Reliability Physics and Failure analysis in Electronic Devices: *Trends & recent relevant results for space systems*

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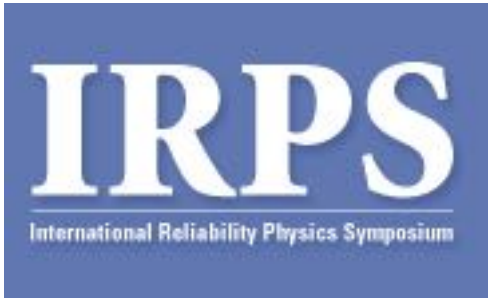
OUTLINE

- Purpose
- IRPS 2015
- IPFA 2015
- ISTFA 2015
- ESREF 2015
- Conclusion



Purpose

- **Trends & recent relevant results for space systems in the field of Reliability Physics and Failure Analysis in Electronic Devices**

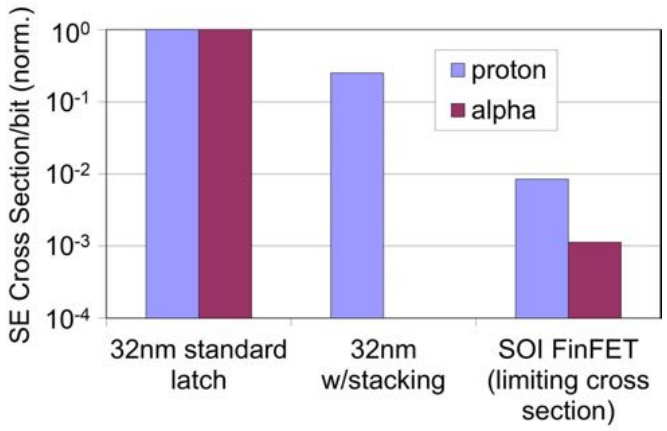
- **IRPS (International Reliability Physics Symposium):** main international conference on *Reliability*
- **ISTFA (International Symposium for Testing and Failure Analysis):** main international conference on *Failure Analysis*
- **IPFA (International Symposium on the Physical and Failure Analysis of Integrated Circuits):** main Asian conference on *Reliability & Failure Analysis*
- **ESREF (European Symposium on Reliability of Electron Devices, Failure Physics and Analysis):** main European conference on *Reliability & Failure Analysis*
- **Deep focus on ESREF**
  - **In Toulouse for the first time - world center for aeronautics with Airbus assembly line, European capital of the space industry and number 1 in France for embedded electronic systems =>** *specific topics dedicated to these applications*

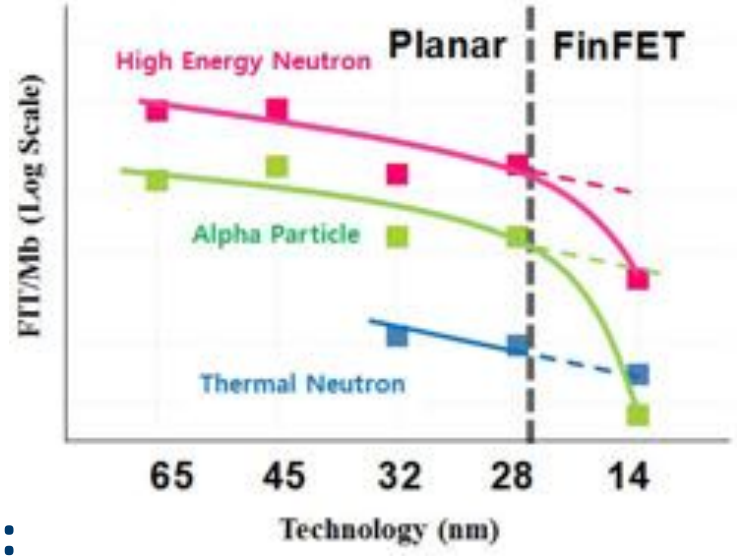
IRPS 2015

- Yuan Chen, NASA, 2015 IRPS Technical Program Chair
- Focus on dielectric breakdown (new session)
- Useful for space applications: radiation topics
  - "Radiation-Induced Soft Error Rate Analyses for 14 nm FinFET SRAM Devices." from Samsung
    - Detailed study of soft errors due to high energy cosmic ray neutrons, alpha particles, and thermal neutrons in 14 nm FinFET and prior CMOS technology nodes.
    - Transitioning to FinFETs greatly improves the soft error rate (by 5-10x) but thermal neutron soft error component decreases less than the other particle components, so thermal neutrons become the largest contributor at 14 nm.
  - Tutorial on Circuit SER (Soft Error Rate), Adrian Evans, iROC (France)
    - SER analysis and mitigation techniques for large SoCs: discussion of approaches for analyzing the effective SER for complex SoCs.
    - How system level reliability, availability and QoS requirements can be mapped down to SoC requirements.
    - How the intrinsic FIT rates of cells can be characterized for industrial cell libraries
    - Estimating the effective SER contribution from memories, flip-flops and combinatorial gates after appropriate de-ratings have been applied.
    - Approaches for identifying critical flip-flops for selective deployment of hardened cells.

IRPS 2015

- **Sessions 2c, 4b and posters on soft errors**
  - **14 interesting papers on this topic (on 185 papers)**
  - **SEU at sea level on up to date technologies, useful info on robustness and mitigation**
    - **SER trend across Samsung's process**
    - **Soft Error cross-section, normalized to 32nm PDSOI standard latch. SOI FinFET gives about 1000X improvement compared to 32nm PDSOI.**





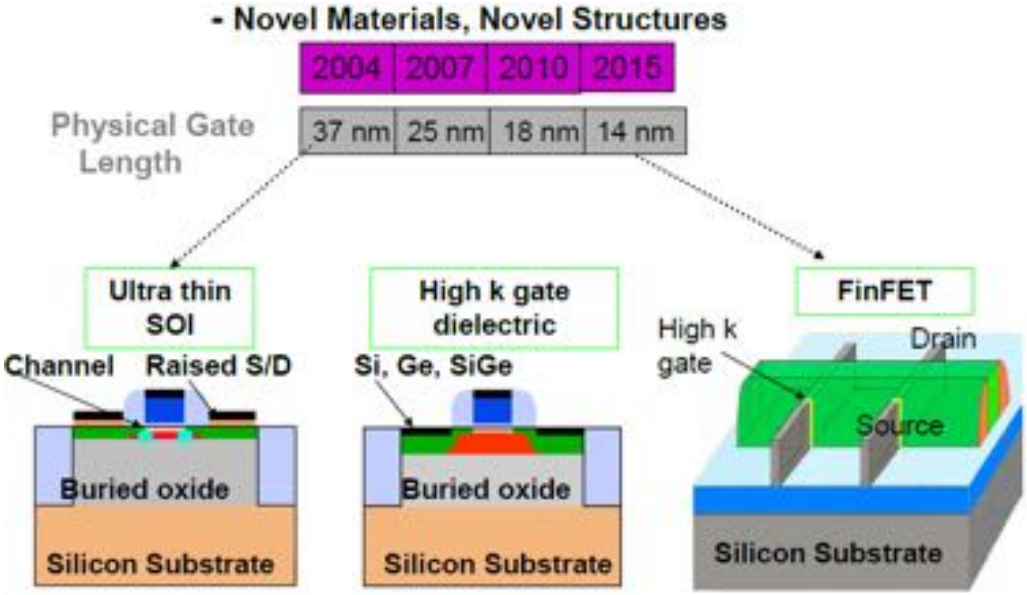
- **Other sessions with irradiation topics:**
  - **Session 2E - Compound/Optoelectronics: Proton irradiation-induced traps causing VT instabilities and RF degradation in GaN HEMTs**

