RADIATION HARDNESS OF MEMRISTIVE SYSTEMS

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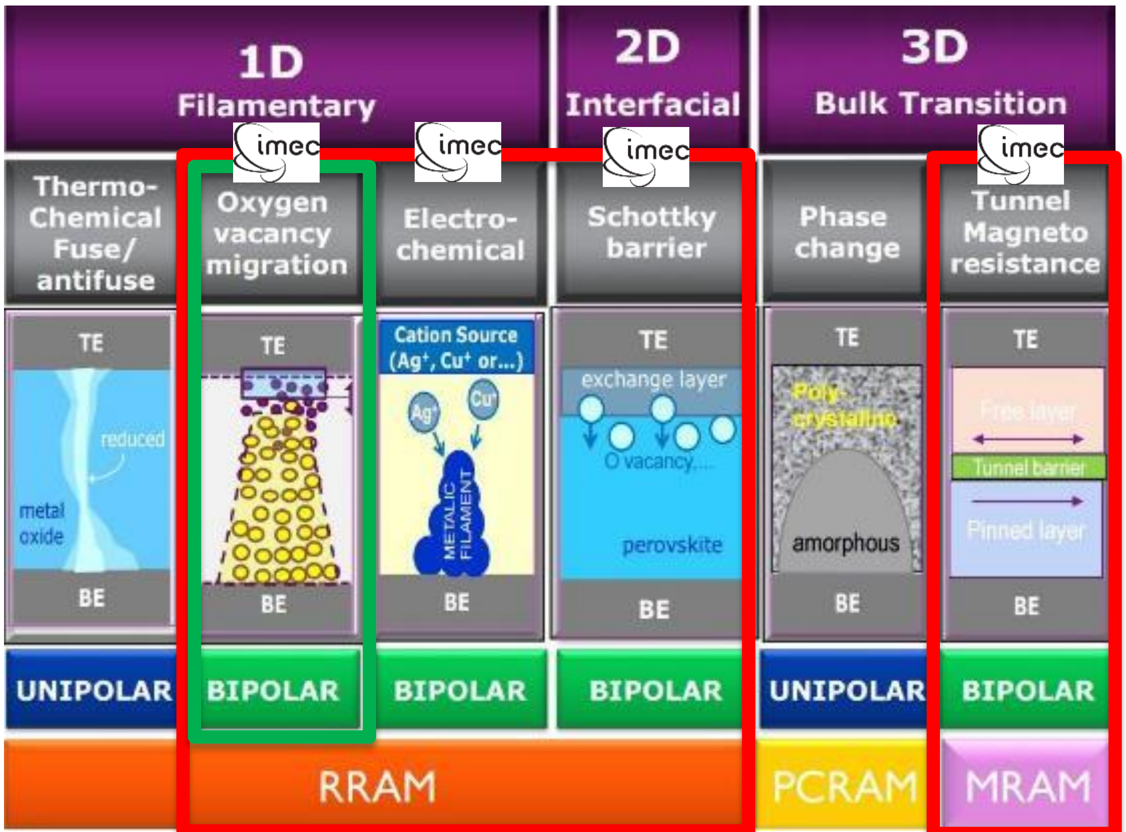
ON BEHALF OF IMEC RRAM TEAM AND VU ISDE TEAM

Workshop on Memristive systems for Space applications
ESTEC - 30/04/2015

OUTLINE

- Introduction
- RRAM for space application
- Reliability: SEU
- Reliability: TID/DD
- Conclusion

IMEC EMERGING MEMORY ACTIVITY

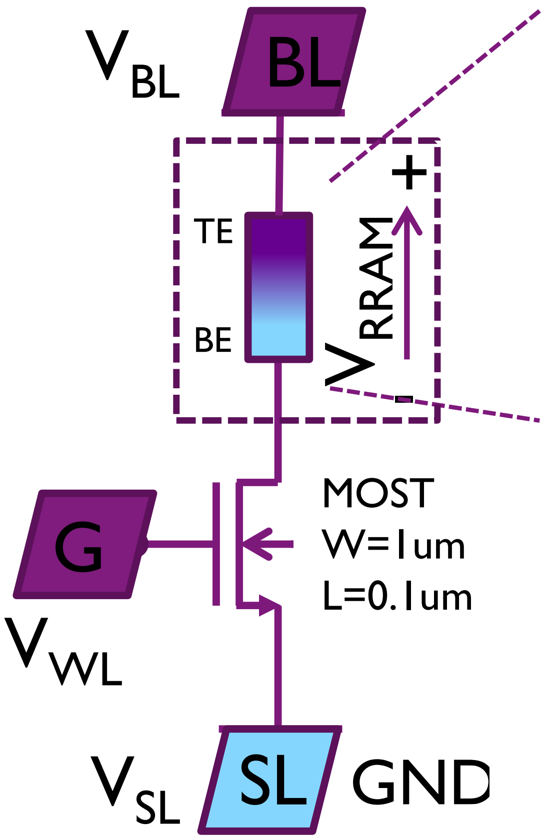


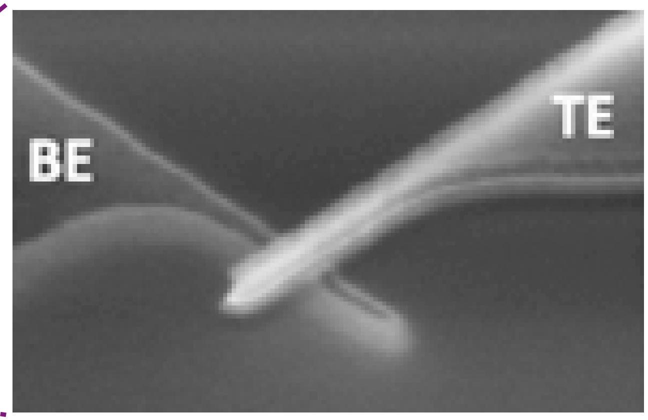
We will focus on Oxide based RRAM (OXRAM)

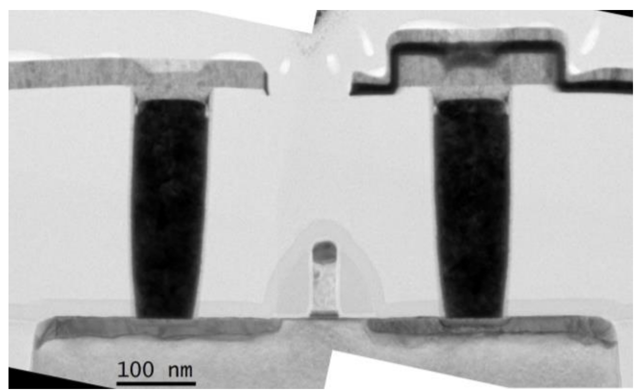
Vacancy migration switching mechanism

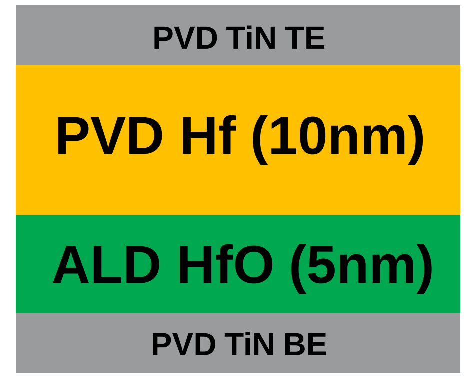
- Several flavors of resistive memory technology at research stage in imec

