

# SERESSA 2022

5<sup>th</sup> to 9<sup>th</sup> of December at CERN, Geneva

## Closing Ceremony

19<sup>th</sup> International School on the Effects of Radiation on Embedded  
Systems for Space Applications



# SERESSA 2022 – Geneva, Switzerland

## General Chairs

- Raoul VELAZCO (CNRS-TIMA, France) and Ygor AGUIAR (CERN, Switzerland)

## Program Chair

- Jaime ESTELA (Spectrum Aerospace, Germany)

## Local Chair

- Rubén GARCÍA ALÍA (CERN, Switzerland)

## Poster Chairs

- Ygor AGUIAR (CERN, Switzerland) and Andrea CORONETTI (CERN, Switzerland)

## □ 24 lectures + 2 software trainings

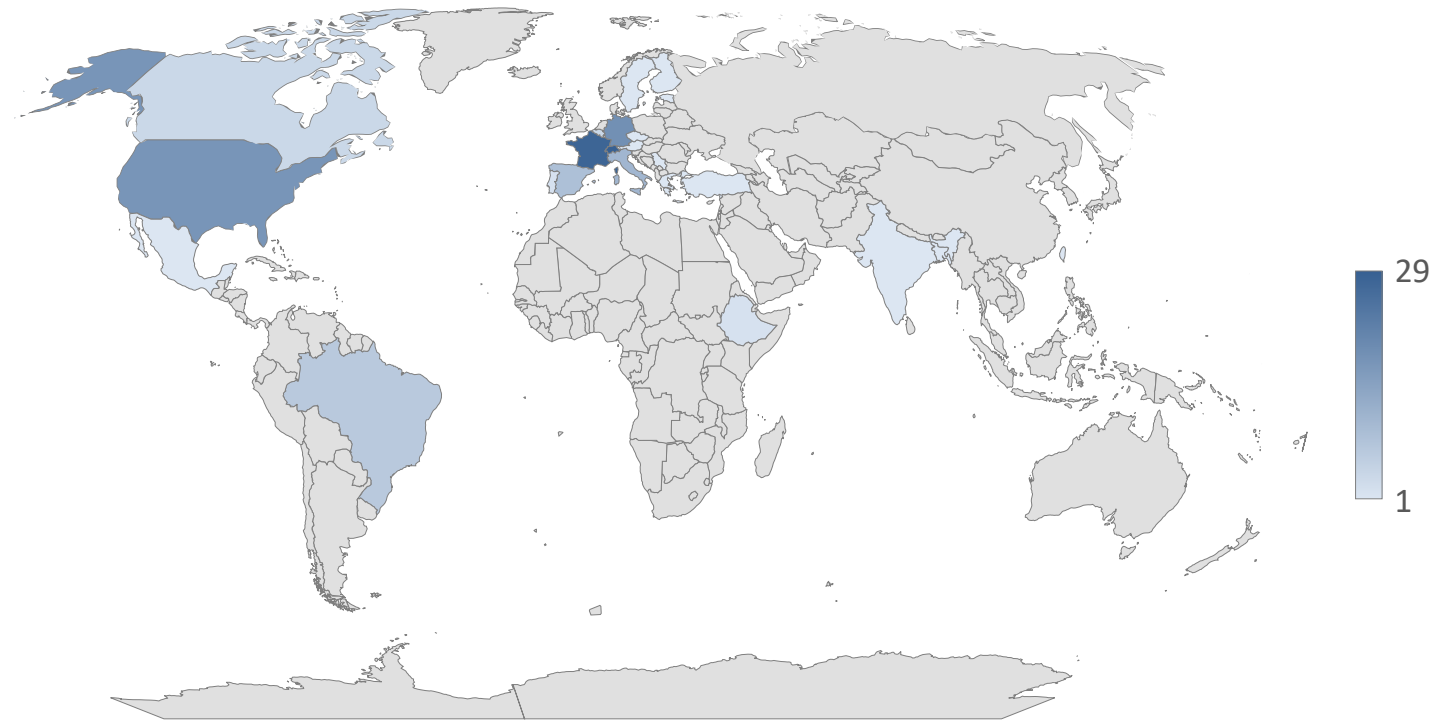
- USA 6, France 5, Germany 5, Switzerland 4, Italy 2, The Netherlands 1, Spain 1, Canada 1 and Brazil 1.
- 152 attendees!