IPFA 2015

- **Held in Taiwan, Asia is more focused on mass market manufacturing**
- **More on up to date technologies reliability**
  - **Keynote 1:** *Reliability and Technology Scaling Beyond the 10nm Node*
  - **Keynote 2:** *3D-IC FPGA: KGD, DFT and Build-in FA capabilities*
- **Less system related topics**
- **Both Failure Analysis and Reliability topics**
- **Also interesting tutorials**
  - **Advanced Technology Scaling and Reliability Challenges**
    - **Overview of key FEOL and BEOL reliability challenges**
    - **Polarity dependence on BTI and SILC in relation to HK/MG devices**
    - **Focus on FinFET reliability learning**
  - **Electrostatic Discharge (ESD) Protection of Low-Voltage RF Integrated Circuits**
  - **Dynamic Fault Isolation Techniques and Case Studies**
  - **Applications of Materials and Failure Analysis Techniques in Semiconductor Industries**

ISTFA 2015

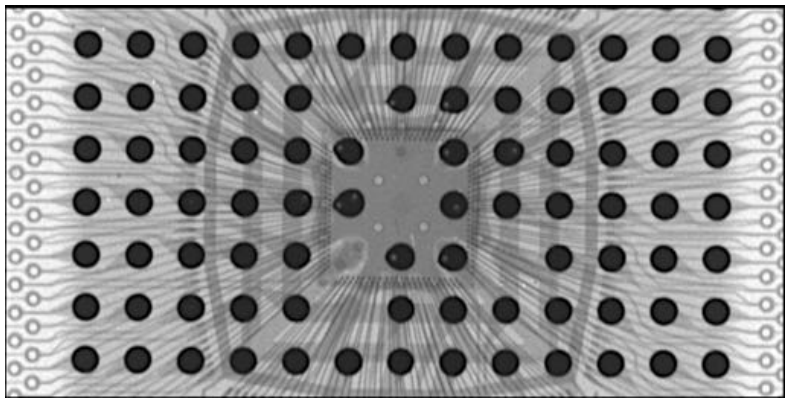
- **2 space related papers**
  - Pulsed Laser Stimulation Coupled with Optical Failure Analysis Technique— A Methodology to Help Space Application Electrical Designers (SEE simulation)
  - Time Domain Reflectometry Case Studies in Electrical Failure Isolation (case study at board level)
- **Updated Tutorial on Emerging Failure Modes of Advanced Technologies**
  - Increased Device Densities introduce new defect modes
  - Emerging Failure Modes Associated with Advanced Technologies
    - Strained Silicon Device Defects
    - FinFET Defects
    - Through Silicon Via Defects



- **Session Detecting Counterfeit Microelectronic**

ISTFA 2015

- Update on Draft SAE AS6171 Standard - Tools and Techniques for Detection and Mitigation of Counterfeit Electronics
  - AS6171 Aerospace Standard standardizes the test and inspection procedures, workmanship criteria, and minimum training and certification requirements to detect counterfeit electrical, electronic, and electromechanical (EEE) parts
  - Can be used for space related counterfeit issues
- Functional Electronic Clones – the most dangerous NEW counterfeit threat faced by the ENTIRE Electronics Industry today
- WISE and ICARUS: New XRay Algorithms to Improve the Detection of Counterfeit Components
  - BGA inspection analysis of bare BGA component showing excessive voiding, a typical characteristic of components that have been re-balled



- Materials analyses for parts validation (mostly package)

LAAS-CNRS

Laboratoire d'analyse et d'architecture des systèmes du CNRS

26th European Symposium on Reliability of Electron Devices, Failure Physics and Analysis

TOULOUSE (France), October 5-9, 2015

Topics

103 oral papers
62 posters

- **A: Quality and Reliability Assessment – Techniques and Methods for Devices and Systems** (17 papers, 7 posters)
- **B1: Si-Nano: Hot carriers, high K, gate materials** (6 papers, 9 posters)
- **B2: Si-Nano: : ESD, Latch-up, radiation effects** (7 papers, 6 posters)
- **C: Failure Analysis** (10 papers, 9 posters)
- **D1: Microwave & Power Wide Bandgap SC Devices** (8 papers, 6 posters)
- **D2: Photonic, Photovoltaic & Organic Devices** (10 papers, 2 posters)
- **D3: Photovoltaic & Organic Devices** (4 papers, 1 poster)
- **E1: Packages & Assembly** (7 papers, 7 posters)
- **E2: MEMS, MOEMS, NEMS & Nano-objects** (4 papers, 4 posters)
- **F: Power Devices** (16 papers, 7 posters)
- **G: Space, Aeronautic and Embedded Systems** (8 papers, 5 posters)
- **H: European FIB User Group (EFUG)** (4 papers, 1 poster)

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2 Keynote Speakers
3 Exchange papers
9 Invited Papers
8 Tutorials
10 Workshops

Keynote 1: ChemCam instrument on the Curiosity rover: from R&D to operations on Mars; be reliable or die…

by Sylvestre MAURICE, IRAP (France)

- **Failure**
  - **Failure of the small laser diode** used to focus the ChemCam telescope on its targets on November 2014 (space qualified part)
  - Main laser that creates flashes of plasma to analyze rocks and soils up to 25 feet from the rover not affected
  - But laser analysis only works when the telescope projecting the laser light to the target is in focus.
- **Mitigation**
  - Hardware failure compensated by implementing an **autofocus capability in the software** (December and January).
  - Tests carried out on a ChemCam clone at the laboratory of Los Alamos.
  - Additional tests in France and on a rover test bed at Jet Propulsion Laboratory, NASA : **GREEN LIGHT** to install the new software on Mars.
- **SuperCam will embed this auto focus ability for Mars 2020 mission**