OXRAM 1T1R CELL EXPERIMENTAL SAMPLE

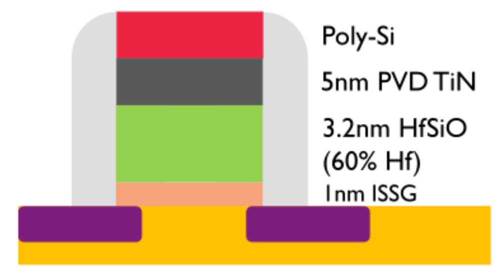






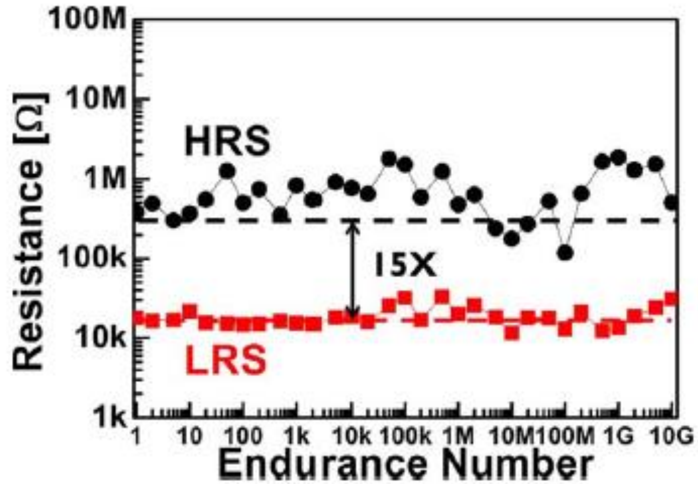


Crossbar device
RME 40x40nm



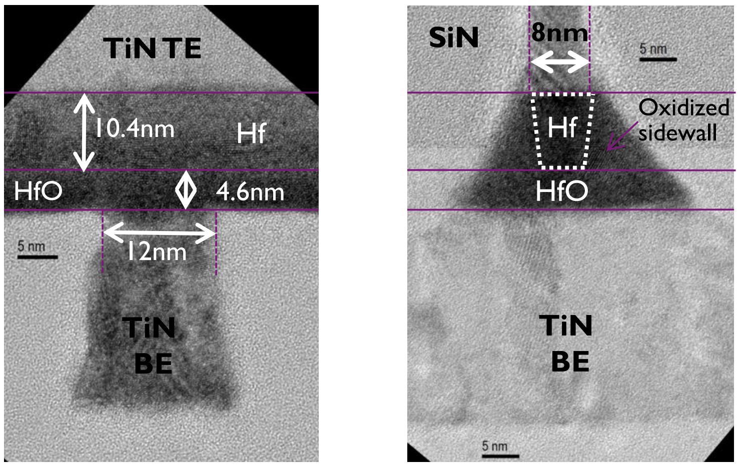
Unhardened 65nm FEOL node

RRAM FEATURES



High Endurance

Chen et al., TED 59(12) (2012)

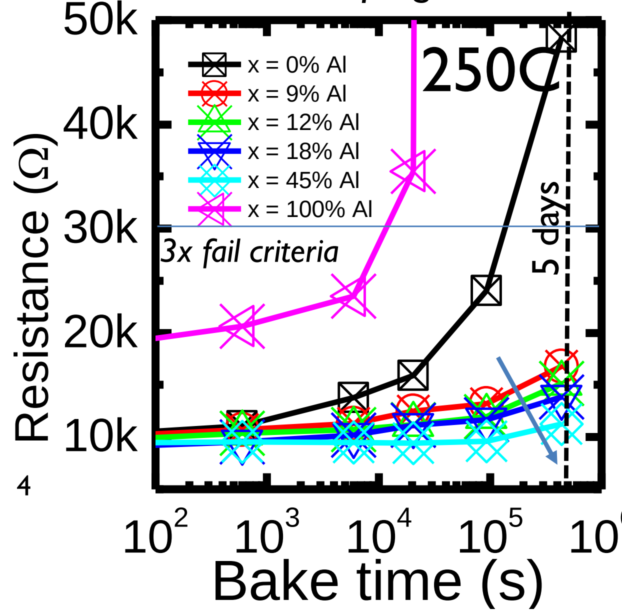


Fully functional sub 10nm device

Fantini et al., VLSI 2014

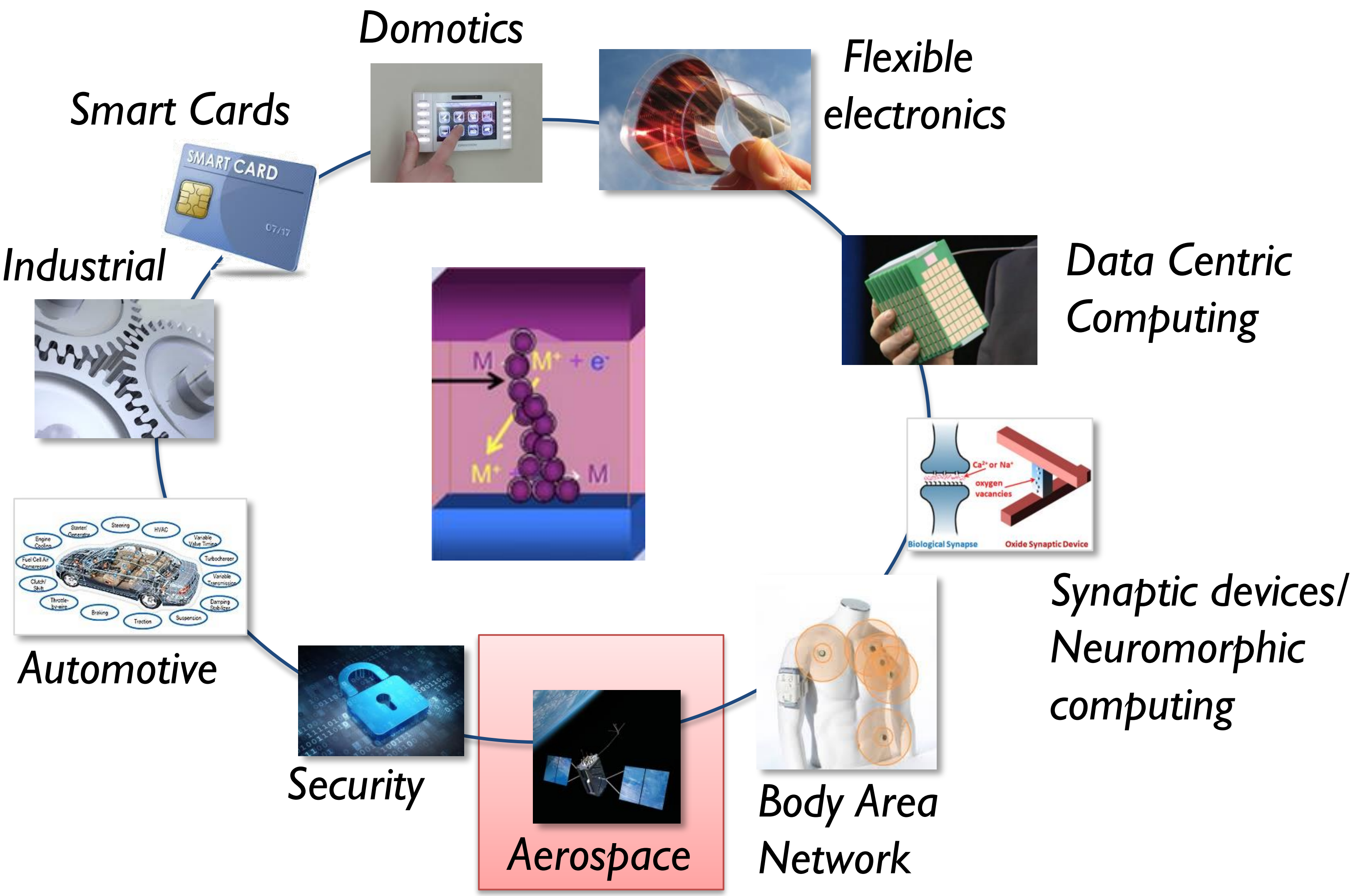
Good Retention

Fantini et al., IMW 2014



Many interesting results…
For which applications ?

POTENTIAL RRAM APPLICATION



RESEARCH GOALS

Many research work on radiation robustness of resistive memory element (filament) alone

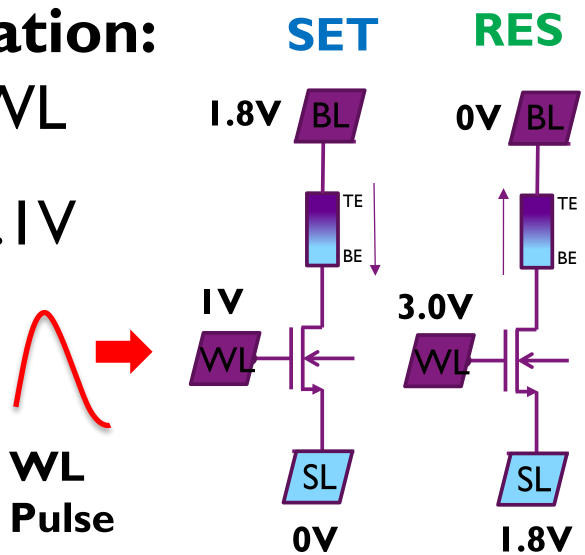
However very few research on the robustness of the basic 1T1R cell structure...