## □ Supported by the **CERN R2E project** and **RADNEXT European project** (Grant agreement No 101008126)



# Some statistics

- ❑ Total of 152 participants
- ❑ 17% of woman
- ❑ 38% are MSc or PhD students
- ❑ 20+ countries:
  - Switzerland – 29
  - France – 28
  - Germany – 19
  - United States – 18
  - Italy – 11



# Technical Program

## 18th International School on the Effects of Radiation on Embedded Systems for Space Applications

from Monday, 5 December 2022 (07:30) to Friday, 9 December 2022 (19:00)

Monday, 5 December 2022	Tuesday, 6 December 2022	Wednesday, 7 December 2022	Thursday, 8 December 2022	Friday, 9 December 2022
08:00 Registration				
08:30 School Opening				
09:00 Fundamental Mechanisms of Non-Destructive SEEs in Devices and Circuits	09:00 Introduction to G4SEE: a toolkit for simulating radiation effects in electronics I - David Lucsanyi (CERN)	09:00 Introduction to G4SEE: a toolkit for simulating radiation effects in electronics II - David Lucsanyi (CERN)	09:00 Introduction to OMERE: a tool for space environment and radiation effects on electronics devices I	09:00 Introduction to OMERE: a tool for space environment and radiation effects on electronics devices II
09:50 Coffee Break	09:50 Coffee Break	09:50 Coffee Break	09:50 Coffee Break	09:50 Coffee Break
10:10 SEE effects on VLSI devices: challenges and solutions - Luca Sterpone	10:10 Radiation Hardness Assurance (RHA) - Stephen Buchner (Naval Research Laboratory)	10:10 The Value of "Test-As-You-Fly": Modernizing FPGA Experimentation And Data Analysis for Critical Space Missions - Melanie Berg (Founder/CEO of Space R3 LLC)	10:10 Accelerator Radiation Environment and Neutron Effects in Electronics - Matteo Cecchetto (CERN)	10:10 Mitigation of Soft Errors at Circuit Level - Ricardo Reis (UFRGS)
11:00 Sensitivity characterization of SRAM-based FPGA against SEU and SET	11:00 COTS in (Deep) Space - Hans-Juergen Sedlmayr (DLR)	11:10 Radiation Hardening by Software: Advanced FDIR and Redundancy Concepts with COTS in Space	11:00 Introduction to 'Radiation to Materials': methodologies and examples - Matteo Ferrari	11:00 CELESTA project
12:00 Lunch break	12:00 Lunch break	12:00 Lunch break	12:00 Lunch break	12:00 Lunch break
13:30 TID Mechanisms in Nanometer-Scale Microelectronic Technologies - Stefano Bonaldo (University of Padova)	13:30 Radiation Mitigation Techniques for Mixed-Signal Circuits - Daniel Loveless (University of Tennessee Chattanooga)	13:30 System-Level Design and Radiation Test Methodologies based on a novel Software-Defined Radio Architectu...	13:30 Analyzing data extracted from radiation tests in advanced SRAMs	13:30 Exam
14:20 Modeling Cumulative Radiation Effects in Semiconductor Devices and Integrated Circuits - Hugh Barnaby (ASU)	14:20 The RADNEXT irradiation facility network - Andrea Coronetti (CERN - University of Montpellier (FR))	14:20 The Phoenix GPS Receiver for Rocket and Satellite Applications: An Example for the Successful Utilization...	14:20 Accurate Abstraction and High Level Modeling and Validation of SEE in Electronic Systems	14:10 School Closure
15:10 Coffee Break	15:10 Coffee Break	15:10 Coffee Break	15:10 Coffee Break	14:40 Visits to CERN installations
15:30 Error rate prediction for programmable circuits: methodology, tools and studied cases	15:30 The challenges of testing COTs devices at European Irradiation Facilities	15:30 Single-Event Effect Criticality Analysis - Anthony Sanders Jonathan Allen Pellish	15:30 Poster Session	
16:20 Modelling and prediction of Single Event Transient and Single Event Upset - Frédéric Wrobel	16:20 Fundamentals of the Pulsed-Laser Technique for Single-Event Effects Testing			
		19:00 Social Dinner		

