DESTRUCTIVE RADIATION EFFECTS IN ELECTRONIC DEVICES: ATMOSPHERIC AND SPACE ENVIRONMENTS

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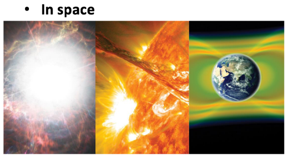
1. INTRODUCTION

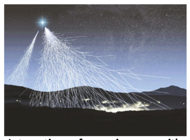
Cosmic radiation

- In space

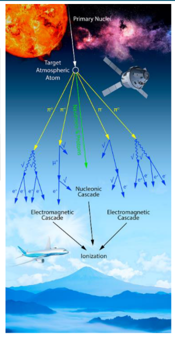


Cosmic radiation components in space: galactic, solar, and trapped.

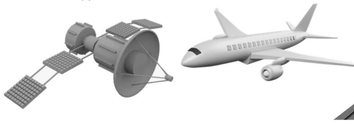
- On Earth



Interaction of cosmic rays with atmosphere.

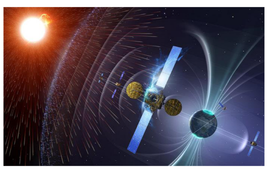


Terrestrial cosmic radiation cascade.



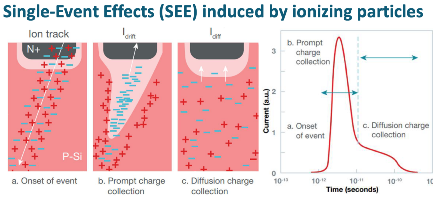
Examples of electronic systems that demand high reliability.

Radiation effects in electronics



Dominant radiation effects in space-borne and terrestrial electronic systems has been observed as Single-Event Effects (SEE).

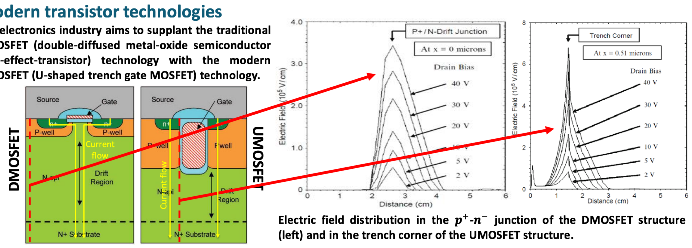
Single-Event Effects (SEE) induced by ionizing particles



Temporal evolution of charge collection in semiconductors due to strongly ionizing particles (left), and typical electric current signal response (right).

Modern transistor technologies

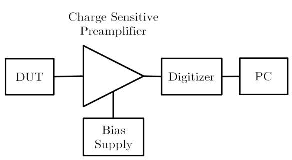
The electronics industry aims to supplant the traditional DMOSFET (double-diffused metal-oxide semiconductor field-effect-transistor) technology with the modern UMOSFET (U-shaped trench gate MOSFET) technology.



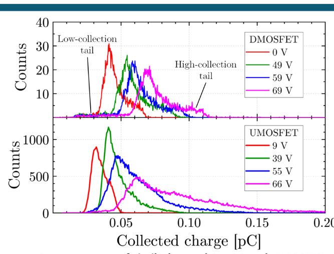
Electric field distribution in the p^+-n^- junction of the DMOSFET structure (left) and in the trench corner of the UMOSFET structure.

2. CHARGE COLLECTION EFFECTS

Alpha-particle irradiation



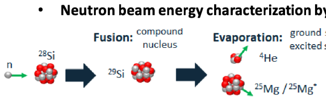
Electronic acquisition system diagram for particle-induced charge spectroscopy.



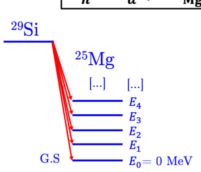
Energy spectra of similarly rated DMOS and UMOSFETs under alpha particle irradiation.

Quasi-monoenergetic neutron irradiation: DT neutron source

- Neutron beam energy characterization by using a silicon surface barrier (SSB) particle detector



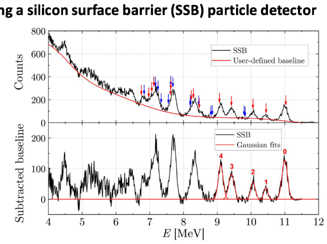
$$E_n = E_\alpha + E_{^{25}\mathrm{Mg}} + E_{exc} - Q$$



$Q = -2.654$ MeV

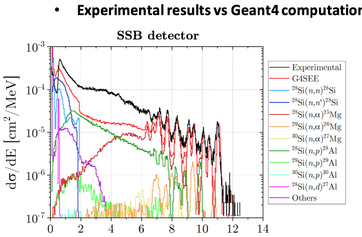
First excited states (E_{exc})

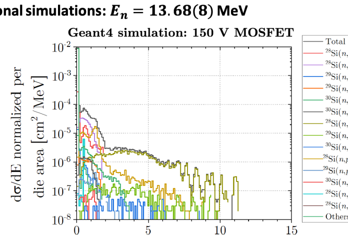
^{25}Mg [MeV]	^{28}Al [MeV]
0.585045(21)	0.0306382(7)
0.974756(22)	0.97235(3)
1.611768(11)	1.013637(9)
1.964624(23)	1.372917(20)
2.56336(5)	1.6203(4)
2.7378(3)	1.622907(20)



Energy spectra of a SSB particle detector um DT neutron irradiation. The arrows represent calculations of the energy levels for ^{25}Mg (red) and ^{28}Al (blue) nuclei.