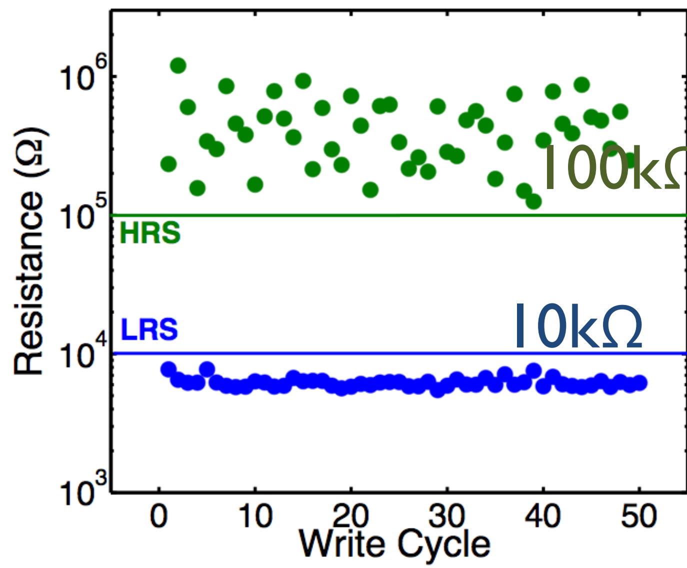
- For reliable assessment on space application is needed to evaluate 1T – 1R interaction
- Impact of SEU, TID, DD

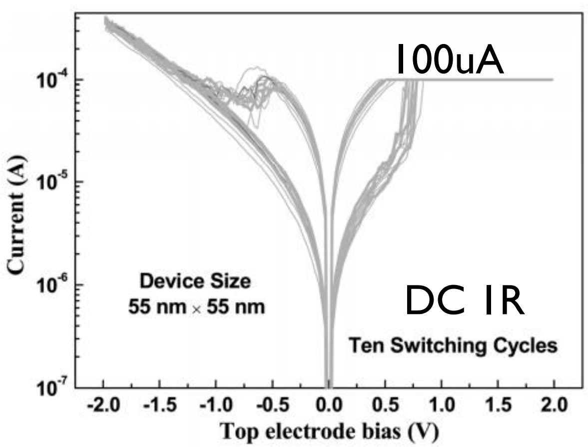
BASICS OF RRAM TESTING

Pulsed operation:
5ns Pulse on WL

DC read @ 0.1V after pulse





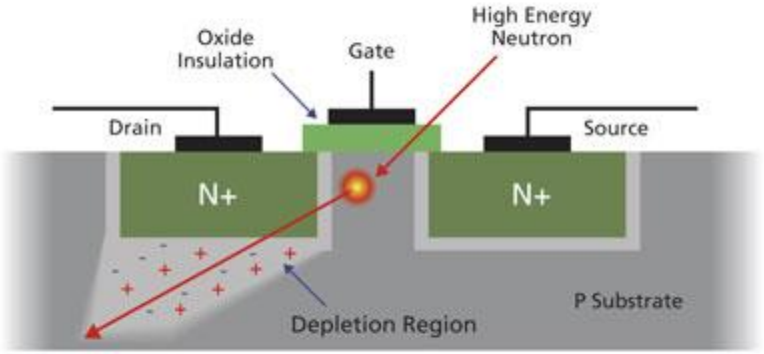


- Cell functionality assessed by DC and pulse before irradiation
- Two logic state can be defined

Single Event Effects

RELIABILITY ISSUE

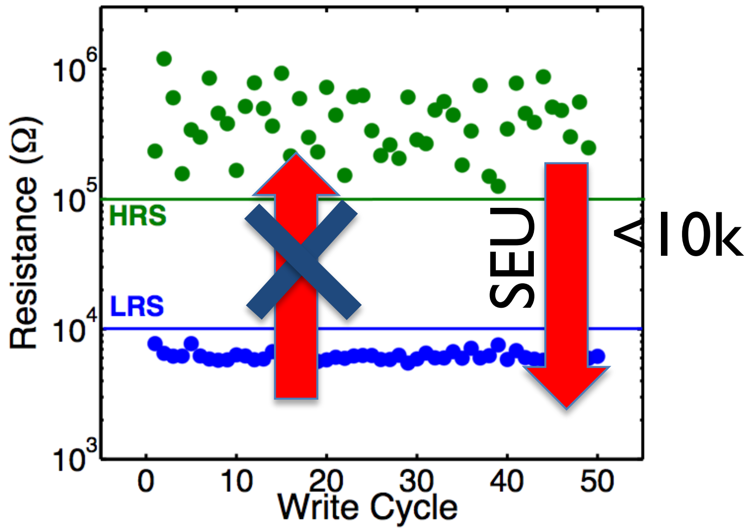
- Single Event Upsets (SEUs)
  - mobile generated charge collected at a sensitive circuit node that causes the node to change states

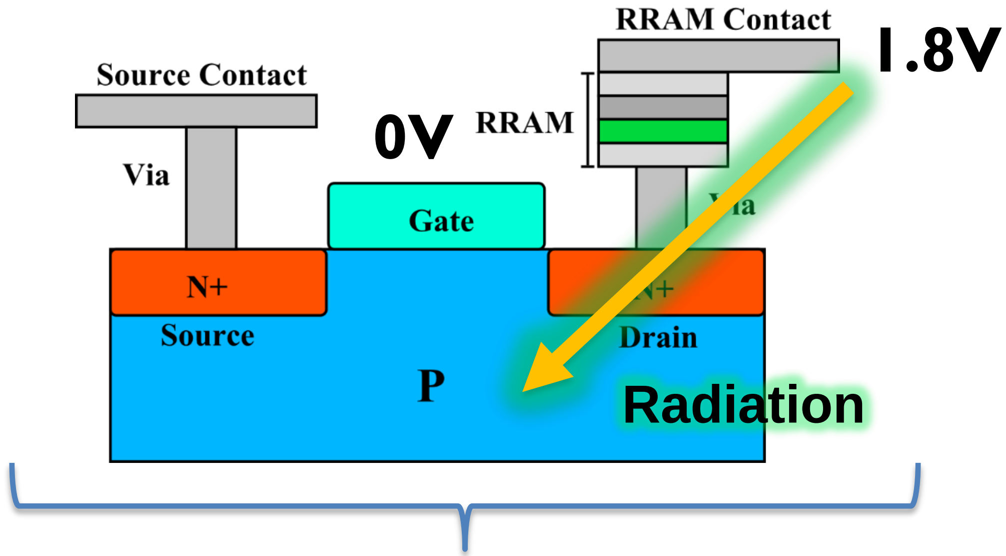


Martin Mason, EE Times, May 2006

SEU IN RRAM

SEU Criteria: HRS < 10kΩ

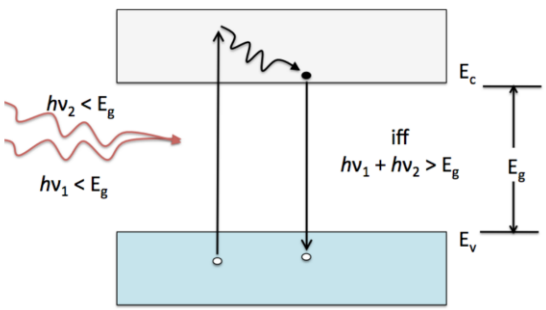


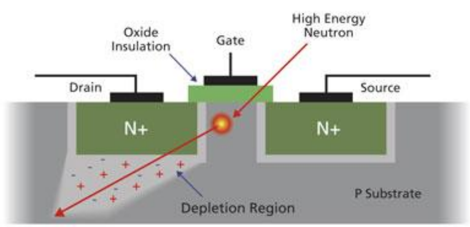


Worst case condition for RRAM:
Unselected cell in HRS state

- RRAM subject to SEU in HRS state. Voltage spike due to collected charge can trigger HRS-to-LRS transition
- No SRAM-like regenerative action. *Impact cumulates trough multiple events (MEU)*

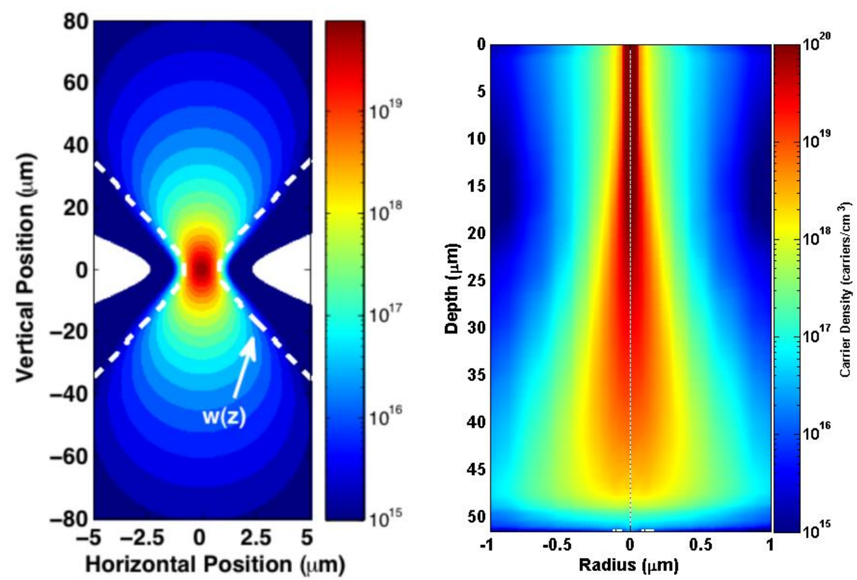
SEU DETECTION BY LASER TESTING





- Two photons are absorbed *to generate an electron-hole pair*
- Goal is to *emulate charge generation from heavy-ions*