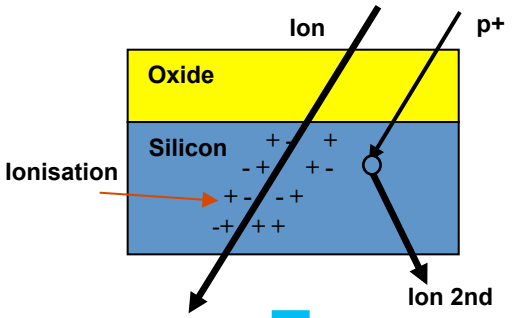
Main topics of interest for space applications

- **Radiations**
  - **Tutorial:** *Radiation effects on components at space level* **- R. Ecoffet, CNES (France)**
  - **Tutorial:** *Radiation and COTS at ground level* **– J-L. Autran, IM2NP (France)**
- **New technologies**
  - **Wearout of DSM technologies**
  - **System level effects**
  - **Wide Bandgap semiconductors**
- **Counterfeit electronics**
- **COTS and lead-free packaging**
  - **Invited paper:** *Modelling the impact of refinishing process on COTS components* **– C. Bailey, Univ. Greenwich (UK)**

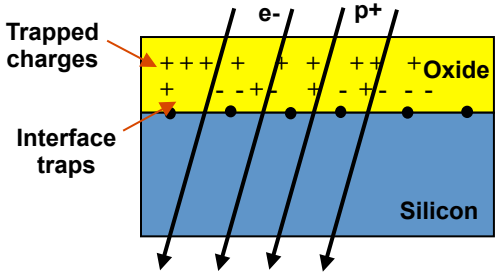
Radiations

Main radiation effects

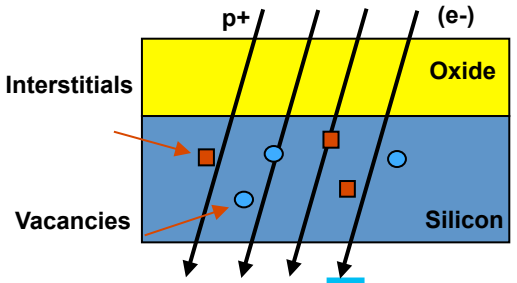
Single Event Effects



Ionising Dose



Atomic Displacement



SET : transient
SEU : upset
SEL : latch-up
SEB : burn-out
SEGR : rupture

Parametric drift
Function loss

Lifetime

Hot pixels
RTS

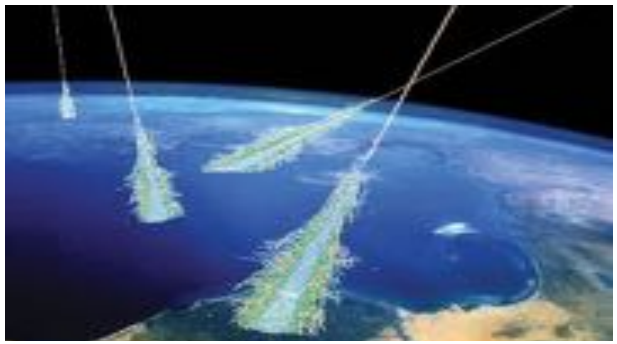
Operating safety
Dependability
Performances

ESREF 2015

Radiation issues at ground level

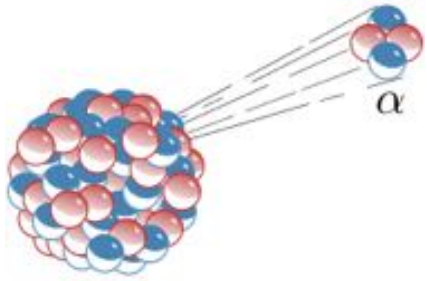
Soft Error Rate (SER) at atmospheric or ground level can be induced by two different types of radiation constraints

EXTERNAL
Atmospheric-particle induced SER

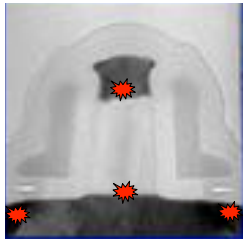


- *High energy neutrons interactions with IC material*
- *Low energy or thermal neutrons interactions with ^{10}B*

INTERNAL
Alpha-particle induced SER



- *U/Th contamination at sub-ppb concentrations*
- *Natural α-emitter isotopes (Hafnium, Platinum)*