# Software Training

First time software trainings are provided at SERESSA

- 2-hour training sessions
- Hands-on experience

## SERESSA 2022

### Introduction to G4SEE:

a toolkit for simulating radiation effects in electronics

Dávid Lucsányi, CERN

#### Abstract:

G4SEE, a novel Geant4-based Monte Carlo simulation toolkit is being developed at CERN for the radiation effects community, and released as a free and open-source code. It has been already demonstrated and validated experimentally by measurements of inelastic energy deposition single events of monoenergetic neutrons below 20 MeV. These two hands-on lectures will give an introduction on how to use the G4SEE toolkit in simple, but real-life scenarios to simulate, analyse and better understand the nuclear physics of Single Event Effects induced by neutrons and protons in microelectronic structures.

G4SEE website: <https://cern.ch/g4see>

#### Short Bio:

Dávid Lucsányi was graduated at Budapest University of Technology and Economics (BME) in 2016 as an Applied Physicist specialised in Nuclear Technologies. He joined CERN TOTEM experiment as a Technical student to work on solid-state detector R&D, then European Space Agency (ESA) as a Young Graduate Trainee (YGT) working on the development of Pyxel astronomical imaging detector effect modelling framework. Since 2020, he is working in CERN Radiation To Electronics (R2E) project as a Fellow on Monte Carlo simulations and analyses of Single Event Effects (SEE) and development of the G4SEE simulation toolkit. In his freetime, he works for Puli Space Technologies, as the Lead Payload Scientist of the NASA prize winner PLWS lunar neutron spectrometer instrument.



#### Organizers:



## SERESSA 2022

### Introduction to OMERE:

a tool for space environment and radiation effects on electronics devices

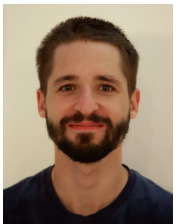
Léo Coïc, TRAD

#### Abstract:

This talk introduces the OMERE freeware and its capabilities. OMERE is a tool developed by TRAD with the support of the CNES according to the need of major actors of the European space industry. It is dedicated to accurately model the space environment for earth and interplanetary missions with industry approved and up to date environment models as well as estimate its effect on electronic devices. During this talk the main capabilities of the OMERE software will be showcased and we will go through the different steps necessary to perform calculations.

#### Short Bio:

Léo Coïc is a radiation engineer at TRAD. He received his master's degree in Space Systems Engineering from ESTACA (France) in 2020. Focused on the effects of radiation on electronic devices, his main activities involve working on single event effects analyses for the industry and R&D studies focused on simulation and experimental characterization of single event effects sensitivity in advanced technologies.



#### Organizers:



# Technical Visits

- ❑ On **Friday, 09/12**, from 15h to 17h.
  - to the [Synchrocyclotron \(SC\)](#), the first accelerator at CERN, and;
  - to [ATLAS](#), one of the LHC experiments

Meeting point = **Reception (Building 33) at 14:50**

# R2E student grant

## ❑ 5 student grants:

- **Arijit Sengupta**, USA
- **Saulo Alberton**, Brazil
- **Mahammadreza Rezaei**, Spain
- **Stefano Marinaci**, Belgium
- **Luca Weninger**, France

## ❑ Selection Committee:

- Dr. Rubén García Alía
- Dr. Ygor Aguiar
- Dr. Andrea Coronetti

## SERESSA 2022

5<sup>th</sup> to 9<sup>th</sup> of December at CERN, Geneva



## CERN R2E Student Grant

Application Deadline  
**September 15th, 2022.**

The Radiation to Electronics (R2E) project at CERN will provide five (5) student grants to support outstanding and highly motivated students willing to enhance their knowledge in radiation effects in electronics.