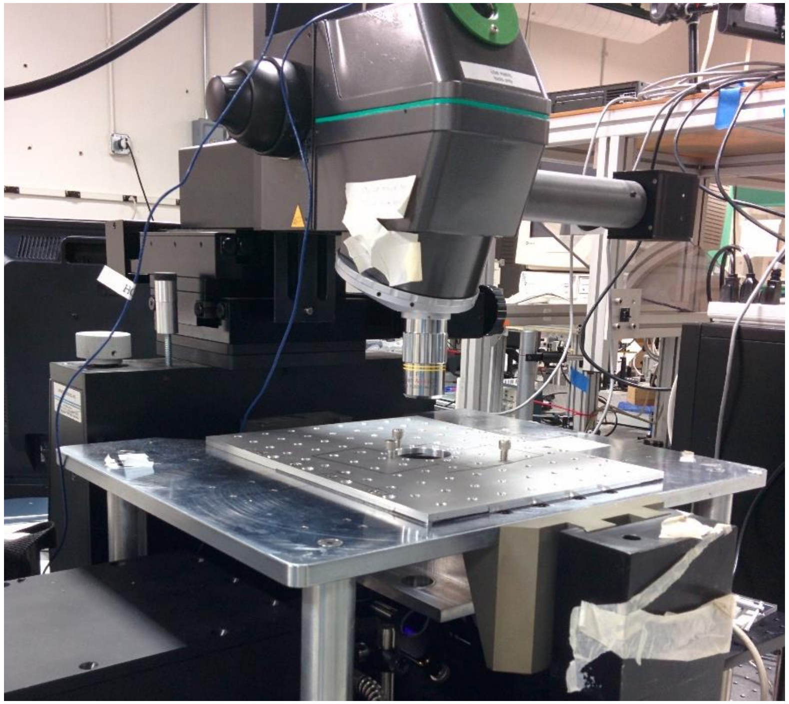
Allows to focus trough Si substrate, but generate wide shape of charges



TPA EXPERIMENTAL SETUP

- 1260 nm wavelength
- 150 fs (nominal) pulse width
- 1.2 um (charge gen spot size)
- 60 pJ-5nJ energy
- 0.1 um stage resolution in x,y,z

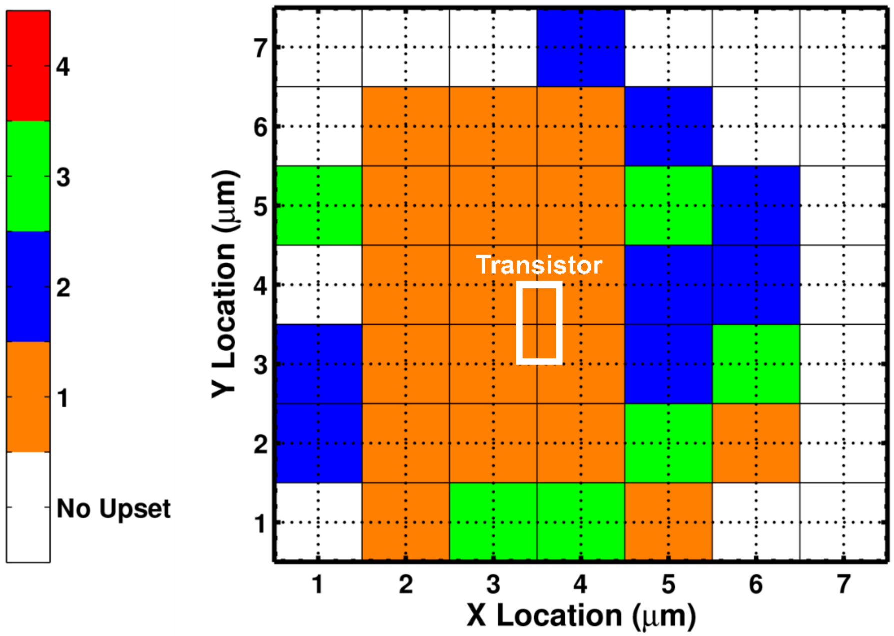
Photodiode to record each incident laser pulse energy



IMPACT OF STRIKE LOCATION ON SEU

Unselected 1T1R cell
HRS state, Vg=0, VB=1.8

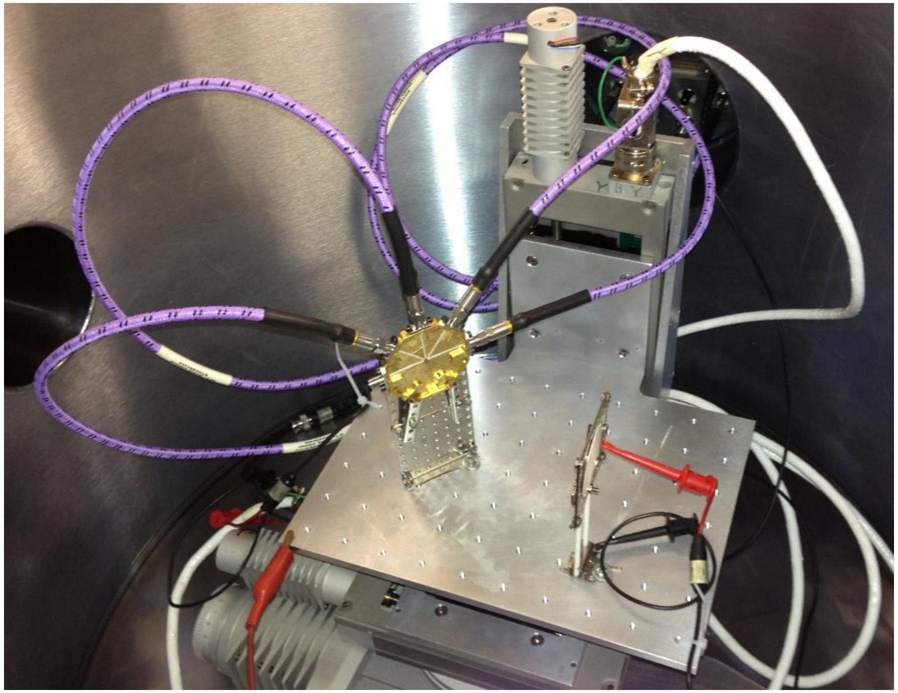
In WC condition a clear dependence of SEU vs strike location can be obtained



Upset events vs strike location

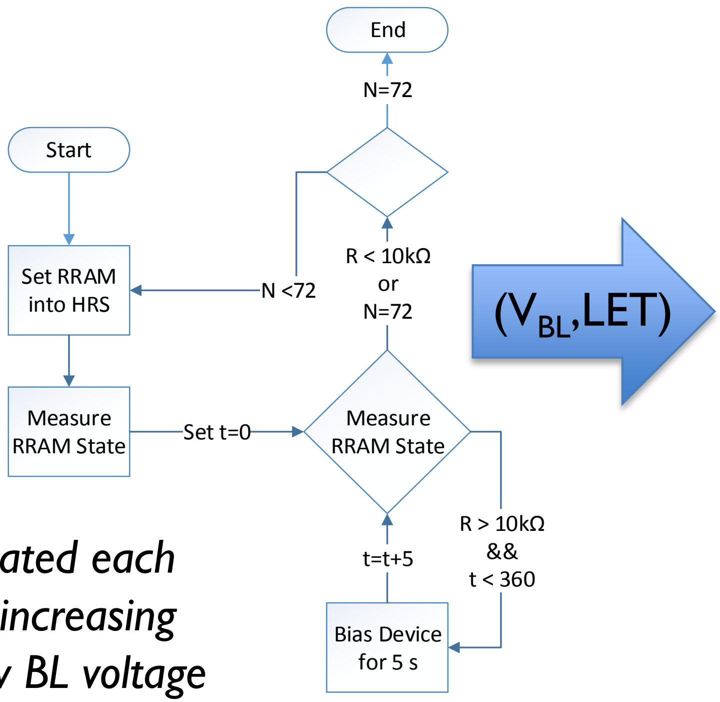
SEU DETECTION BY IRRADIATION

- **Vanderbilt Pelletron**
  - 250 keV – 4 MeV protons
  - 500 keV – 6 MeV alpha particle
  - 14.3 MeV Oxygen
  - 16 MeV Chlorine
- **Lawrence Berkeley National Lab**
  - 4.5, 10, 16 MeV/u ion cocktails

