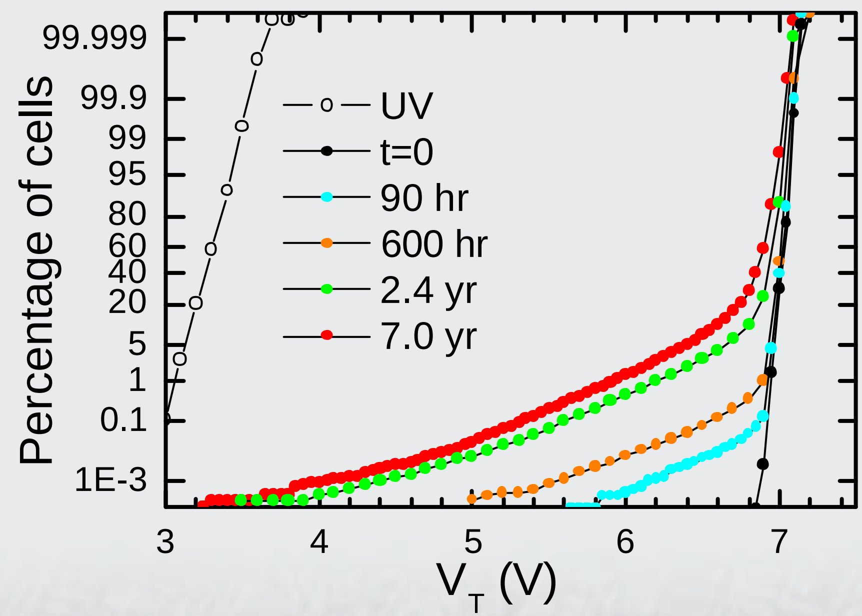
Data retention tests at room temperature – **Tox=8nm**