To participate to the selection process, check our website:

<https://indico.cern.ch/e/SERESSA2022>

Organizers:





# SERESSA Best Student Posters Award



1<sup>st</sup> Place:

Natalija Für, Corinna Martinella, Ulrike Grossner, Piyush Kumar and Marianne E. Bathen

## Investigation of material damage caused by heavy-ions in degraded SiC Schottky diodes

### Investigation of material damage caused by heavy-ions in degraded SiC Schottky diodes

N. Für<sup>1</sup>, C. Martinella<sup>1</sup>, P. Kumar<sup>1</sup>, M. E. Bathen<sup>1</sup>, and U. Grossner<sup>1</sup>

<sup>1</sup>Advanced Power Semiconductor Laboratory, ETH Zurich, Physikstrasse 3, 8092 Zürich, Switzerland  
E-Mail: nfuer@student.ethz.ch

#### 1 Introduction

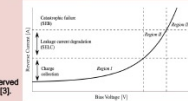
SiC Schottky diodes:

- Low on-state voltage.
- Minimal turn-off switching loss.
- Almost no reverse recovery behaviour.

- Interest of the space industry towards SiC power devices has increased.
- Radiation environment limits the adoption.
- Current commercial technologies of SiC power devices are sensitive to radiation.

⇒ Risk increase of single event effects (SEEs).

Fig. 1. Summary of radiation responses observed in SiC Schottky Barrier Diodes, remade after [3].



#### 2 Microbeam Experiment

4<sup>th</sup> Gen. CREE SBD selected as DUTs.

- DUTs were reverse biased at a fixed voltage ( $V_{R,ref} = 0$  V, 300 V or 500 V).

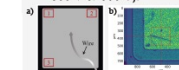


Fig. 2. Irradiated region a) and radiation frame b).

#### 3 Minority Carrier Transient Spectroscopy

MCTS:

- Investigation of electrically active point defects in a semiconductor.
- 365 nm optical pulse is for 100 ms, while reverse biased at  $V_R = -5$  V and -10 V.
- Start was in range 20-300 K, with 50 K steps until 450 K.

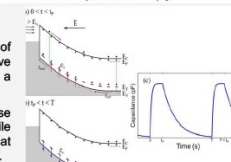


Fig. 3. minority carrier transient spectroscopy (MCTS) measurement: (a) capture of the minority charge carriers from the valence band to the deep level ( $E_t$ ) while optical pulses are applied; (b) emission of the minority charge carriers from the deep level after the optical pulse; (c) measured capacitance transient as a function of time ( $t$ ).

#### 4 Results and Discussion

$V_{R,ref} = 500$  V: SELC.

$V_{R,ref} = 300$  V: No SELC and generally no SEE signatures.

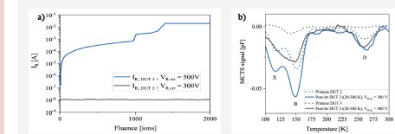


Fig. 4. (a) MCTS spectrum before and after irradiation for DUT with and without SELC and (b) leakage current measurement for the corresponding samples.

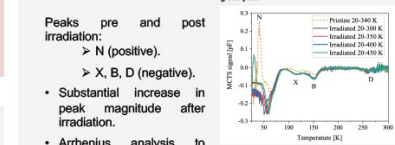


Fig. 5. MCTS spectrum before and after irradiation for various temperatures, measured at a  $V_R = -5$  V.

TABLE III SUMMARY OF THE OBSERVED ENERGY LEVELS FROM MCTS ANALYSIS (DUTs, $N_A = 3000$ BEFORE AND AFTER IRRADIATION)				
Level	Defect	$E_t - E_v$ [eV]	$N_{t,net}$ [ $10^{12} \text{ cm}^{-3}$ ]	$N_{t,net}$ [ $10^{12} \text{ cm}^{-3}$ ]
X	Under investigation	0.195 ± 0.005	2.68	1.21
	Boron	0.273 ± 0.03	3.43	2.13
D	Boron	0.54 ± 0.01	1.06	0.7

#### 5 Conclusion

- The levels associated with Boron increase in intensity after irradiation for both samples (with and without SELC signature).
- Consequently, a change in defect distribution was observed even though no sign of electrical degradation was reported after the heavy-ion irradiation.
- The results indicate an early stage of electron trapping in the defects, and an interplay of the defects caused by the irradiation with residual Boron, a common impurity introduced during the SiC growth.