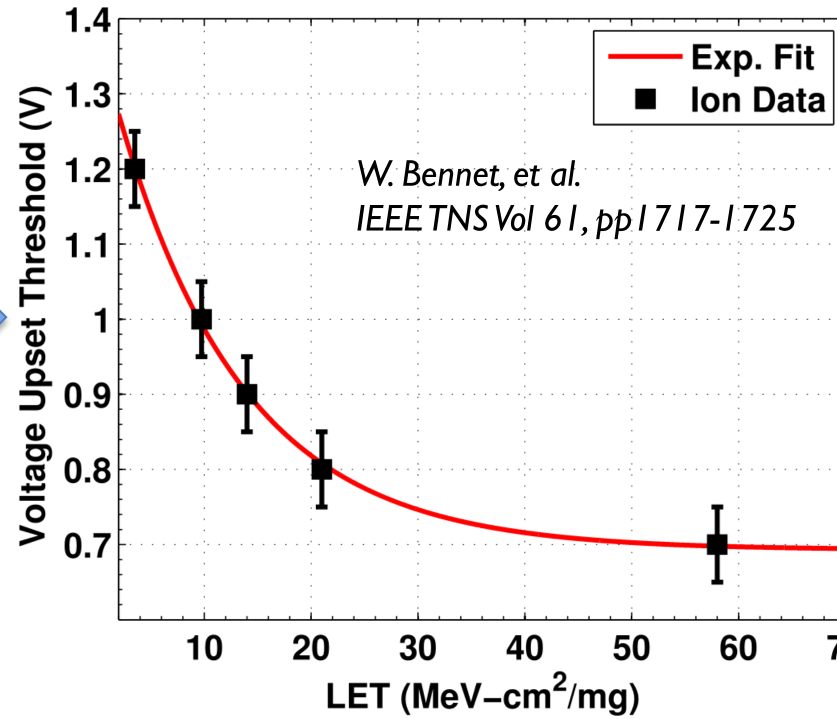


IN SITU SEU MONITOING

Test Flow



Repeated each time increasing 50mv BL voltage



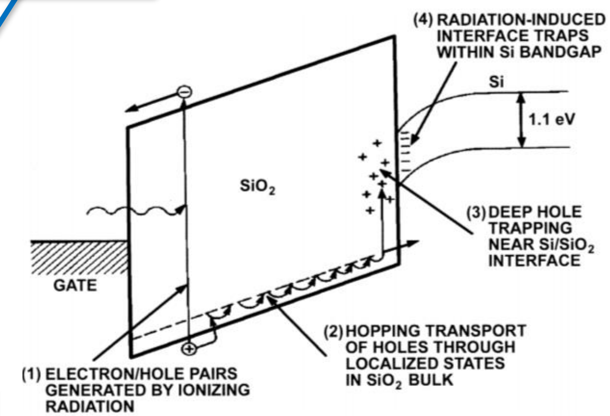
- ΔR is exponentially related to the applied voltage, likewise the threshold for upset
- Same as TPA, with 0.7 V minimum voltage for upset

Total Ionizing Dose / Displacement Damage

RELIABILITY ISSUES

X-rays

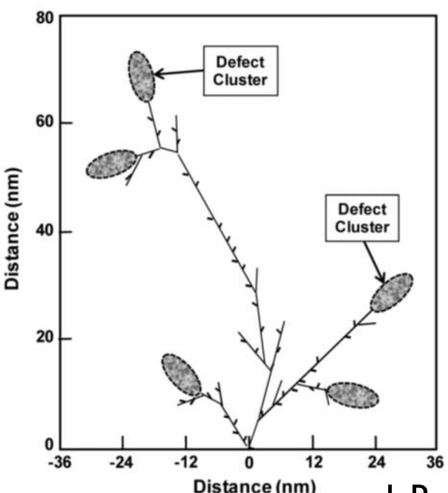
- Total Ionizing Dose (**TID**)
  - radiation generated oxide trapped charge causes devices to perform out of specification (***increased off state current, STI leakage***)



T. R. Oldham, TNS, June 2003

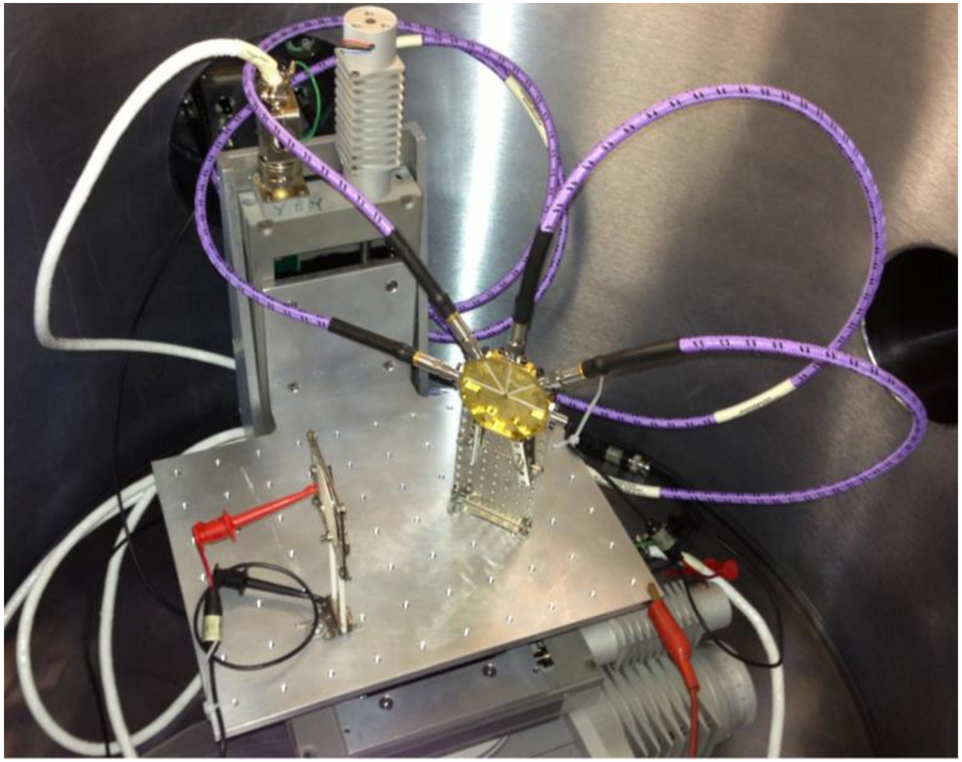
Proton

- Displacement Damage (**DD**)
  - atomic displacements caused by incident particle collisions results in ***reduced minority carrier lifetime, as well as reduce mobility***