Cell $V_T$ distribution for 1Mb arrays

**10 cycles**



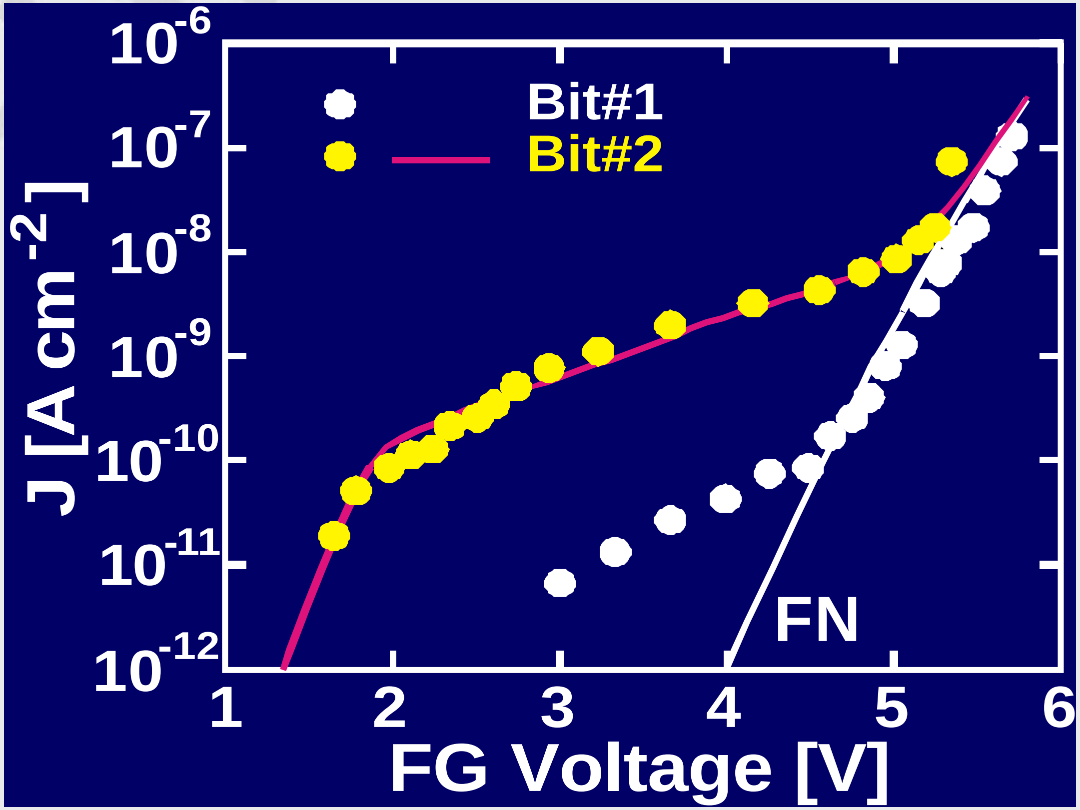

**$10^5$ cycles**

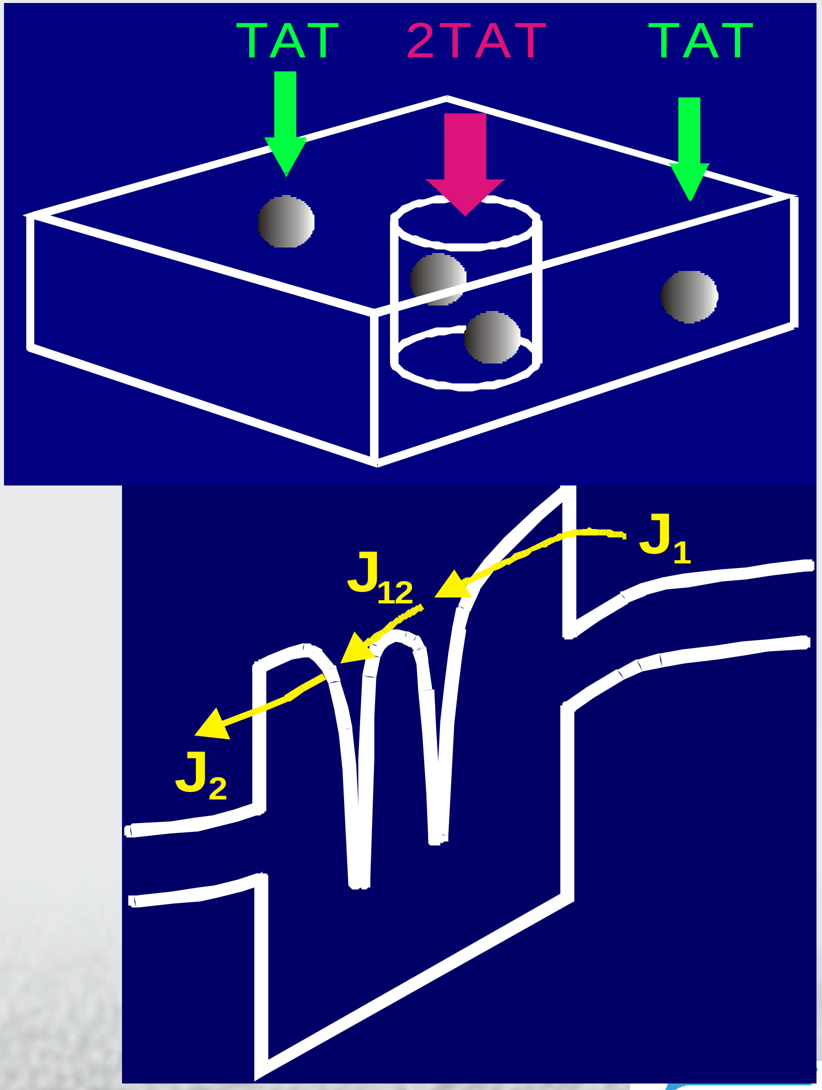



**SILC: Stress Induced Leakage Current**

**P. Cappelletti et al., IEDM 2004**

# Physical Model: Trap Assisted Tunneling




**Typ SILC current ~$10^{-20}$A**
**=> Used Tox>10nm**

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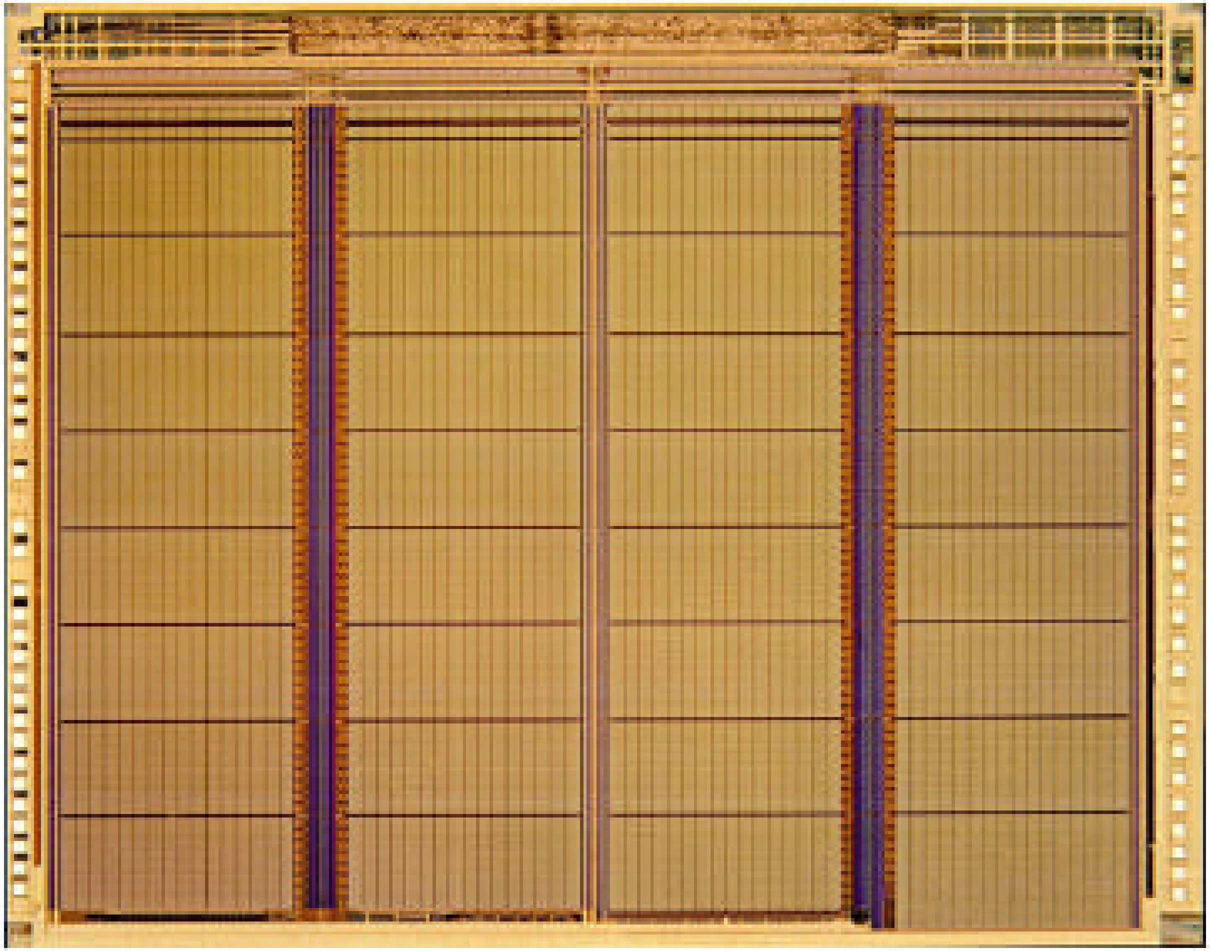
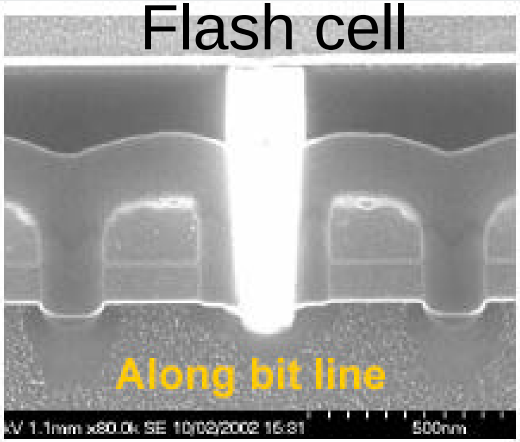
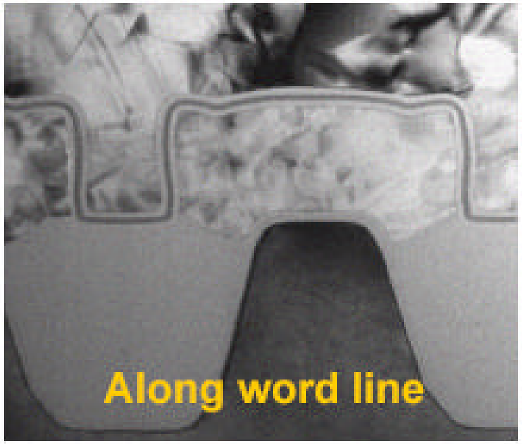
# CHIP OVERVIEW, NOR 130nm technology



128 Mb, 1.8V, Multibank

Flash cell




**Chip size 36mm$^2$**
**Array efficiency >60%**

# TID(1): X and g rays experiments results

## NOR FLASH

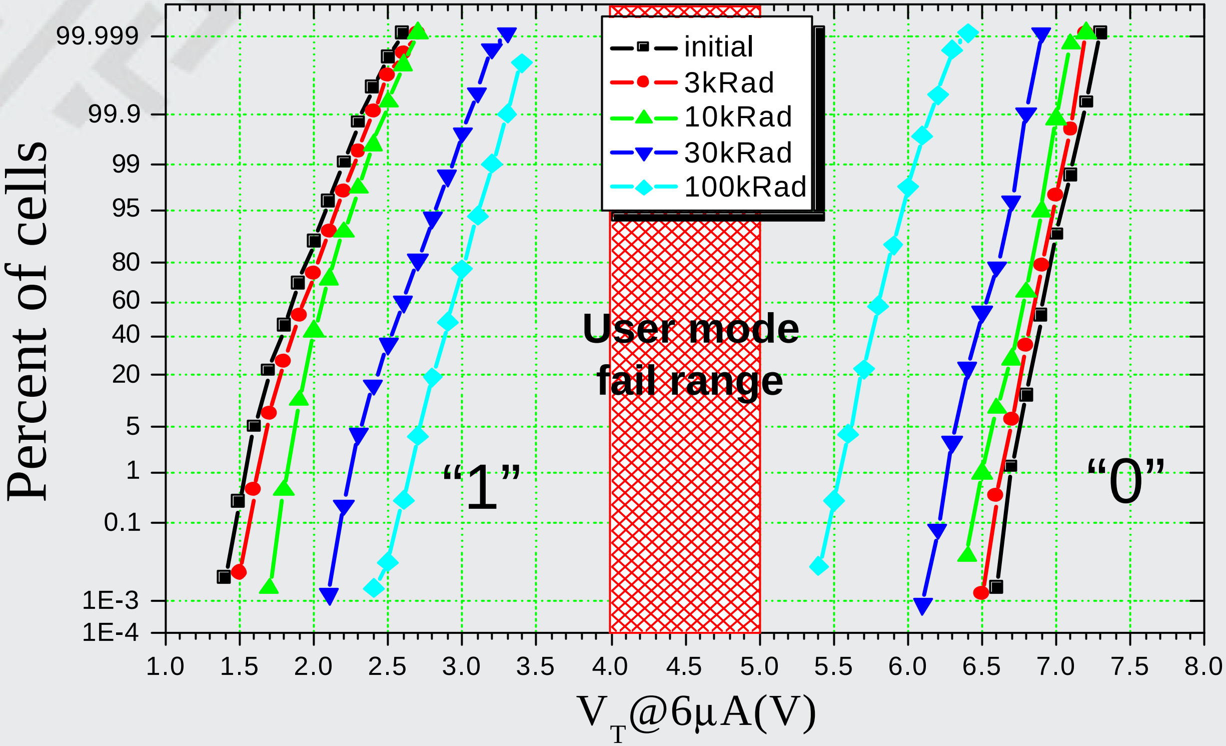
- Tests on 0.13-0.18um tech, 4-32Mbit parts, 1.8-3.0V Vdd, by using the X-$\gamma$ rays facility at INFN Laboratori Nazionali di Legnaro, Pd, I.