#### References

- [1] C. Martinella, M. E. Bathen, A. Javanainen, U. Grossner, "Heavy-ion-induced defects in degraded SiC power MOSFETs", presented at ICOSRM 2022, Davos 11-16 September 2022, Switzerland.
- [2] D. Meinshel, et al., "Characterization of energy levels related to impurities in epitaxial 4H-SiC ion implanted p-n junctions", Diamond and Related Materials, Volume 16, no. 1, pp. 6-11, 2007.
- [3] F. Witulski, et al., "Single-Event Burnout of SiC Junction Barrier Schottky Diode High-Voltage Power Devices", in IEEE Trans. Nucl. Sci., vol. 65, no. 1, pp. 256-261, Jan. 2018.
- [4] Capen, I.; Brodar, T. Majority and Minority Charge Carrier Traps in n-Type 4H-SiC Studied by Junction Spectroscopy Techniques. Electron. Mater. 2022, 51, 115-125.



# SERESSA Best Student Posters Award



2<sup>nd</sup> Place:

Arijit Sengupta, Arthur Witulski, Dennis Ball, et al.

## Design of SEB-hardened Silicon Carbide Power Devices for Space Applications

### Design of SEB-Hardened Silicon Carbide Power Devices for Space Applications

A. Sengupta<sup>1</sup>, A.F. Witulski<sup>1</sup>, D.R. Ball<sup>1</sup>, R. D. Schimpf<sup>1</sup>, K.F. Galloway<sup>1</sup>, R. A. Reed<sup>1</sup>, M. L. Alles<sup>1</sup>, M.W. McCurdy<sup>1</sup>, A.L. Sternberg<sup>1</sup>, E.X. Zhang<sup>1</sup> and B. Jacob<sup>2</sup>

<sup>1</sup>Department of Electrical and Computer Engineering, Vanderbilt University, Nashville, TN, USA

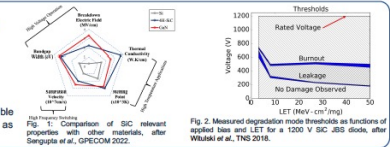
<sup>2</sup>General Electric Global Research, Niskayuna, NY

#### Introduction

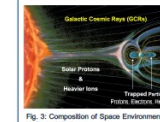
Silicon Carbide (SiC) devices are an excellent choice for high power density, high switching frequency, high voltage applications as seen in Fig. 1. The SiC devices have:

1. Higher Breakdown Voltage (~10x vs. Si)
2. Lower On-State Resistance (~1/100 vs. Si)
3. Higher Temperature Operation (~3x vs. Si)
4. High Thermal Conductivity (~10x vs. Si)

However, SiC power MOSFETs and junction barrier Schottky (JBS) diodes are both susceptible to heavy-ion irradiation, including single-event leakage current (SEL) induced degradation, as well as single-event burnout (SEB), as seen in Fig. 2.



#### SEB-Hardened SiC Devices



- Space environment comprises of trapped particles such as protons, neutrons and heavy ions, solar protons and heavier ions, and galactic cosmic rays (GCRs) as shown in Fig. 3
- But currently, there are no rad-hard SiC devices that can be operated reliably over a bias voltage of 250 V in space environment

- In collaboration with GE Research, Vanderbilt University has designed rad-hard SiC MOSFETs and diodes for the NASA Lunar Surface Technology Research (LuSTR) program that are intended to be reliably operated up to 1200 V without any catastrophic SEB as shown in Fig. 4
- Previous research at Vanderbilt has shown that the mechanism of SEB in SiC devices is related to electric field modification that results in a nearly short circuit between the bulk and the drain contact

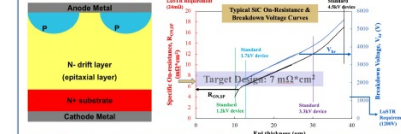
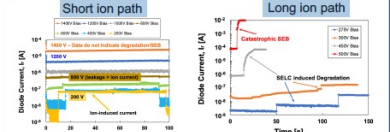


Fig. 4: (a) Typical cross-sections for planar, vertical power junction-barrier Schottky diode, after Ball et al., TNS 2020 and (b) Typical SiC On-Resistance & Breakdown Voltage curves vs the Epitaxial thickness, showing the specifications for the target design, after Sengupta et al., APS/DOS 2022.