J. R. Srour, TNS, June 2013

EXPERIMENTAL SETUP



TID testing: 10 keV X-ray ARACOR irradiator

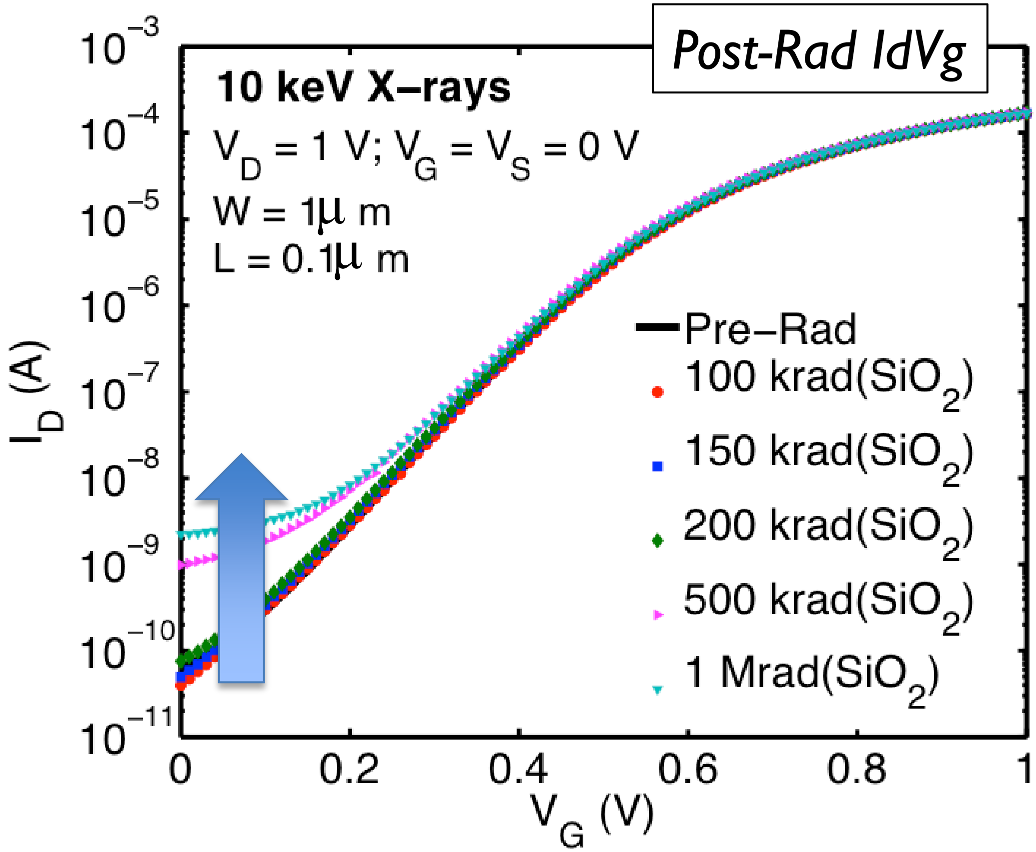
DD testing: Pelletron accelerator

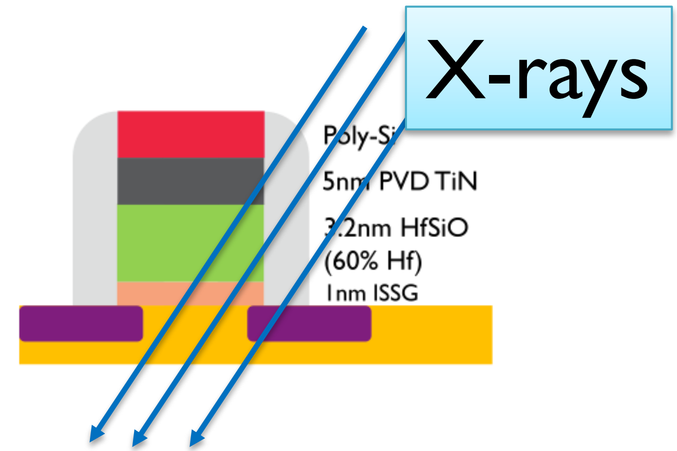
50 ***in-situ*** AC switching *after each exposure*

- *Pulsewidth: 5ns*
- *Voltages: 1.8V SET/RES*

- High speed package mounted to end station of Vanderbilt's pelletron accelerator

UNHARDENED MOST DEGRADED AFTER TID

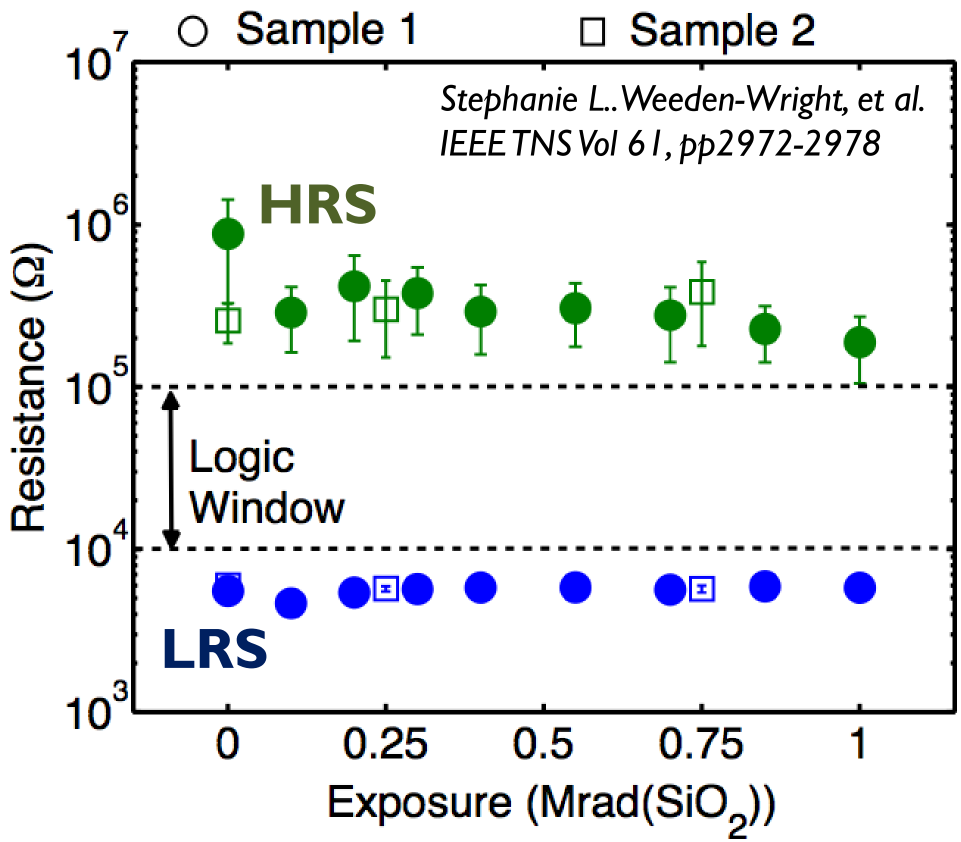


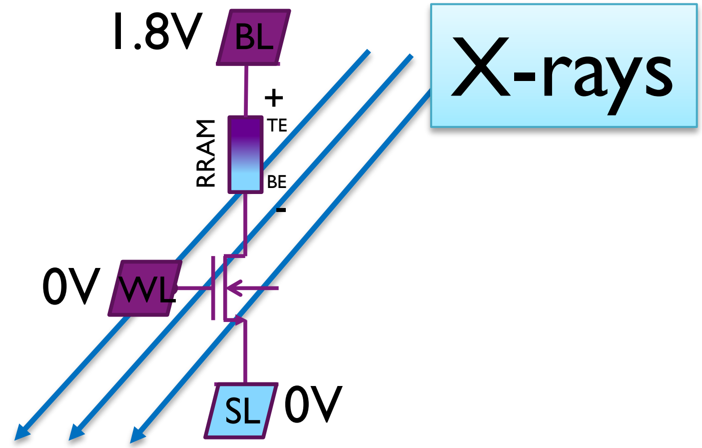


Irradiation conditions:
Vg = Vs = Vb = 0V
Vd = 1.8V

- NMOS biased in off-state during irradiation
- NMOS IOFF current *degraded*

SWITCHING PRESERVED IN 1T1R RRAM CELL





Test condition:

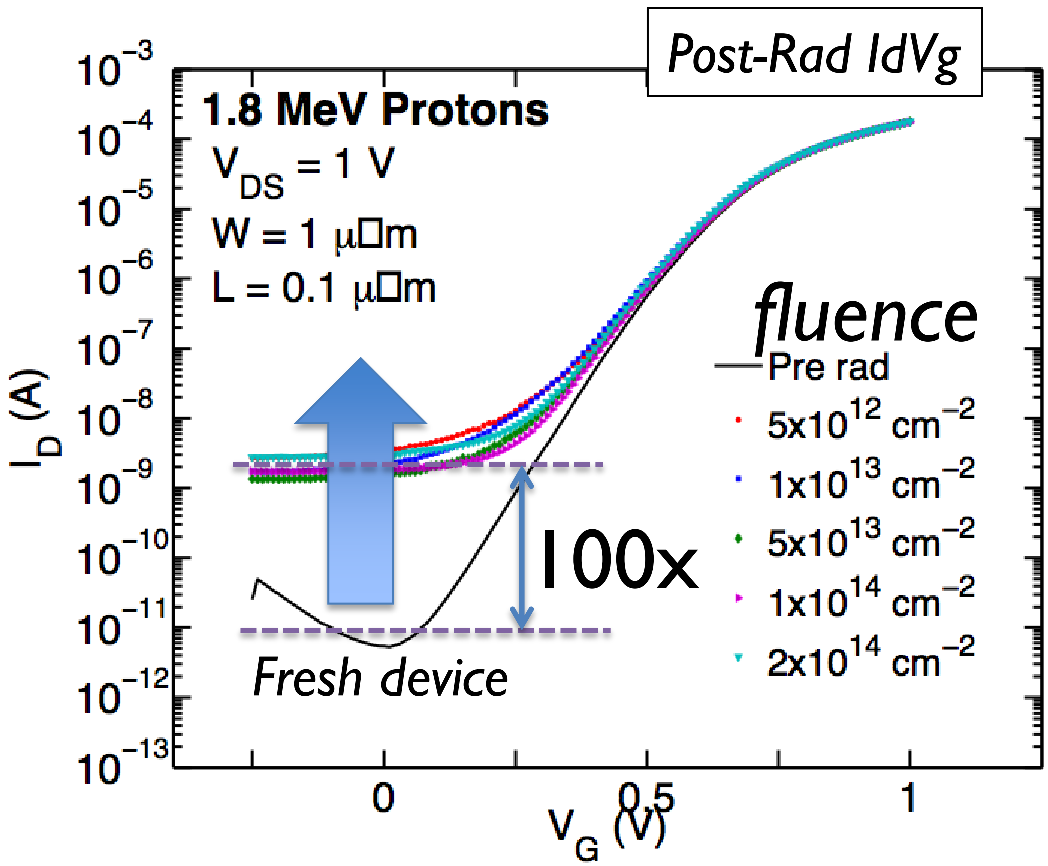
PW=5ns, |V|=1.8V

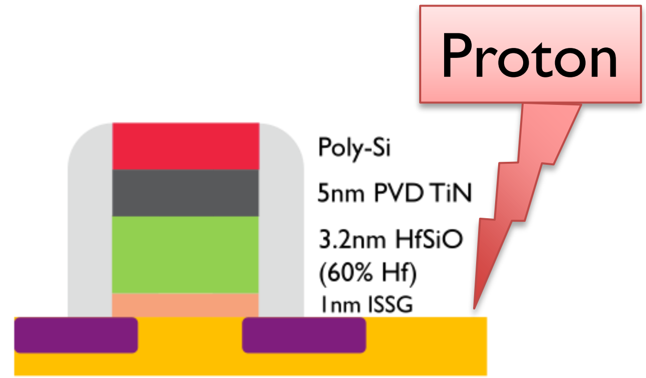
50 clycles/exposure

Bias: Unsel.OFF

- 1T1R RRAM resistive (logic) window **unaffected** by strong ionizing sources

UNHARDENED MOST DEGRADED AFTER DD

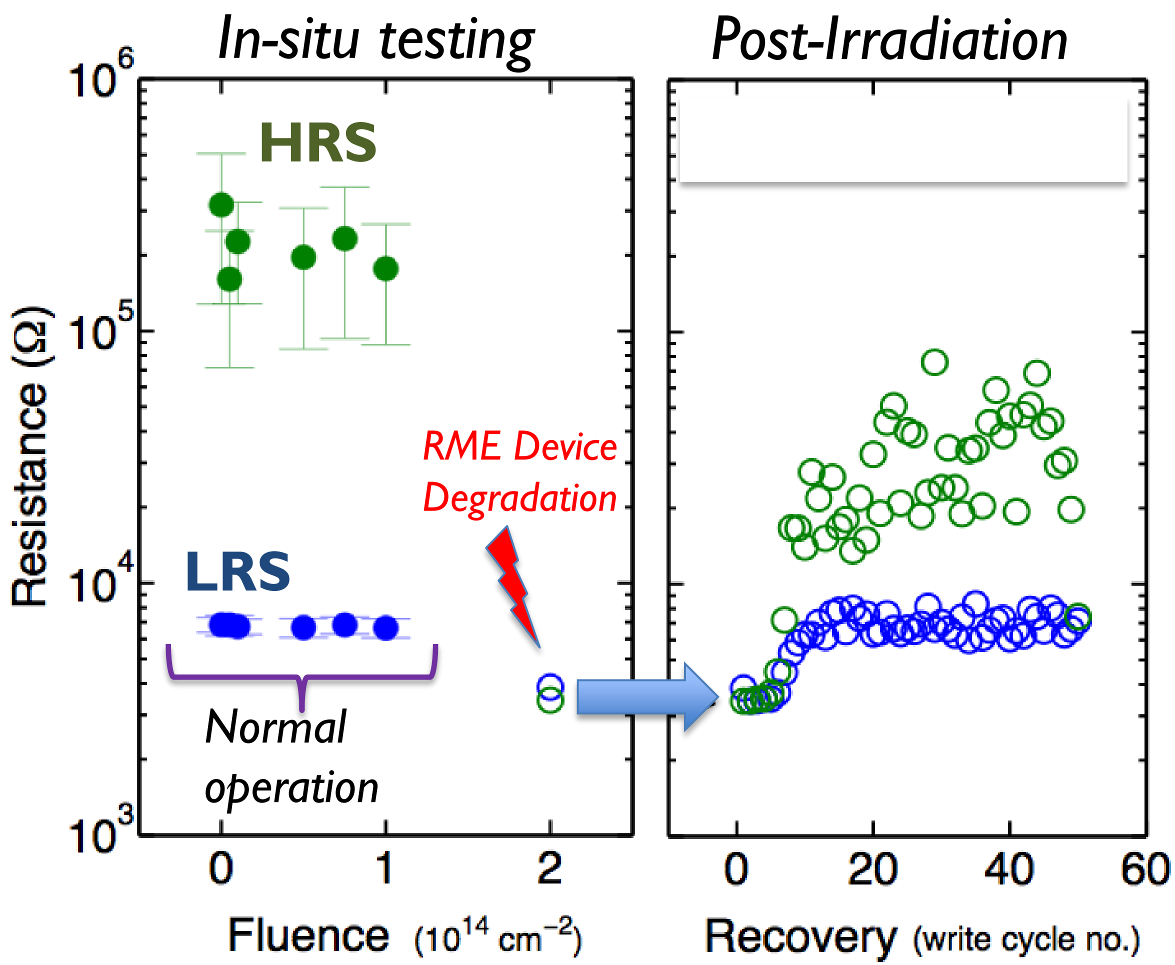


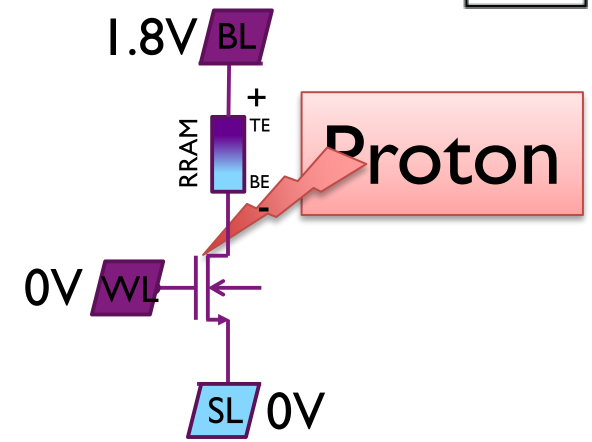


Irradiation conditions:
Vg = Vs = Vb = 0V
Vd = 1.8V

- NMOS IOFF current degraded (factor 100x)

1T1R CELL DEGRADED AT HIGH FLUENCE





Test condition:

PW=5ns, |V|=1.8V

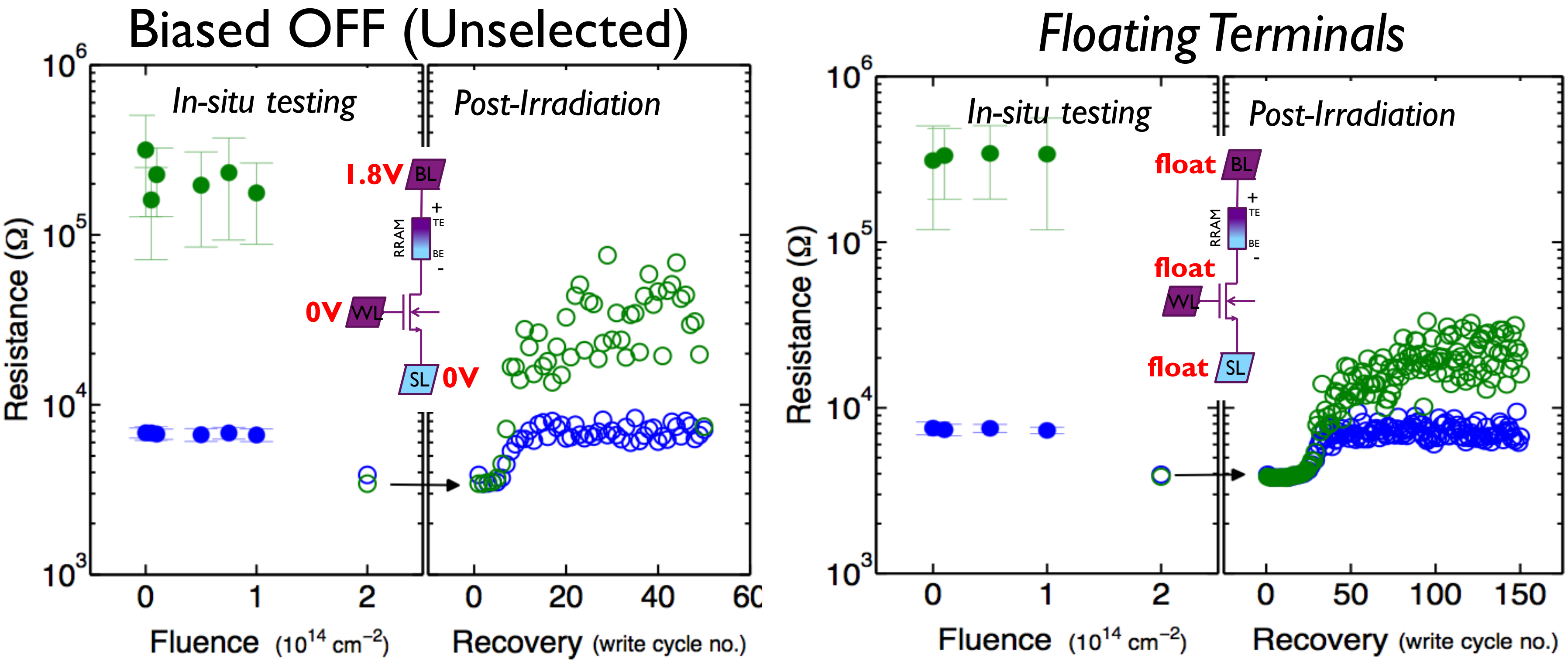
50 clycles/fluence

Bias: Unsel.OFF

Normal LRS level can be recovered

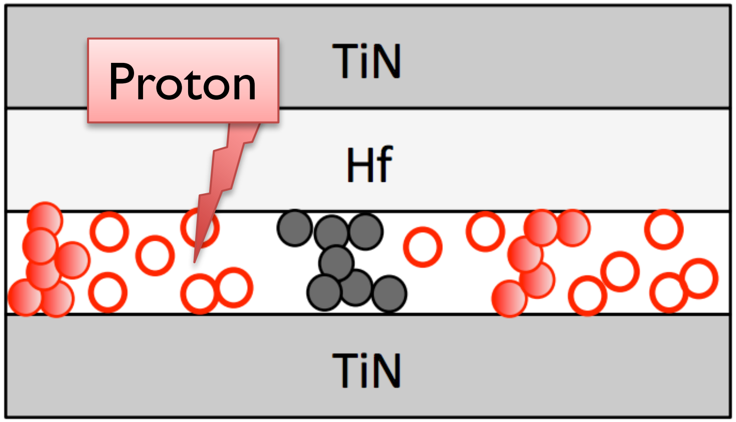
Stephanie L..Weeden-Wright, et al. IEEE TNS Vol 61, pp2972-2978

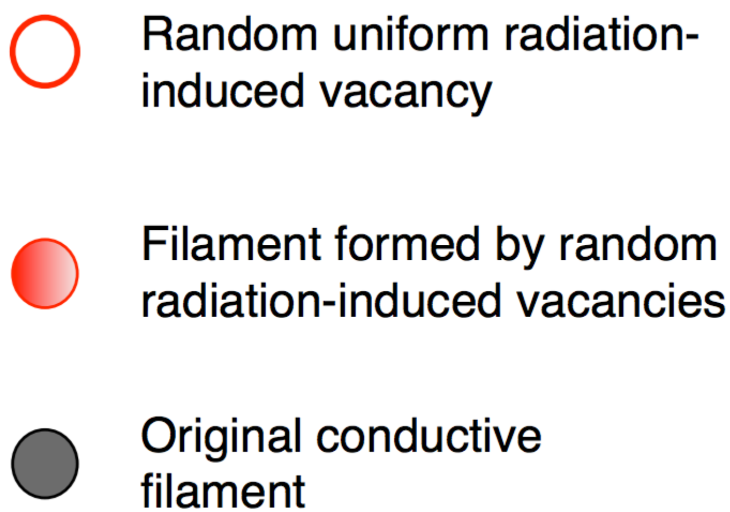
BIAS INDIPENDENT DEGRADATION



- *Same degradation independently from biasing* condition (OFF-biased vs floating terminals)

PHYSICAL PICTURE

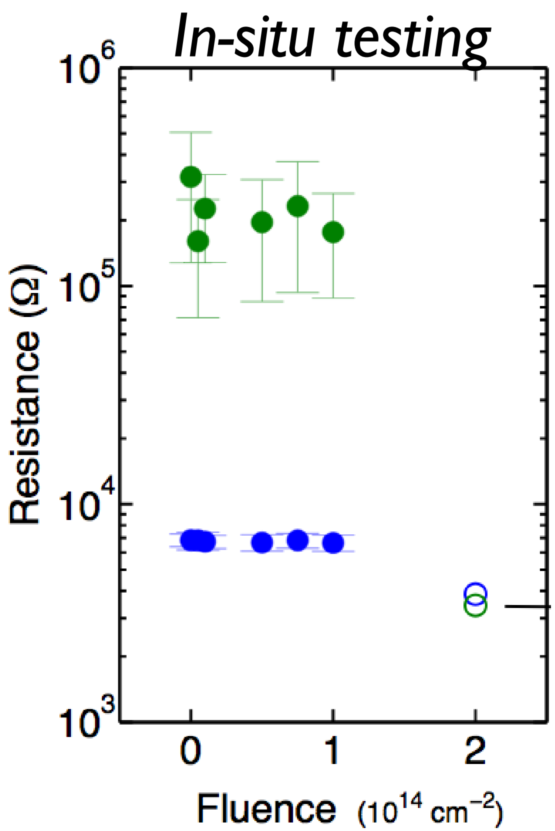


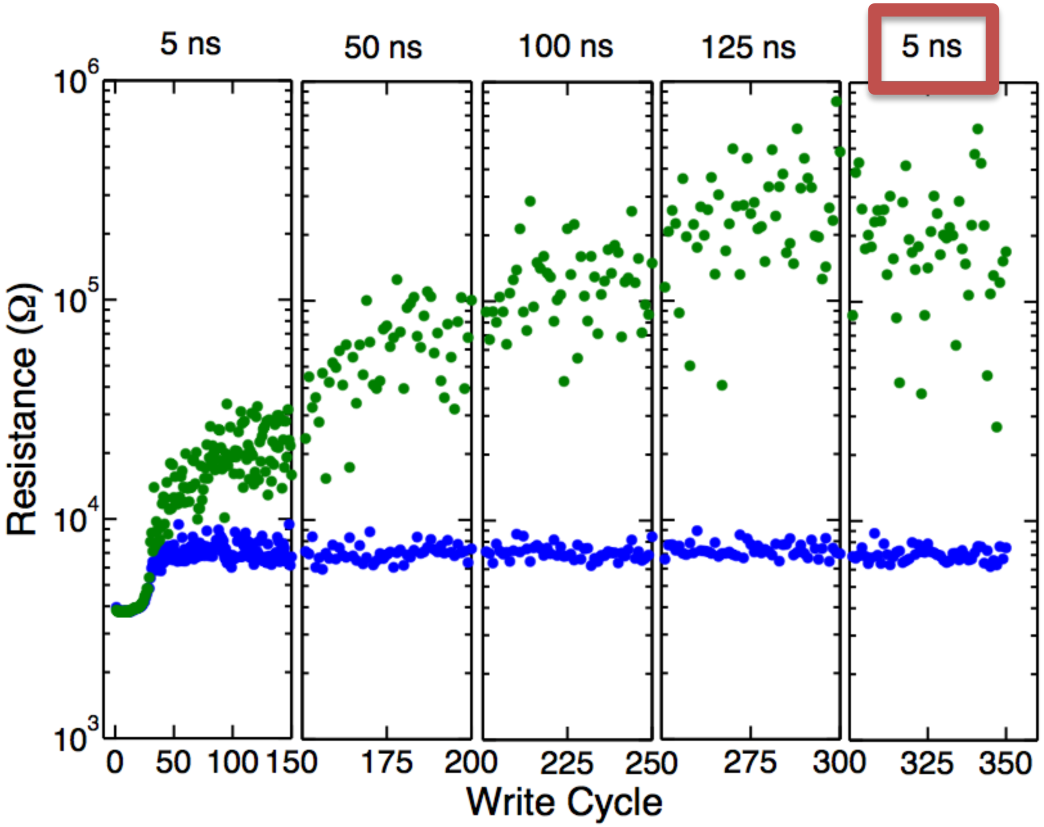


R. Degraeve, *et al.*, IEEE Trans. Electron Devices, vol. 45, no. 4, pp. 904-911, April 1998.

- Degradation only due to displacement in oxide
- DD damage randomly generate Vo defects
- Device degradation apparent only when a percolating path formed in // with filament

DEMONSTRATION OF FULL-RECOVERY





- Pristine resistance window can be recovered
- Short pulse switching restored *after recovery*

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- Reliability: SEU
- Reliability: TID/DD
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CONCLUSION

- Unselected 1T1R RRAM cells are vulnerable to SEU in HRS state. LET to trigger depends on BL voltage
- Damage in access transistor *does not cause degradation* of 1T1R RRAM performances.
- ***No degradation*** of RRAM performances in TID testing up to high doses (1 Mrad)
- ***Recoverable degradation*** of RRAM resistive window in DD test, high fluency condition
  - Attributed to Radiation-Induced percolating path formation of conducting defects → "Burned trough cycling"

VANDERBILT UNIVERSITY ISDE TEAM

Research capabilities:

- Physical modeling of radiation interaction with semiconductors
- Radiation-aware EDA model development
- Rad-hard circuit and IC design

Applications include:

Aeronautics

Aerospace

Defense Systems

Information Technology

Medical