From Tutorial J-L. AUTRAN

Some Good News…

Expected SER performances between Bulk, FinFET and SOI

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	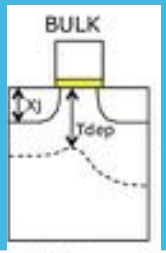	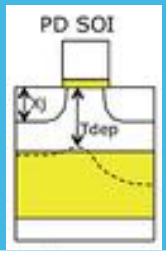	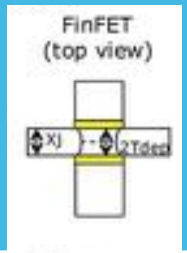	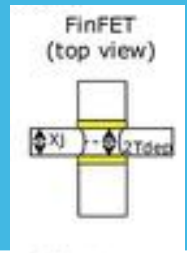	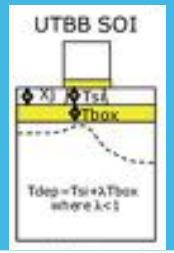
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Muon-SER	**New (1000x) SER risk** under evaluation			
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	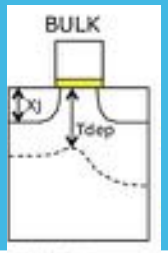	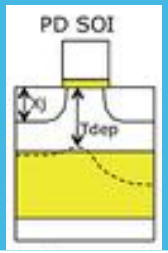	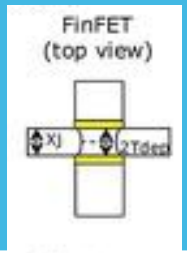	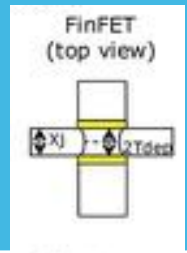	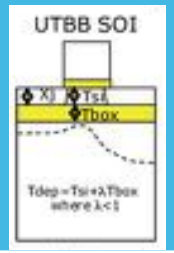
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	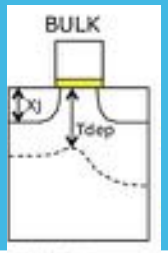	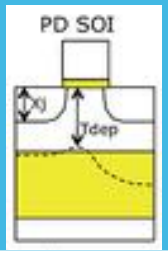	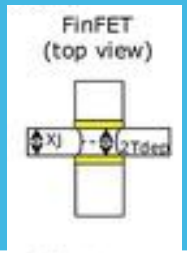	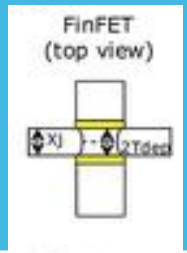	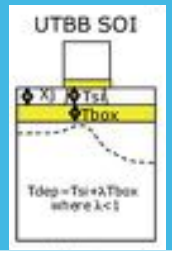
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	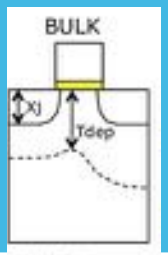	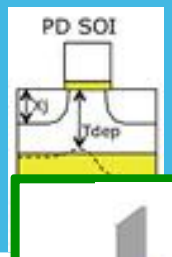	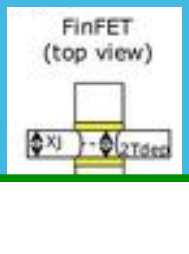	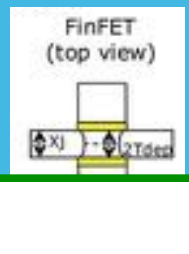	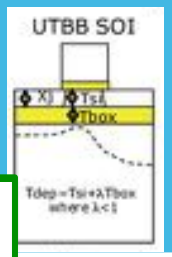
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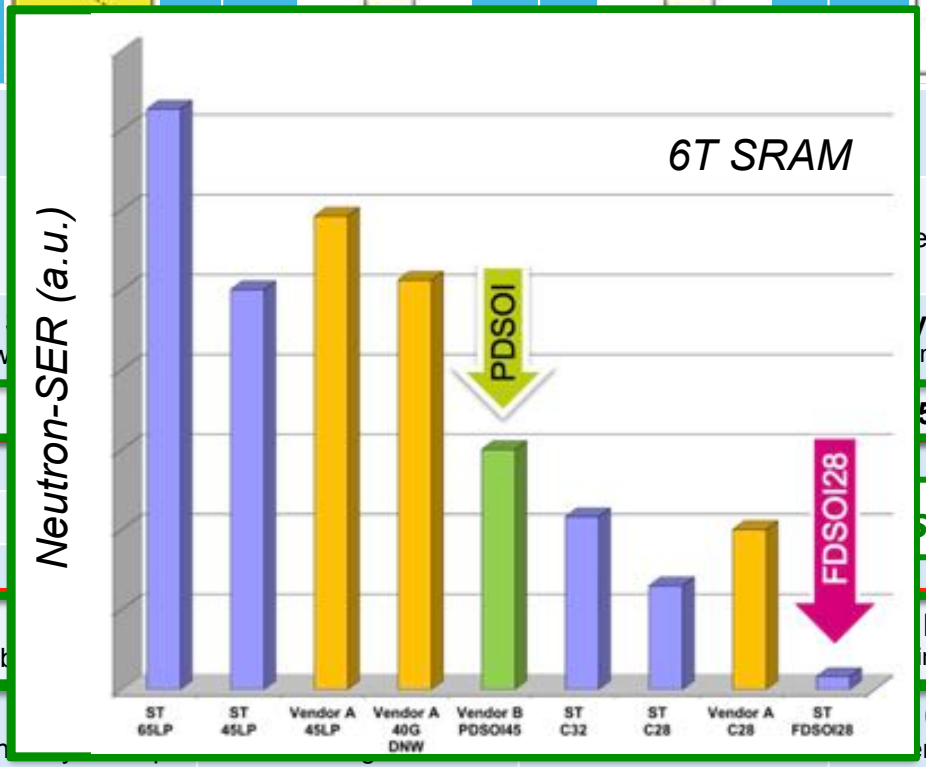


From Tutorial J-L. AUTRAN

Wearout of DSM technologies

ESREF 2015 **Best Paper Award**

To be presented at next IRPS 2016

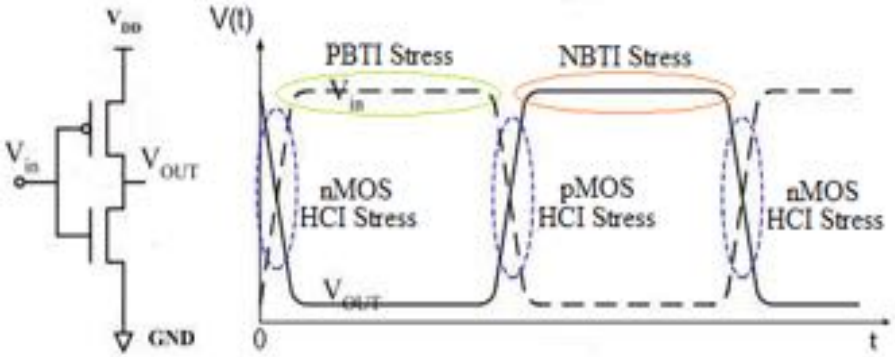
System-Level Variation-Aware Aging Simulator
T. Liu et al, Georgia Tech (USA)

- **Estimation of the lifetime of state-of-the-art microprocessors due to a variety of front-end-of-line (FEOL) wearout mechanisms**
- **The software takes into account:**
  - Operating temperatures and IR drops while running benchmarks
  - Stress probabilities while running benchmarks
  - System performance requirements
  - A wide variety of FEOL wearout mechanisms
  - A wide variety of use scenarios
- **Statistical timing analysis identifies critical paths and provides accurate estimates of the distribution of lifetimes, under PVT and aging**

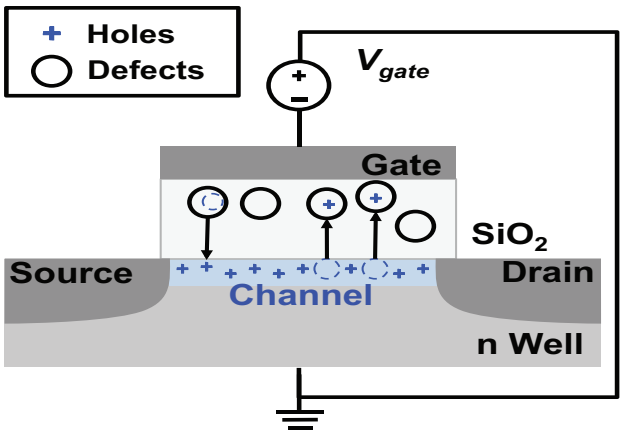
Best Paper Award

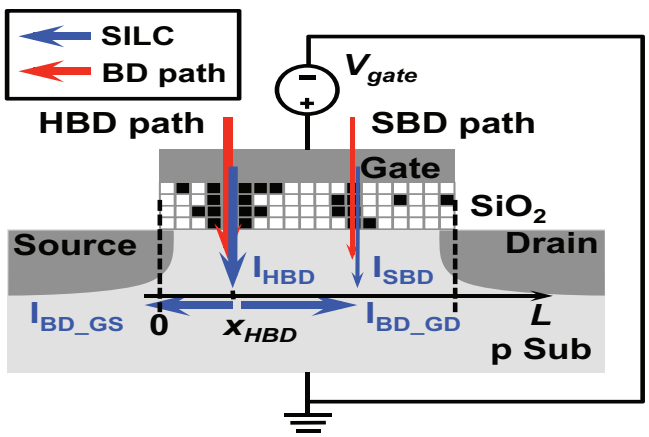
Bias Temperature Instability (BTI), Hot Carrier Injection (HCI) Gate Oxide Breakdown (GOBD)