- Results from a new experiment at the Vanderbilt Pelletron, shown in Fig. 5(a), demonstrated that for short range ions that do not fully penetrate the epitaxial region, the ions are incapable of causing any permanent damages such as SELC induced degradation or catastrophic SEB
- This supports the concept of increasing the epitaxial layer thickness to combat SEB in the devices up to a higher bias voltage. The specific on-resistance and breakdown voltage have been plotted in Fig. 4 in terms of the epitaxial thickness
- Two new devices are being fabricated leveraging existing 3.3kV design to speed up the design flow, and optimizing epitaxial thickness based on data shown in Fig. 7 and an estimated range of SEB performance for the new device is also shown

#### Heavy-ion Irradiation Testing



- Heavy-ion testing at VU Pelletron showed no SELC induced degradation or SEB up to a bias of 1400 V as shown in Fig. 5 (left)
- Heavy-ion testing at TAMU Cyclotron showed SEB at 500 V with long-range ions, as shown in Fig. 5 (right)

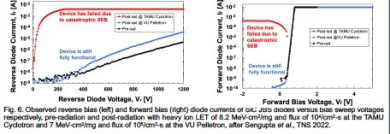


Fig. 6: Observed reverse bias (left) and forward bias (right) diode currents at various times during irradiation with heavy ion LET of 6.2 MeV/cm²-mg and flux of 10¹⁰cm⁻²-s at the TAMU Cyclotron and 7 MeV/cm²-mg and flux of 10¹¹cm⁻²-s at the VU Pelletron, after Sengupta et al., TNS 2022.

- Pre-rad and post-rad sweeps show the JBS diodes were fully functional post-irradiation with short-range ions at VU Pelletron but failed post-irradiation with long-range ions at TAMU Cyclotron
- 1700 V and 3300 V SiC devices were also irradiated at TAMU Cyclotron

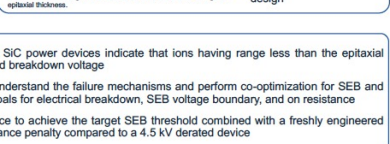


Fig. 7: Accumulated device radiation test data showing where new baseline data from TAMU Cyclotron for the GE 3.3 kV planar device (a) data fits in with previous data from Ball et al., TNS 2021. Region for (b) shows estimated range of threshold for SEB in devices with greater epitaxial thickness.

#### Discussion

- Results from the recent experimental and simulated heavy-ion responses in SiC power devices indicate that ions having range less than the epitaxial thickness do not cause degradation or catastrophic failure even above the rated breakdown voltage
- Heavy-ion irradiation test results and device simulations have been used to understand the failure mechanisms and perform co-optimization for SEB and electrical performance resulting in a simulated design that meets the LuSTR goals for electrical breakdown, SEB voltage boundary, and on resistance
- The newly fabricated devices use the epitaxial thickness of a GE 4.5 kV device to achieve the target SEB threshold combined with a freshly engineered gate and source design and modified surface structures to reduce the performance penalty compared to a 4.5 kV derated device



VANDERBILT UNIVERSITY



GE Global Research



# SERESSA Best Student Posters Award



3<sup>rd</sup> Place:

Saulo Alberton, Alexis Cristiano Vilas Bôas, Nilberto Heder Medina, Marcilei Aparecida Guazzelli, et al.