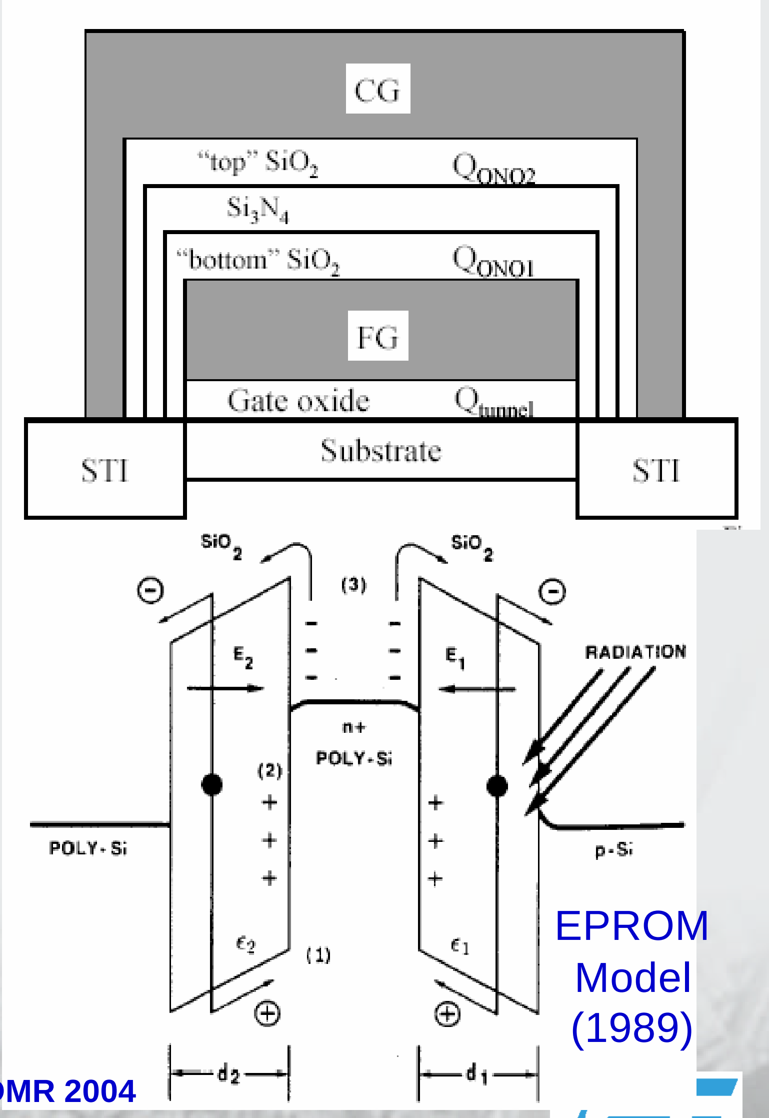
→ Full-spec parts after at least 100kRad*, unpowered
Full-spec parts after at least 10kRad*, biased

- As reference:
  - aeroportual X-ray inspection dose: ~5-50mRad
  - PCB X-ray inspection dose: <0.1kRad

* (10keV X-rays or $^{60}$Co $\gamma$-rays, Si dose)

# Flash cell Vt distribution before/after X-rays exposure



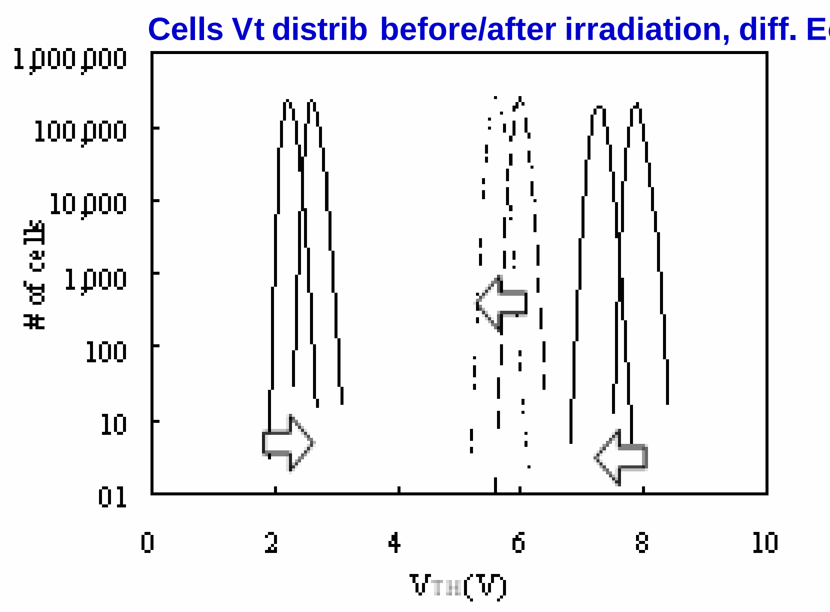

EPROM Model (1989)

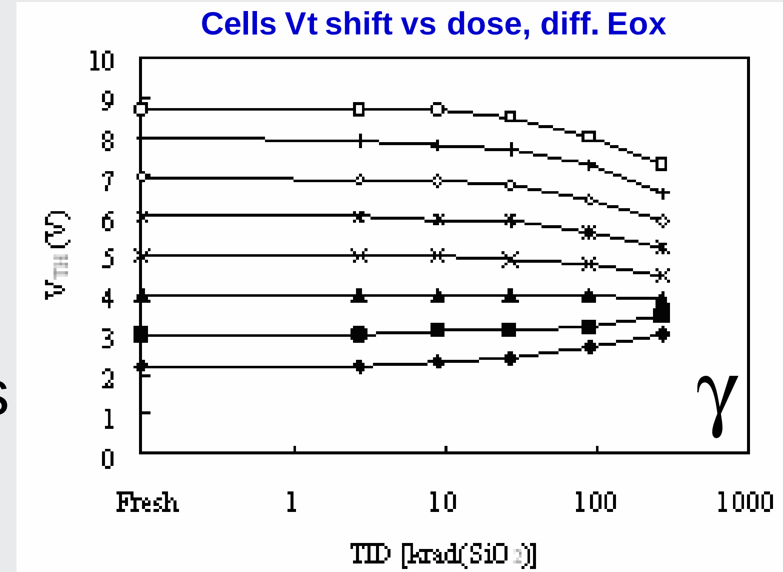
**Data from 0.5Mcell, diff. samples, 0.15um tech**