- **BTI and HCI cause device degradation under stress at different times: modeled as a shift in the threshold voltage**

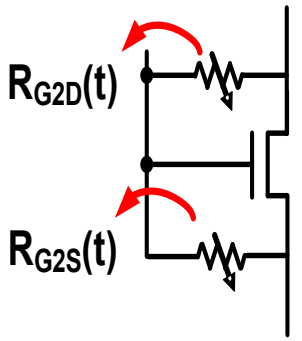


- **GOBD: hard & soft breakdown**



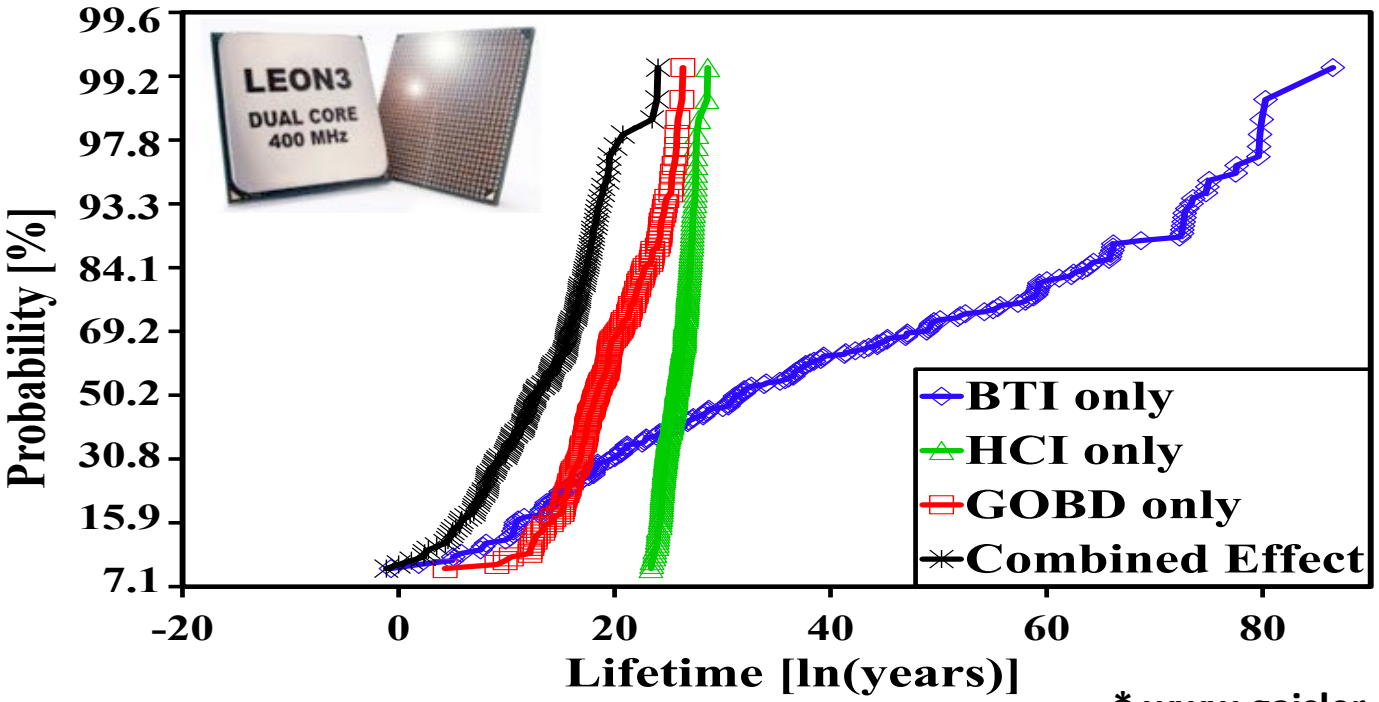


Device-level GOBD model



Combined Result on LEON3* 32-bit Microprocessor

- **Gate oxide breakdown** (GOBD) is the most critical wearout mechanism,
- For some samples, BTI can be dominant
- The combined lifetime distribution has contributions from all mechanisms