## Charge generation induced by alpha particles and neutrons in advanced power transistors

### Charge generation induced by alpha-particles and neutrons in advanced power transistors

SERESSA  
2022

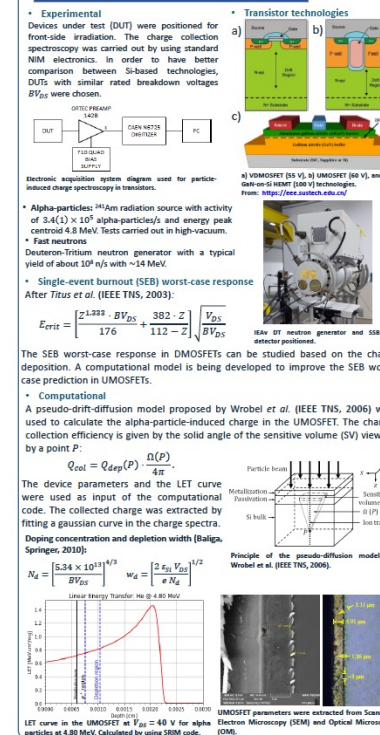
S. G. Alberton<sup>1</sup>, A. C. Vilas Bôas<sup>2</sup>, N. H. Medina<sup>1</sup>, M. A. Guazzelli<sup>2</sup>,  
V. A. P. Aguiar<sup>1</sup>, N. Added<sup>1</sup>, C. A. Federico<sup>1</sup>, O. L. Gonçalves<sup>2</sup>,  
T. C. Cavalcante<sup>3</sup>, E. C. F. Pereira Junior<sup>3</sup>, R. G. Vaz<sup>3</sup>

<sup>1</sup>Department of Nuclear Physics, University of São Paulo, Brazil  
<sup>2</sup>Physics Department, Centro Universitário FEI, Brazil  
<sup>3</sup>Institute for Advanced Studies, Brazilian Air Force, Brazil

#### 1. Introduction

Alpha particles and neutrons can induce Single-Event Effects (SEEs) in power transistors. Few studies have been published for alpha-particle- and neutron-induced SEEs in UMOFETs, the current main candidate to supplant the traditional DMOSFET technology, and in the state-of-the-art GaN-on-Si HEMTs. In this work, experimental results of SEEs induced by 4.8 MeV alpha particles and quasi monoenergetic fast neutrons provided by a Deuteron-Tritium neutron generator in DMOSFET, UMOFET, and GaN HEMT are presented. The neutron-induced SEE responses of these devices are compared to the response of a silicon detector. The main aspects of the ion-induced charge collection mechanisms in the UMOFET are discussed. Based on an existing model from the literature for SEE worst-case response prediction in DMOSFETs, an improved predictive model for SEB worst-case response in UMOFETs is being developed.

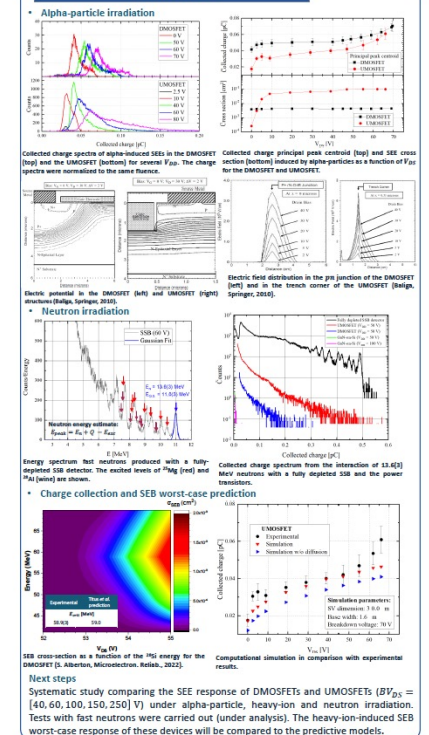
#### 2. Methodology



#### 4. CONCLUSIONS

It was experimentally verified that ion-induced carrier multiplication is a prominent phenomenon in the UMOFET technology. In general, it results from the alpha-particle and neutron experiments that the UMOFET is more susceptible than the DMOSFET to suffer from SEEs, except for very low  $V_{DS}$ . The high susceptibility to SEEs in the UMOFET is attributed to its high cell density and the intense electric field near the trench gate corner. Among the tested devices, the GaN-on-Si HEMT presented very high robustness to SEEs induced by fast neutrons. We provide first evidence that the methodology of Titus et al. is relevant for SEB failure prediction in DMOSFETs. Although this model is not able to accurately reproduce the charge collection/deposition in UMOFETs, an implemented computational model was able to successfully reproduce the charge collection in the UMOFET. Based on this model, an improved predictive model for SEB worst-case response in UMOFETs will be developed.

#### 3. Results





# Thank you and see you at **SERESSA 2023!**