**Source: 10keV x-rays. $S_i$ dose**

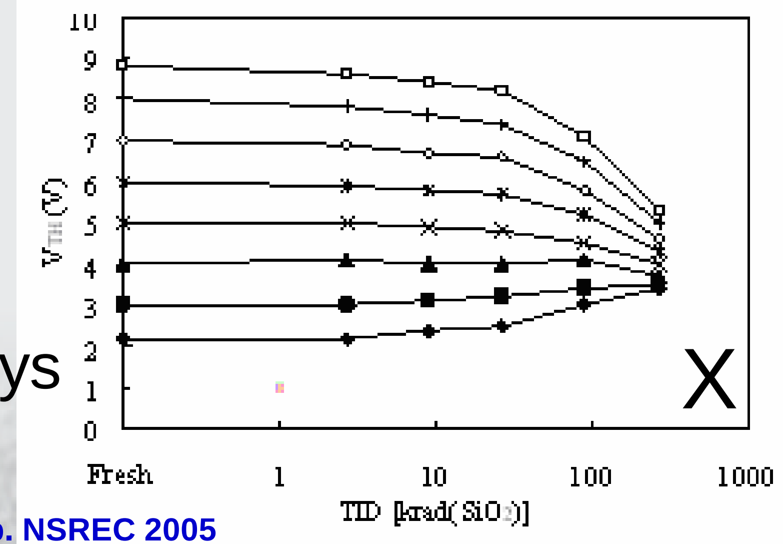
**Cellere et al., TDMR 2004**

# X and g rays effects



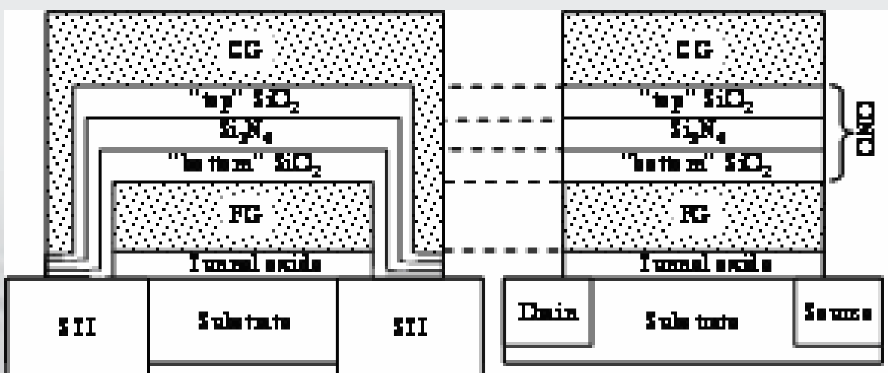




$^{60}$Co γ-rays




10keV X-rays

Test-chip NOR 0.13um tech.
Tox 10nm, Tono 15nm




Cellere et al., sub. NSREC 2005

# TID(2): Alpha particle experiments results

## NOR FLASH

- Accelerated tests performed on 0.15um tech, 32Mbit, 1.8V, unpowered parts by using the $^{241}Am$ alpha source in ST Crolles, F. (JEDEC standard JESD89)

The alpha particles effects are negligible.

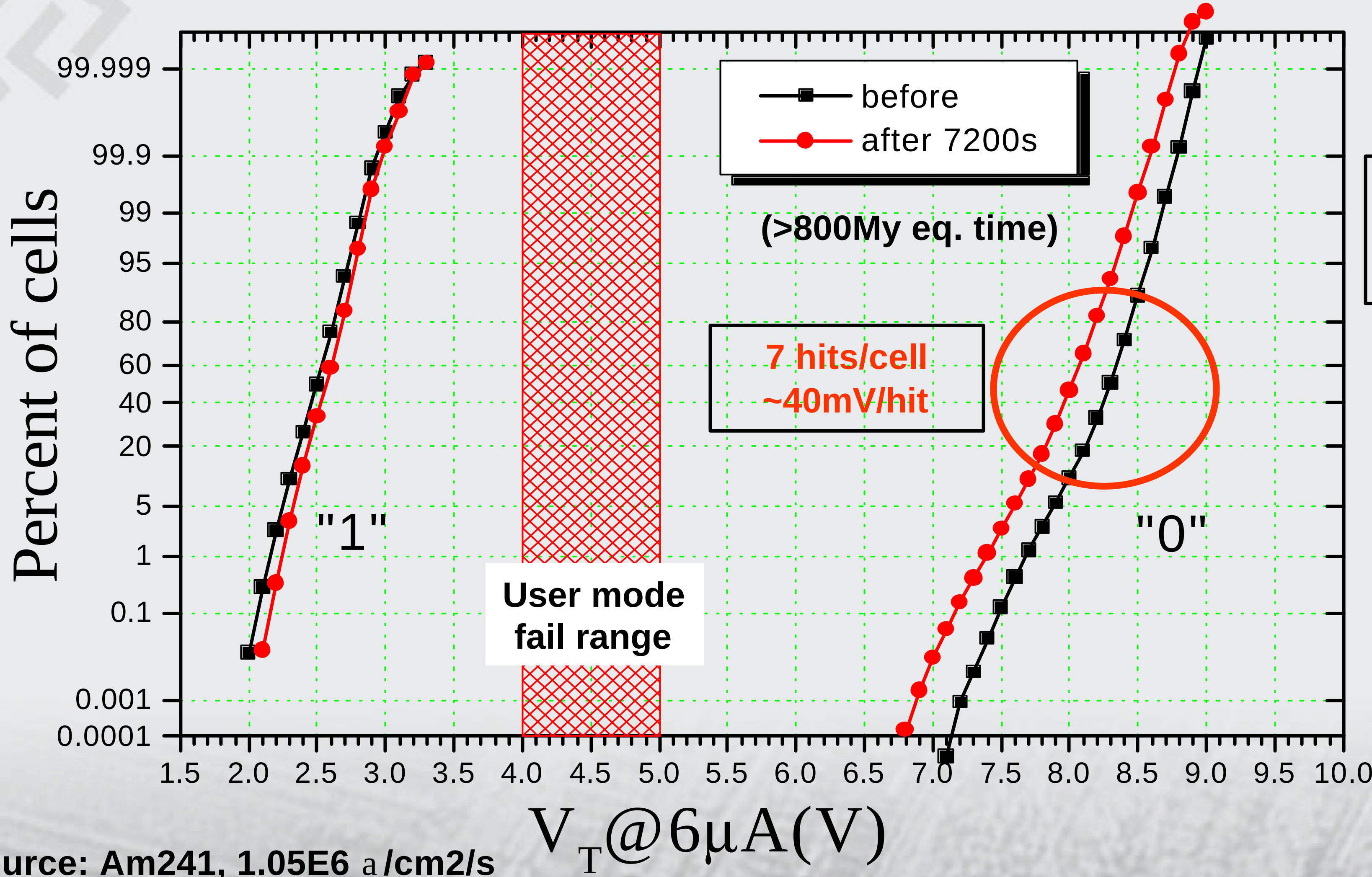
No fails in read pattern after **more than 800 million years** of equivalent time in std environment*

- Expected array failure rate*: < 10E-6 FIT/Mbit, unpowered

*with total flux from the package and process materials equal to 0.001 alpha/cm$^2$/h

- 1 FIT= 1 Failure In Time= 1 fail/10+9 hour

# Flash cell Vt distribution before/after alpha particle exposure




Data from 8Mcell, 0.15um tech

Source: Am241, 1.05E6 a /cm2/s

# TID(3): neutron experiments results

## NOR FLASH

- Accelerated tests performed on 0.13-0.18um tech, 4-32Mbit, 1.8-3.0V, unpowered parts by using the Los Alamos National Labs. neutron source (JEDEC standard JESD89)

The neutrons effects are negligible.