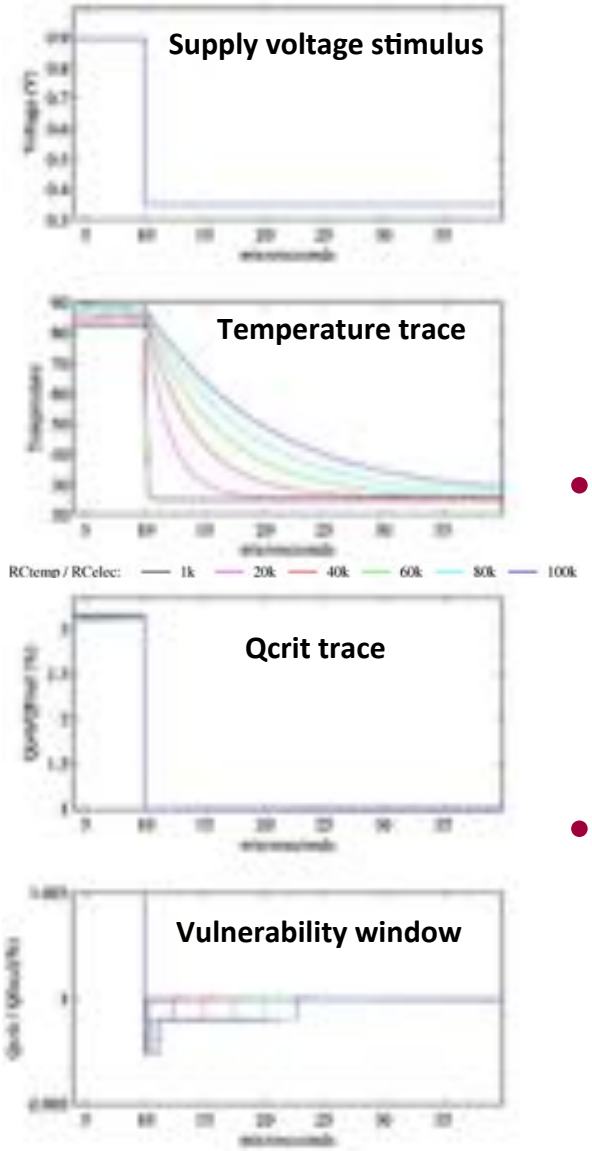
ESREF 2015

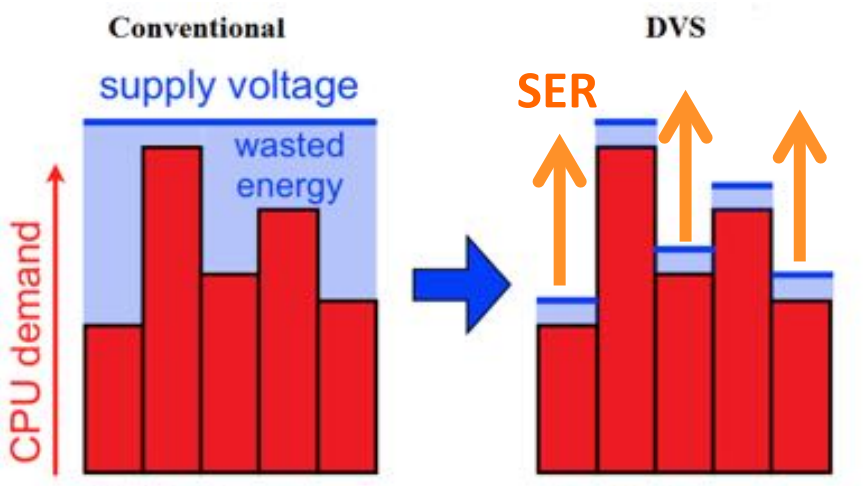
* www.gaisler.com

DSM technologies and system level effects

Impact of Dynamic Voltage Scaling and Thermal Factors on SRAM Reliability – F.R. Rosa et al, Univ. Fed. Rio Grande (Brazil)

Predictive Technology Model 16nm





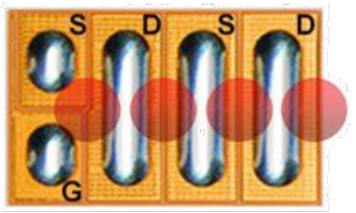
- **Self-heating model allows showing that SRAM are more sensitive to radiation when the supply voltage is transitioning from a higher to a lower voltage:** *Qcrit reduced up to 5 times*

- **A watchdog circuit could be used to monitor the DVS deployed automatically by the processor management unit in order to be aware for the SER modification in critical intervals of time.**

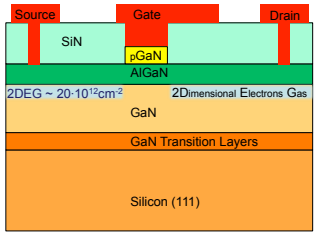
Wide BandGap Devices

Experimental Study of Single Event Effects Induced by Heavy Ion Irradiation in Enhancement Mode (EM) GaN Power HEMT-C. Abbate et al, Univ. Cassino / Univ. Padova (Italy)

- An experimental study about SEE sensitivity of commercially available **EM GaN power HEMT** from EPC.
- Two different charge amplification mechanisms are identified as it happens in DM GaN power HEMT;
- Higher voltage EM GaN power HEMT are subjected to **Single Even Burnout;**
- Failure mechanism associated with the activation of a parasitic BJT proposed for the SEB.