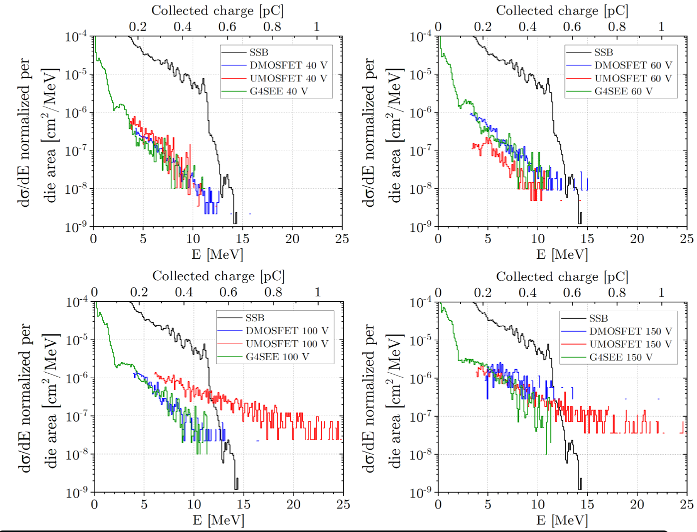
- Experimental results vs Geant4 computational simulations: $E_n = 13.68(8)$ MeV





2. CHARGE COLLECTION EFFECTS (CONT.)

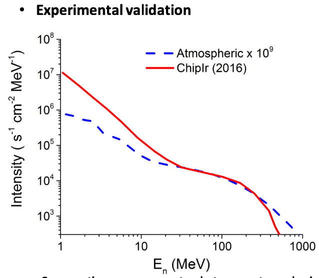
- Experimental results vs Geant4 computational simulations



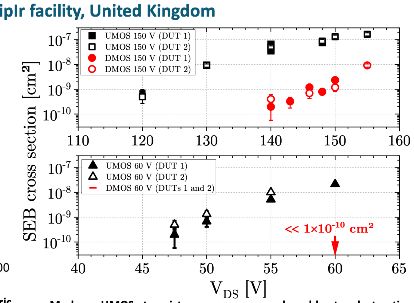
3. DESTRUCTIVE EFFECTS: ATMOSPHERIC ENVIRONMENT

Atmospheric neutron irradiation: ChipIr facility, United Kingdom

- Experimental validation



Comparative energy spectra between atmospheric neutrons and the ChipIr spallation facility.

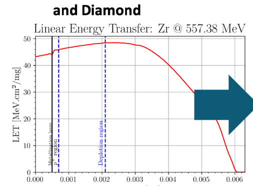


Modern UMOS transistors are more vulnerable to destructive radiation effects in the atmospheric environment.

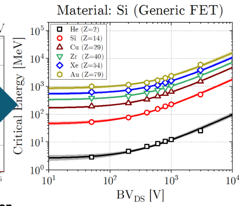
4. DESTRUCTIVE EFFECTS: HEAVY ION BEAMS

The ion-induced worst-case response prediction in semiconductor power devices

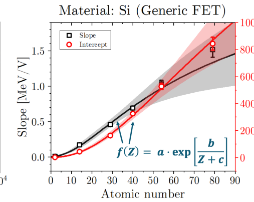
- Computational systematics applied for several semiconductor materials: Si, SiC, Ge, GaAs, GaN, and Diamond



Linear Energy Transfer (LET) curve of Zr ion bombarding a Si-based generic FET structure. Calculated by using the SRIM code.



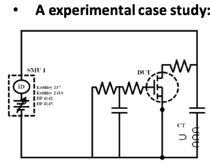
The critical ion energy prediction shows a linear dependence on the device's breakdown voltage.



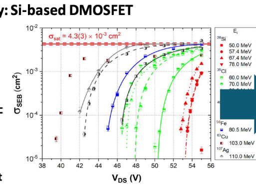
Slope and intercept fit parameters as a function of the ion atomic number.

Heavy ion beam irradiation: São Paulo Pelletron 8UD particle accelerator, Brazil

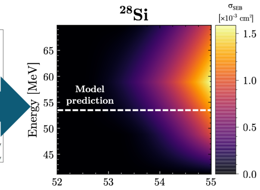
- A experimental case study: Si-based DMOSFET



Protective circuit for indirect measurements of destructive radiation effects.



Single-Event Burnout cross-section measurements in a Si-based DMOSFET.



Heat map of experimental data and model prediction.

CONCLUSIONS

The particle-induced charge in traditional and modern transistor technologies, DMOS and UMOS, was experimental and computationally studied. From alpha particle and monoenergetic fast neutron irradiations, it was observed that the modern UMOSFET technology is more prone to experiencing premature charge multiplication effects due to internal electric field stress. In general, experimental results confirm that the UMOSFET is significantly more vulnerable to suffering catastrophic failure modes in atmospheric environments. Additionally, through experimentally validated computational results, we propose a comprehensive protocol for qualifying destructive radiation effects on semiconductor power devices with particle accelerators.

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