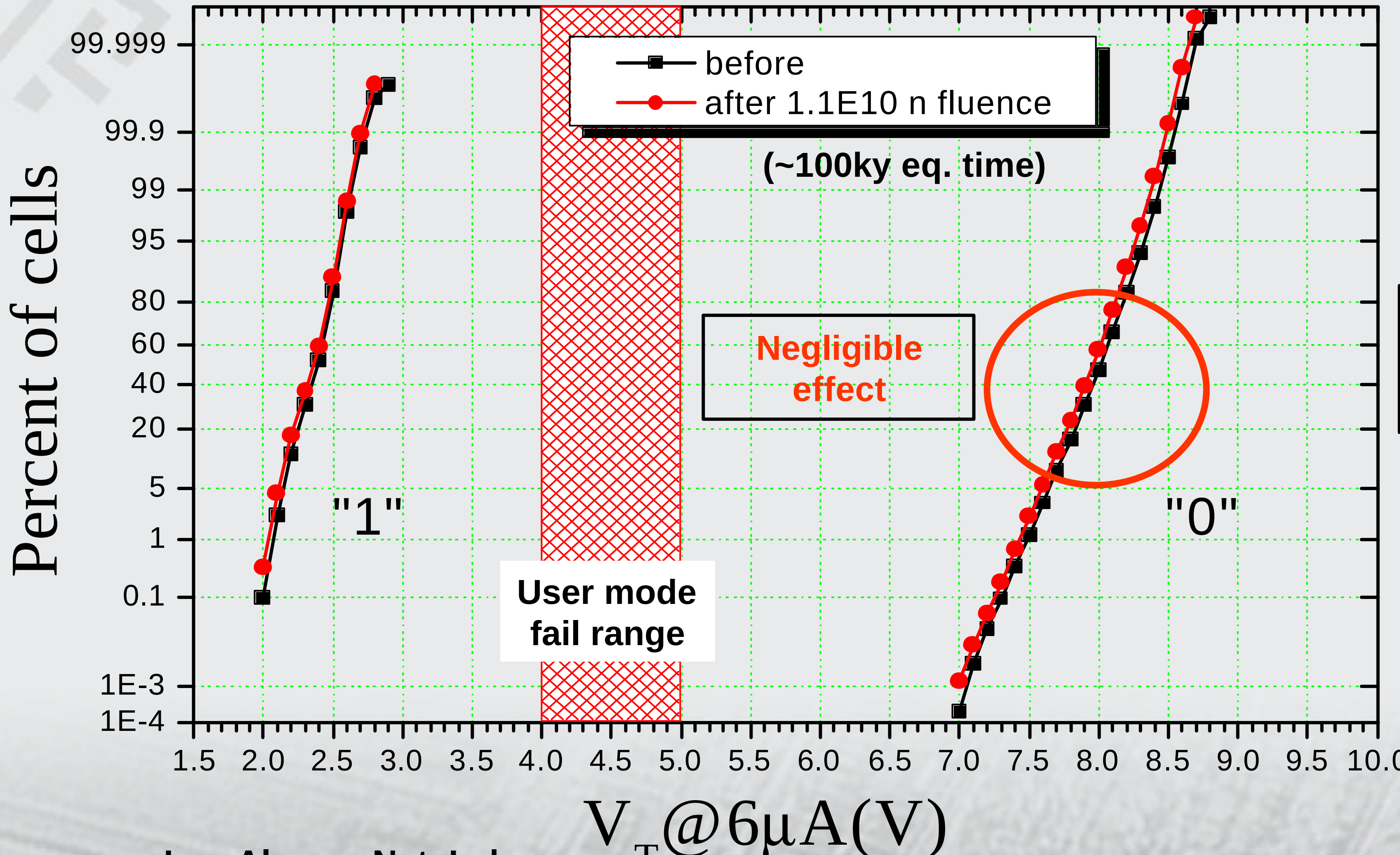
No fails in read pattern after **more than 100.000 years** of equivalent time at ground level*, unpowered

- Expected array failure rate*: << 0.04 FIT/Mbit, unpowered

*with total flux at ground level equal to 14 n/cm2/h (NY sea level)

- 1 FIT= 1 Failure In Time= 1 fail/10+9 hour

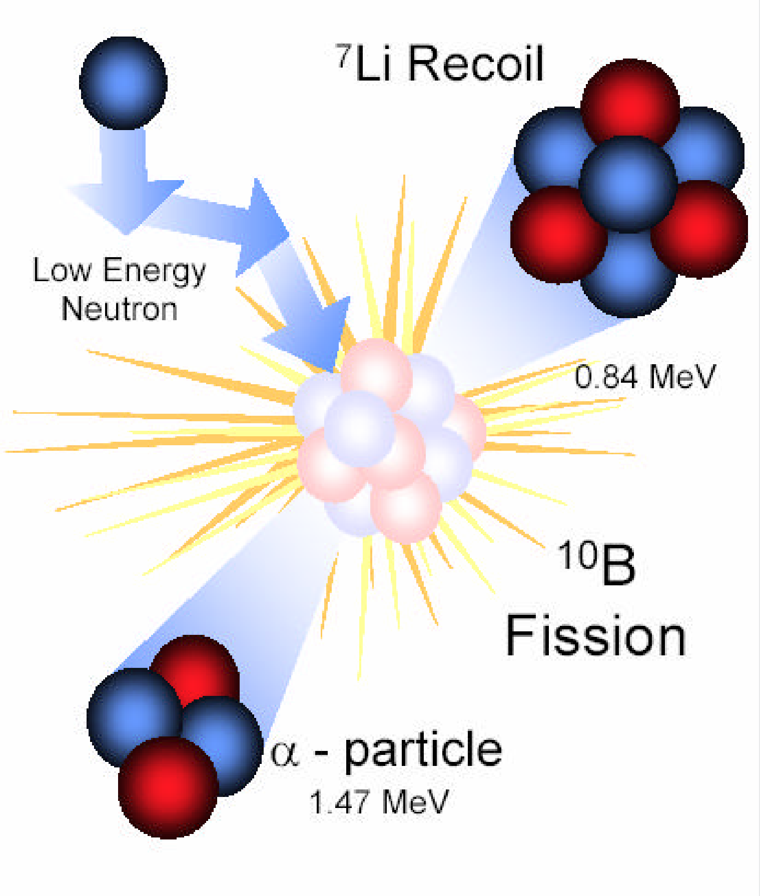
# Flash cell Vt distribution before/after neutron exposure

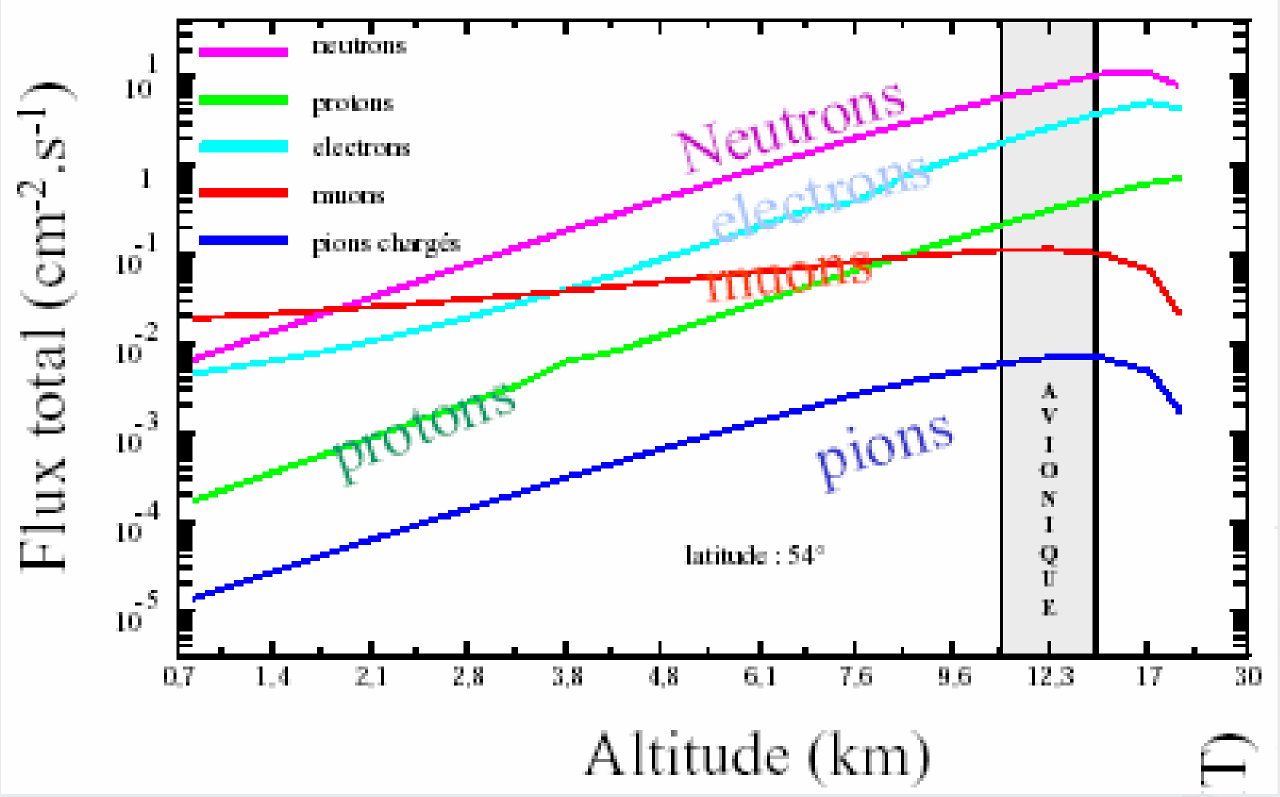



Data from 1Mcell, 0.15um tech

**n source: Los Alamos Nat. Labs**

# More about neutrons




Main neutrons effect:
$^{10}B$ fission
=> Again, alpha case

The neutron flux increases by 3 decade from 0 to 12km (avionic quota). Also at avionic altitude the neutrons effects are still expected to be negligible (previous data became 100 year equivalent)

# SEE: heavy ions experiments results

## NOR FLASH

- Tests performed on 0.09-0.18um tech, 4-32Mbit, 1.8-3.0V, unpowered parts by using the SIRAD irradiation facility at LNL-INFN Laboratori Nazionali di Legnaro, Pd, I.