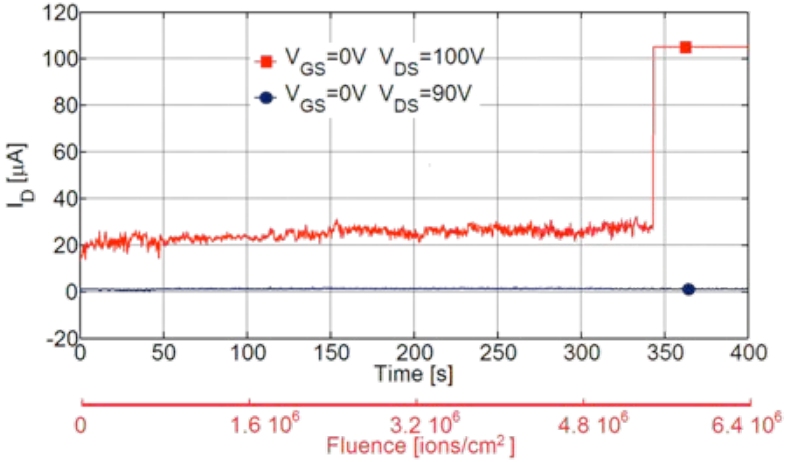


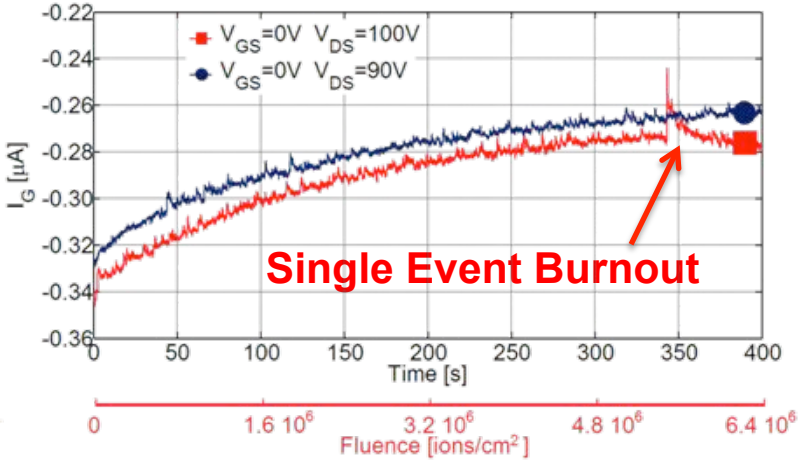
EPC1007 rated at 100V



ESREF 2015

^{127}I at 276 MeV





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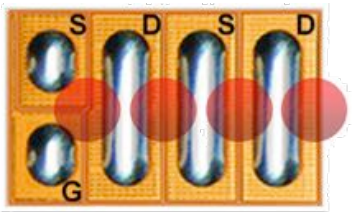
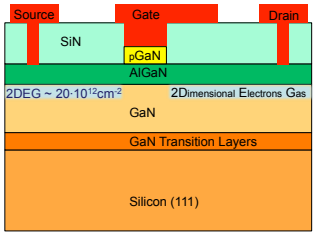
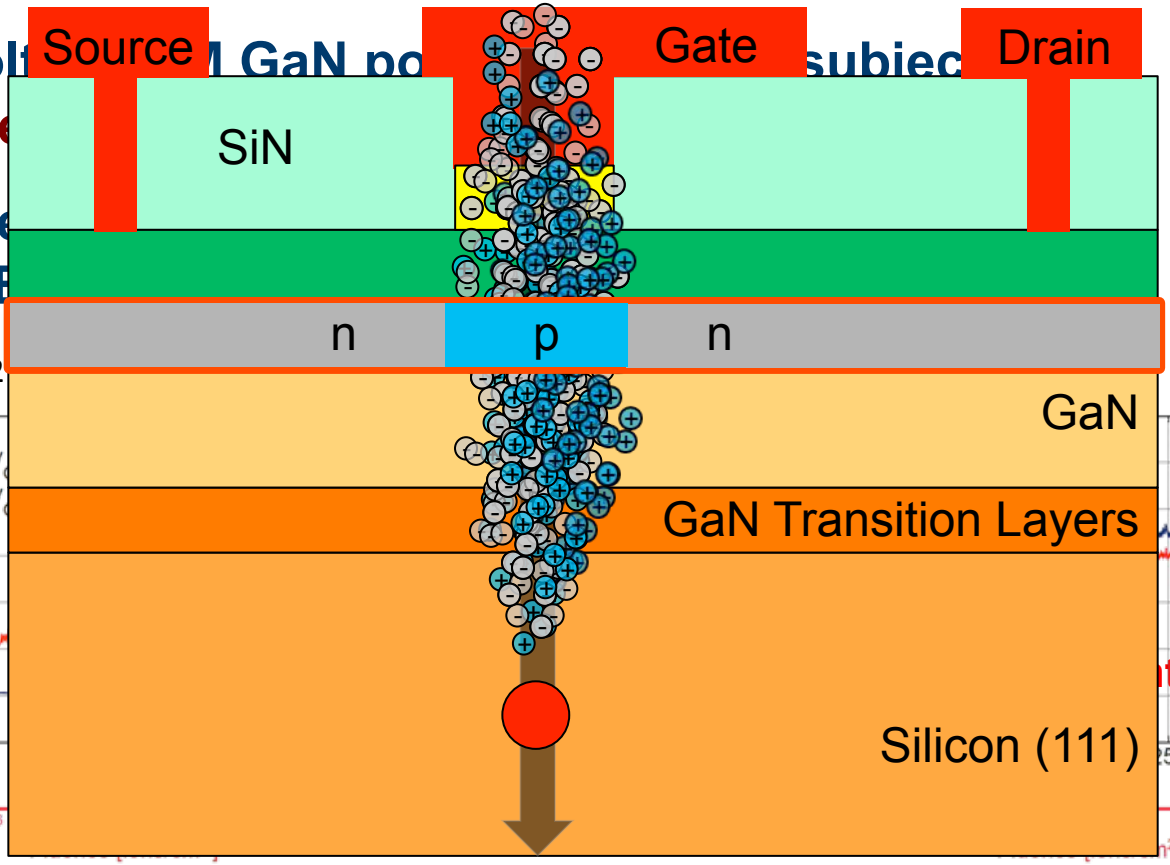
- Two different charge amplification mechanisms are identified as it happens in DM GaN power HEMT;
- Higher volt… GaN po… subjec… Single Eve…
- Failure me… parasitic …



EPC1007 rated at 100V

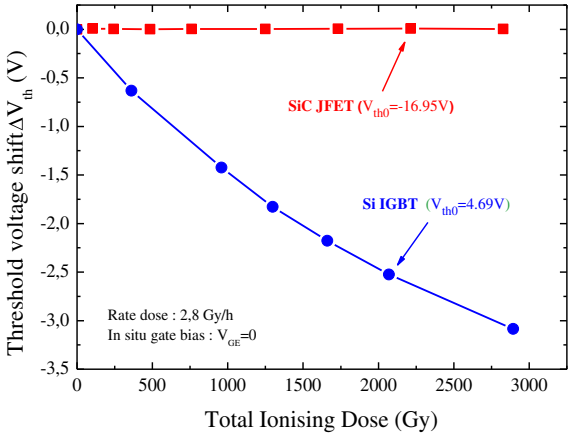


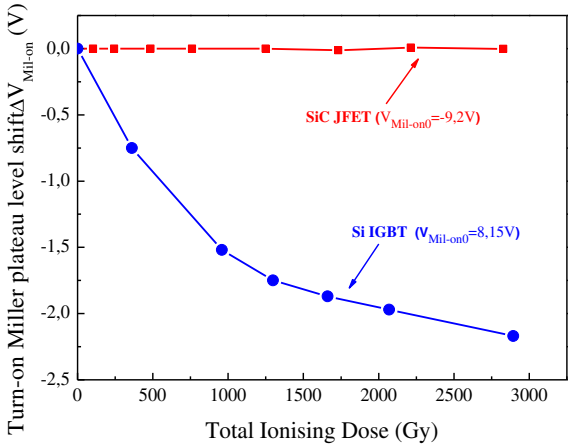


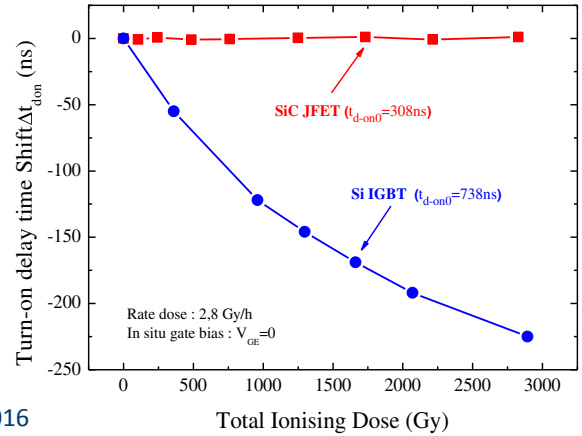
ESREF 2015

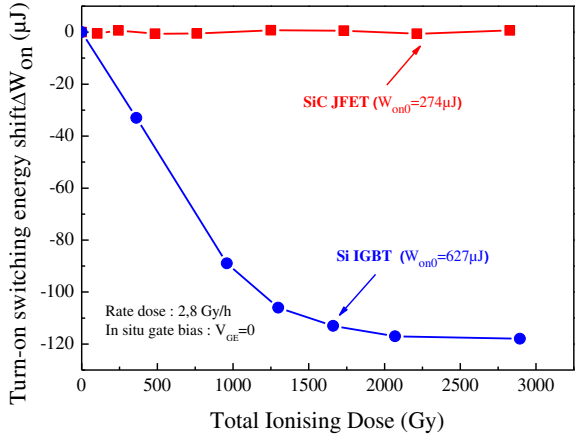
Experimental and comparative study of gamma radiation effects on Si-IGBT and SiC-JFET – B. Tala-Ighil et al, Univ. Caen/EAMEA/SATIE (F)

- SiC-JFETs have extremely high radiation resistance wrt the Total Ionising Dose (TID) effects compared to the Si-IGBTs
- No parameter change up to 2900 Gy with 2.80Gy/h dose rate







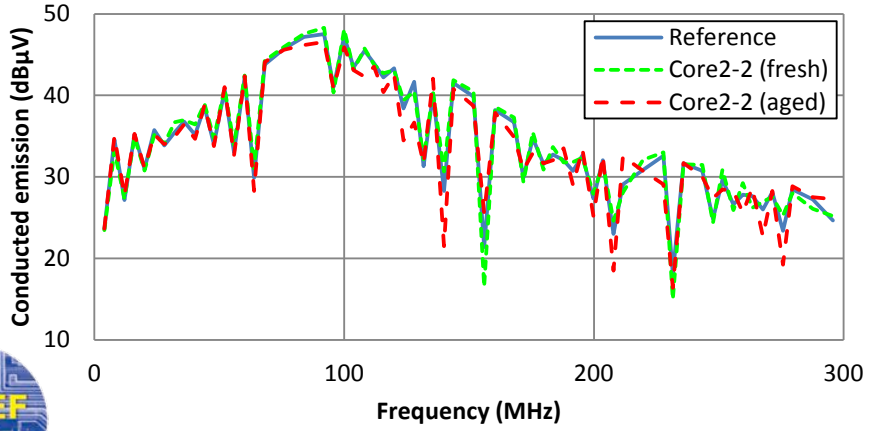


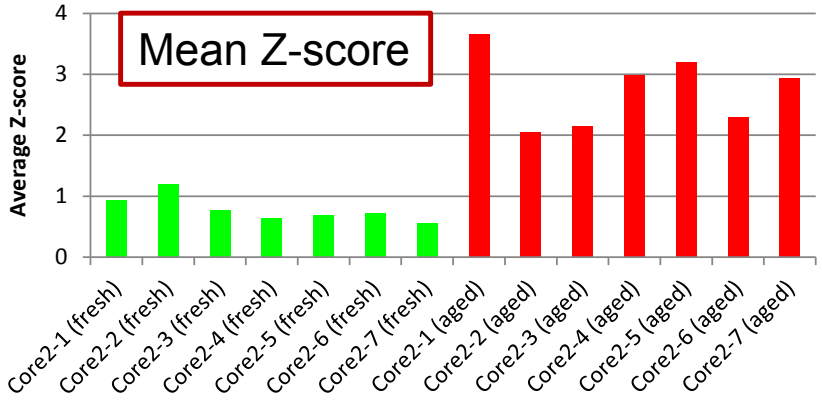
Counterfeit Electronics

Electronic counterfeit detection based on the measurement of electromagnetic fingerprint – H. Huang et al, LAAS-CNRS (F)

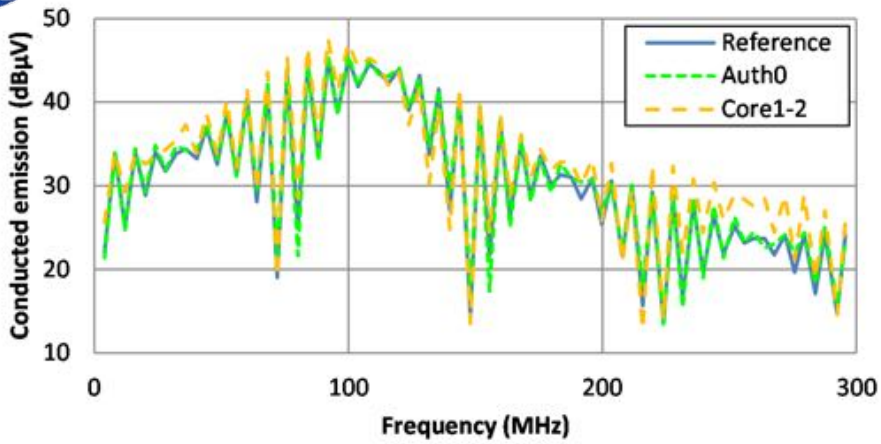
- **Use of Electromagnetic Emission (EME) fingerprint as non-destructive, rapid and cheap counterfeit detection method**

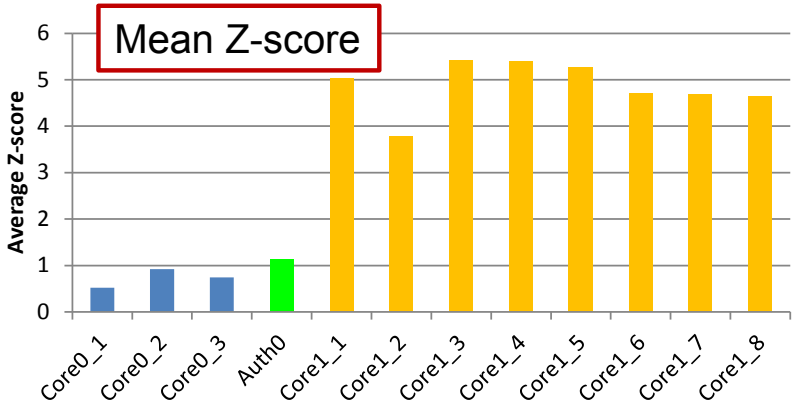
Detection of a stressed component





Detection of technology differences





Conclusions

- Space is not an important topic for international conferences dedicated to Reliability or Failure Analysis, ESREF 2015 is an exception
  - Keynote on CHEMCAM
  - Dedicated sessions, tutorials and workshops
- IRPS 2015: very interesting papers on radiation topics (including some directly related to space).
- ISTFA 2015: dedicated to FA, also embeds interesting stuf on counterfeit detection.
- IPFA 2015: more focused on manufacturing of up-to-date technologies. A good place to learn more about Reliability and Failure Analysis on these technologies.
- All reliability and Failure Analysis topics can interest Space components engineers
  - These conferences are dealing with electronic components that will be used for space applications in a short while.


ESREF 2016
ESREF 2016
27th EUROPEAN SYMPOSIUM ON
RELIABILITY OF ELECTRON DEVICES,
FAILURE PHYSICS AND ANALYSIS
19-22 September, 2016 in Halle (Saale), Germany
www.esref.org - Submission Deadline: March 7, 2016

Thank you