The heavy ions effects **are not** negligible.

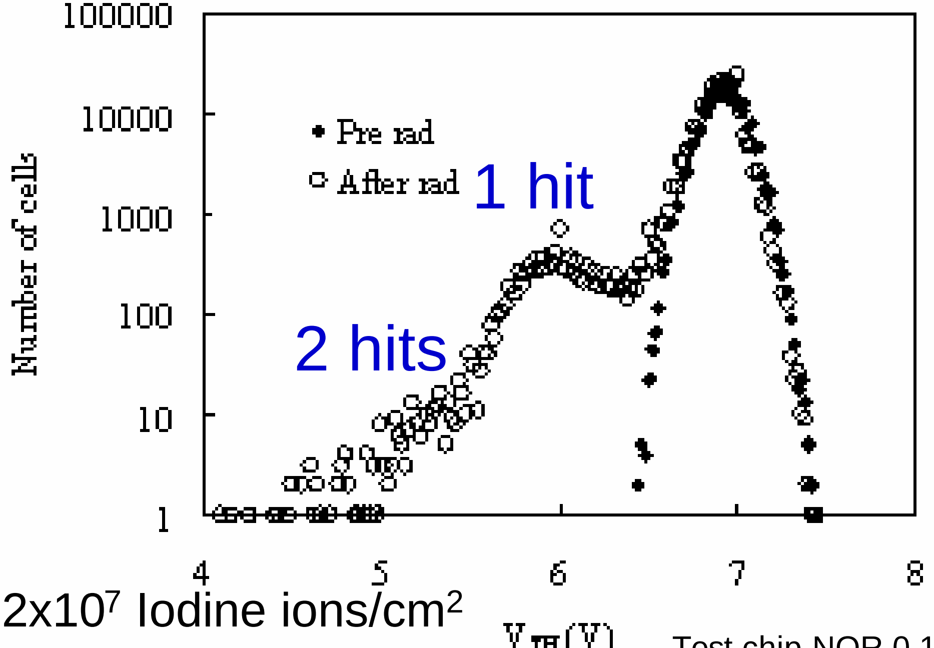
A fail in read pattern may appears just after a single, high LET, hit!

However, the flux of high LET heavy ions at ground level **is** negligible, thus this is an issue only for aero-spatial applications

# Heavy Ions effects (1)

| Ion | E (MeV) | LET in $SiO_2$ ($MeVcm^2/mg$) |
|---|---|---|
| C | 87.15 | 1.68 |
| F | 128.8 | 2.29 |
| Cl | 177.8 | 13.23 |
| Ti | 203.2 | 20.93 |
| Ni | 210 | 28.14 |
| Br | 250.3 | 40.88 |
| Ag | 266.2 | 57.34 |
| I | 286.6 | 64.15 |

Cell Vt distrib. Before/after irradiation

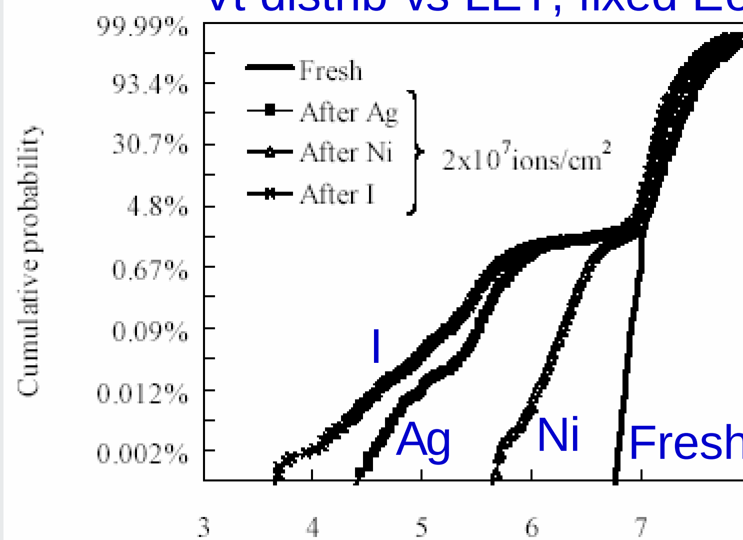



2x10[7] Iodine ions/cm[2]

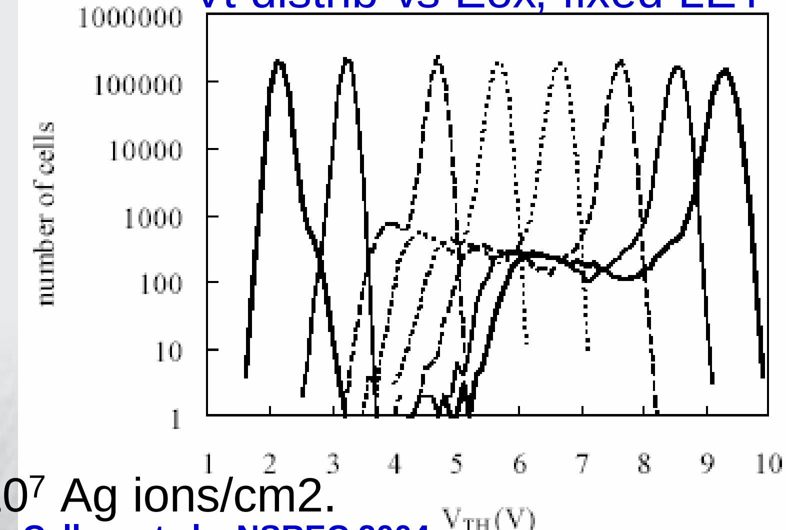
**Cellere et al., TDMR 2004**

Test-chip NOR 0.13um tech.

Vt distrib vs LET, fixed Eox



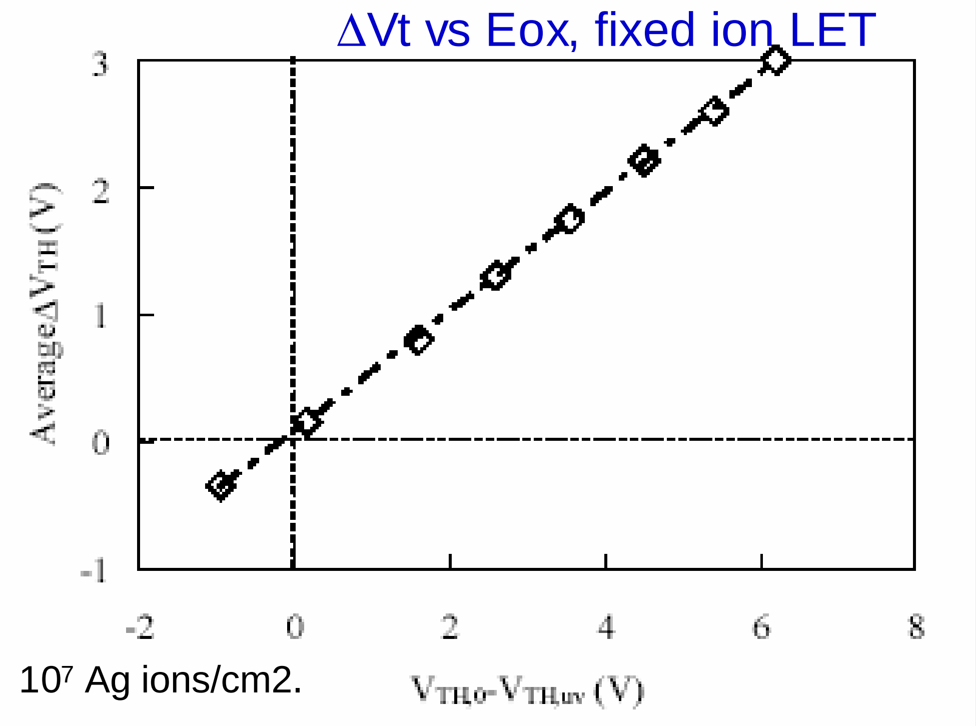

Vt distrib vs Eox, fixed LET

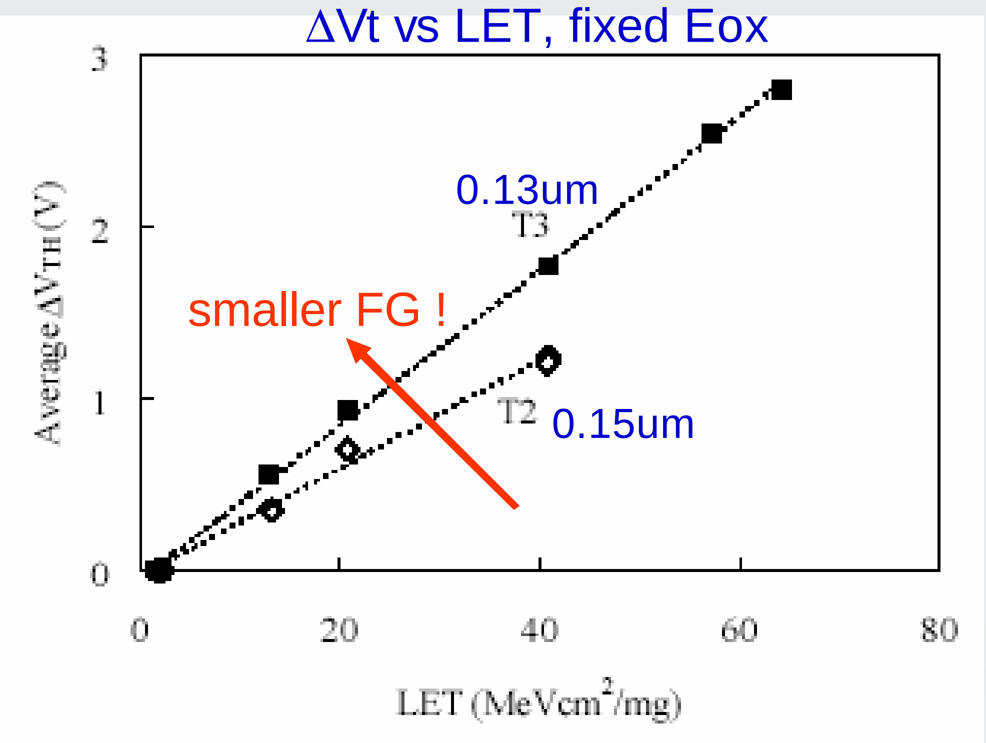



10[7] Ag ions/cm2.

**Cellere et al., NSREC 2004**

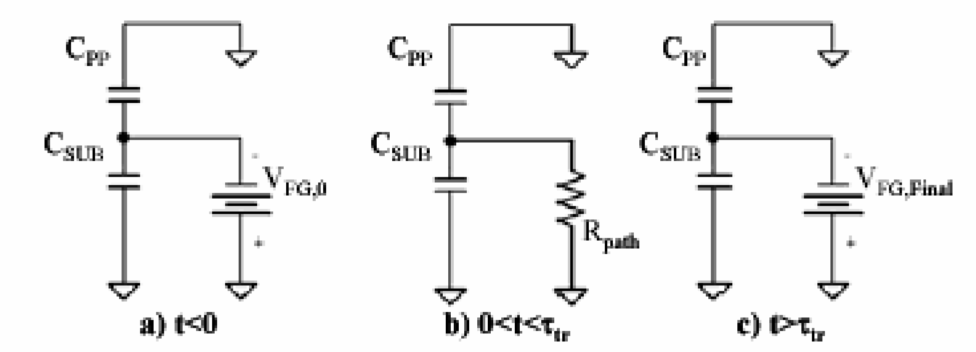
# Heavy Ions effects (2)




The proposed model:
the impinging ion set-on a temporary conduction path through the tunnel oxide

**Cellere et al., NSREC 2004**



# Heavy Ions post-irradiation effects (1)

## Room temperature retention trial on heavy ions irradiated samples

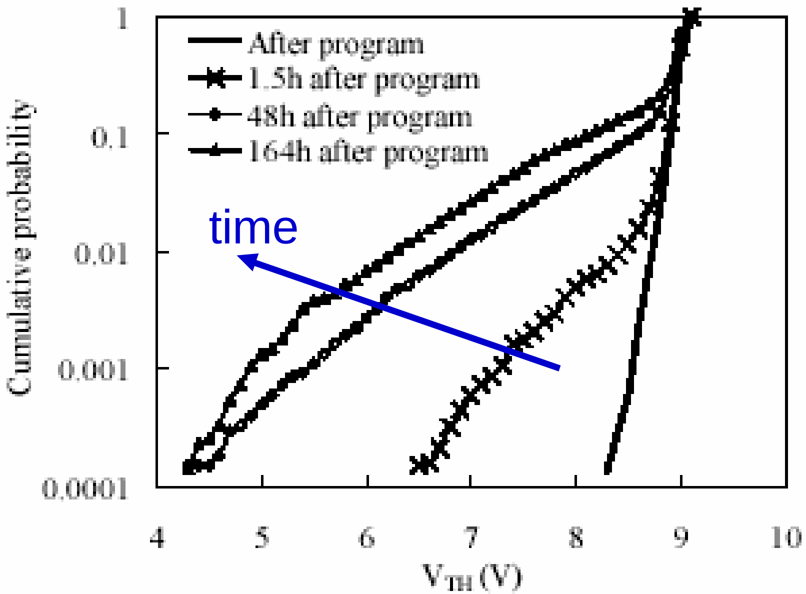



Fig.1. Cumulative distribution of $V_{TH}$ for cells hit by Iodine ions, after being re-programmed.

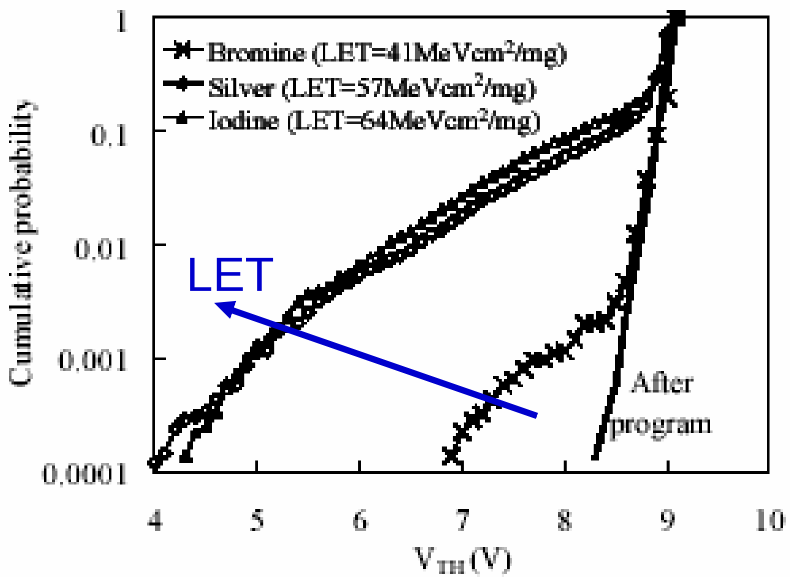
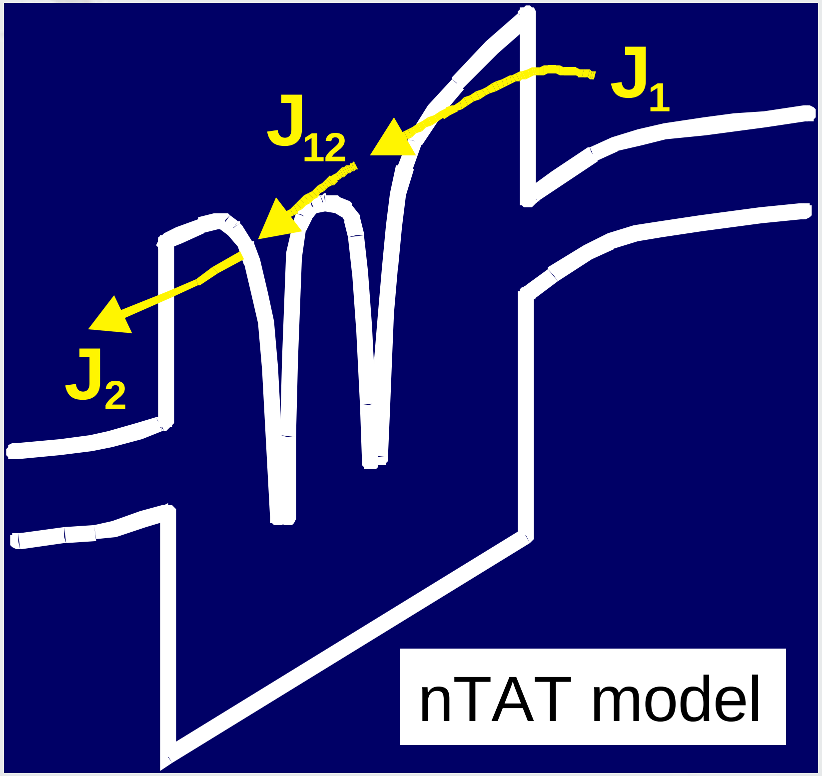



Fig.2. Cumulative probability of $V_{TH}$ for cells being hit by different ions, immediately after program, and 164 hours after program. $E_{OX}$=3MV/cm during irradiation.

## RILC: Radiation Induced Leakage Current

Cellere et al., sub. NSREC 2005

# Heavy Ions post-irradiation effects (2)



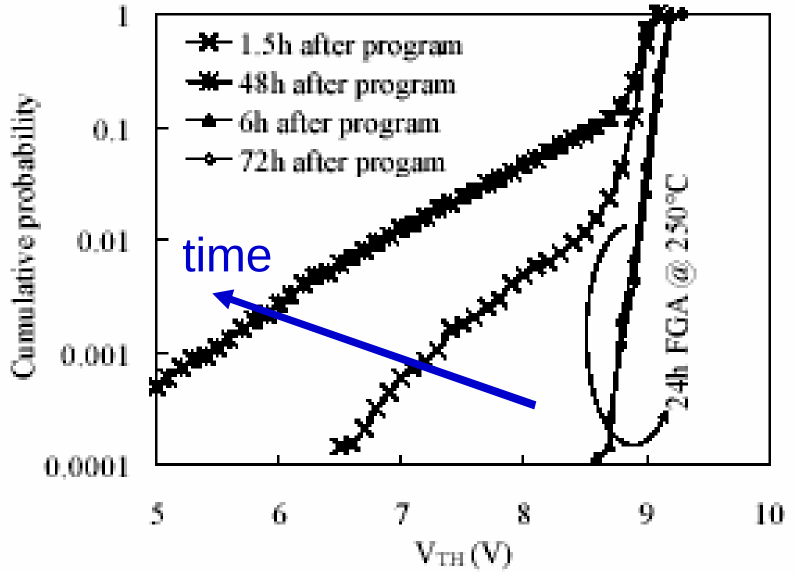




Fig.4. Cumulative probability of $V_{TH}$ for two devices: the first was programmed after being irradiated, the second was at first subjected to Forming Gas Anneal, then programmed.

Cellere et al., sub. NSREC 2005

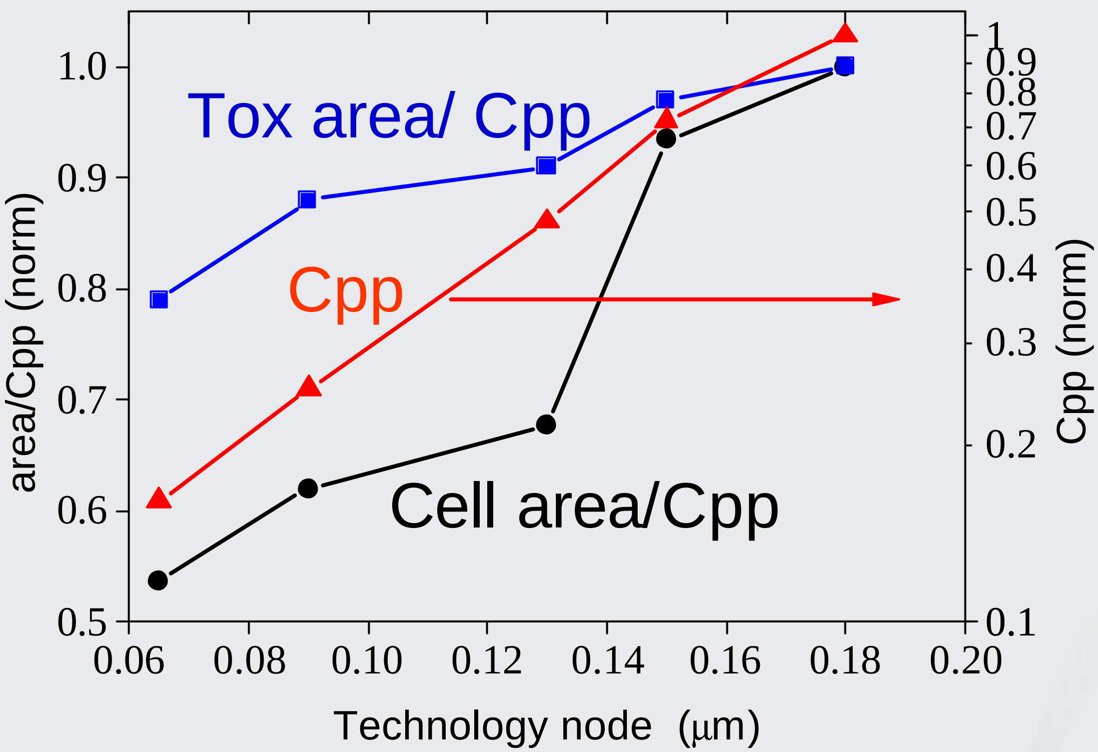
## RILC from Trap Assisted Tunneling

# Technology scaling effects

As technology scales down,
Tox thickness ~ const (or thinner)
Tono thickness ~ const (or thinner)
=> Interactions ~ const (or lower)

At fixed radiation fluency,
#event/cell ~ cell_area
Impact effect, ΔVt ~ 1/Cpp
=> #event * ΔVt ~ area/Cpp

TID ~ area/Cpp
SEE ~ 1/Cpp




At fixed radiation fluency,
TID phenomena (X, γ, α, n) don't worse with technology scaling
SEE phenomena from high LET heavy ions worse with technology scaling

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# Summary

- The current semiconductor NVM mainstream is based on the Flash technology and it is expected that NOR and NAND Flash will dominate NVM production for the rest of this decade.

- Accelerated tests has been performed on 0.09-0.18um tech, 4-32Mbit, 1.8-3.0V parts by using the Los Alamos National Labs. neutron source, USA, a $^{241}$Am alpha source in ST Crolles, F, (JEDEC standard JESD89), the X-$\gamma$ rays and the SIRAD irradiation facility at LNL-INFN Laboratori Nazionali di Legnaro, Pd, I.

- Focusing on Flash cell data retention, it is measured an absolutely negligible effect of alpha and neutron radiations, while in X and $\gamma$ rays case the effects are still negligible after at least a 100kRad dose.

- Flash memory is extremely robust against irradiations. While Flash memory does possess some sensitivity to cosmic irradiation, other circuits are many orders of magnitude more vulnerable, thus Flash will not be the reliability-limiting factor for a typical system.

# References (1)


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