Radiation Effects in Modern and Emerging Technologies

Announcement for the 2025 IEEE NSREC Short Course

MONDAY
JULY 14, 2025
NASHVILLE,
TENNESSEE
USA

On behalf of the 2025 IEEE Nuclear and Space Radiation Effects Conference (NSREC) Committee, I cordially invite you to attend the 46th IEEE NSREC Short Course. An outstanding group of technical experts will provide an in-depth discussion of radiation effects in traditional, advanced, and emerging devices and systems, including CMOS, nonvolatile memories, and systems based on these technologies.

Matthew Marinella
Arizona State University
Short Course Chair

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COURSE DESCRIPTION

A short course, "Radiation Effects in Modern and Emerging Technologies", will be presented at the 2025 IEEE Nuclear and Space Radiation Effects Conference. The radiation effects community is encountering changes in devices, circuits, and systems which will give both existing new opportunities for radiation hard electronics, but also create new challenges. This course has been designed to provide both the background and fundamentals combined with the recent findings needed to understand this evolving field.

The short course is organized into four sections. Each has two subsections that start with the fundamentals resulting from decades of research, follow up with the application of these principles to radiation effects in modern and emerging technologies. The first two sections cover cumulative and transient effects in CMOS, starting with fundamentals and extending into modern technologies. The third section focuses on nonvolatile memory, covering fundamentals and extending the discussion to modern and emerging memories. Finally, the course concludes with a section on a discussion of radiation effects in systems.

The short course is intended for students, researchers and engineers working in the field of radiation effects and radiation hard electronics. In addition, will be relevant to device, circuit, and system designers and managers involved in implementing these systems. It provides a unique opportunity for IEEE NSREC attendees to benefit from the expertise of excellent instructors, along with a critical review of state-of-the-art knowledge in the field. Electronic copies of detailed course notes will be provided to each participant. Continuing Education Units (CEUs) will be available. For the interested attendees, an exam will be given at the end of the short course. The course is valued at 0.6 CEUs and is endorsed by IEEE and the International Association for Continuing Education and Training (IACET).

PART I – CUMULATIVE EFFECTS IN CMOS

The history of cumulative radiation effects on MOSFET and CMOS technologies traces back to the early days of semiconductor devices and their deployment in space and military applications. As CMOS technologies gained prominence in the 1960s and 1970s, researchers observed that ionizing radiation exposure could degrade the performance of these majority carrier devices. This discovery led to an increased focus on understanding the mechanisms of total ionizing dose (TID) radiation-induced damage, typically characterized by trapped charge accumulation in the dielectric and trap buildup at dielectric-semiconductor interface. By the 1980s, as CMOS integrated circuits became more complex, the effects of TID radiation on MOSFETs became a critical area of study, especially for space missions and other high-radiation environments. Early studies of TID effects concentrated on traditional bulk and silicon-on-insulator (SOI) technologies with an emphasis on ionization damage to the relatively thick gate oxides and even thicker buried oxides (used in SOI). As CMOS technologies scaled, the threats posed by ionizing radiation to ever thinner gates oxides began to diminish, leading to greater concentration on sidewall isolating dielectrics, particularly for bulk processes. In the first section of the short course, **Prof. Hugh Barnaby** of Arizona State University will present the history of TID effects in these older technologies, with a review of the fundamental concepts associated with charge generation, recombination, carrier transport, defect creation and annealing, which are still important today. The second part of the course given by **Dr. Marc Gaillardin** of CEA will focus on cumulative radiation effects on modern/emerging CMOS, which have made or will make their way into mainstream integrated circuits. These advanced MOSFETs include ultra-thin body SOI (UTBSOI) devices (e.g., partially and fully depleted SOI); Fin-based Field Effect Transistors (FinFETs), and Gate All Around (GAA) Transistors. Recent investigations have shown some recognizable effects but also novel response characteristics that are unique to the very complex structural features, chemistry and material systems used in these advanced process nodes. The course will also review some of the less studied but important concerns encountered in MOSFETs and beyond CMOS transistors that are exposed to cumulative radiation dose such as displacement damage and enhanced low dose rate sensitivity.

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PART II – MODELING SINGLE EVENT TRANSIENT EFFECTS IN CMOS

Dr. Dennis (Scooter) Ball of Vanderbilt University, and **Dr. Jeffrey Black** of Sandia National Laboratories, will give a presentation on the multi-tooled approaches to modeling and simulation of single event transients in CMOS technologies. The course will cover the modeling tools being used: Technology Computer Aided Design (TCAD), radiation transport, circuit simulation, and fault injection/emulation. An example will be presented demonstrating how each of the tools are used to reproduce ground-based accelerator experimental data and then used to predict environmental rates. Further examples will be provided showing how single event modeling is done in emerging technologies like FinFETs and Gate All Around (GAA) FETs and what we have learned from modeling results.

PART III – RADIATION EFFECTS IN NONVOLATILE MEMORIES

Flash memories are ubiquitous in all digital systems today and are also attractive as non-volatile storage in space, because their capacity is unmatched by any rad-hard memory. In the first part of the short course**, Prof. Marta Bagatin** of the University of Padova will cover the effects of ionizing radiation in Flash memories. After reviewing the operation principles of these devices, total ionizing dose and single event effects will be illustrated. Possible short- and long-term phenomena following radiation exposure both in the memory cells and in the peripheral circuitry will be covered. The course will be supported by experimental data, analysis, and simulations, highlighting the impact of the technological evolution in a journey from traditional, planar devices to the most novel 3D integrated architectures. In the second half of this short course, **Dr. T. Patrick Xiao** of Sandia National Labs will review the current understanding of the effects of ionizing radiation and displacement damage on emerging non-volatile memories such as charge-trapping memory, magnetic memory, resistive memory, phase change memory, and electrochemical memory. The physics of radiation effects in emerging memories is often fundamentally distinct from effects on commercial NAND flash and other CMOS electronics. For non-charge-based memories, this leads to very high intrinsic radiation tolerance, making them attractive for space applications. Furthermore, as the end of Moore's law has slowed progress in computer processors, there has been significant research momentum to repurpose these emerging memories as low-power analog computational devices. However, using a traditionally binary memory as an analog memory can greatly increase radiation sensitivity. This course will also review the operation and design principles of analog in-memory computing systems and how the accuracy of analog computing is affected by radiation effects.

PART IV – RADIATION EFFECTS IN MICROELECTRONIC SYSTEMS

In the first part of this course, prepared in collaboration with **Prof. Mike Wirthlin** and **Prof. Jeff Goeders,** both of BYU will discuss radiation effects in modern, complex systems, with a focus on FPGAs, GPUs, and SoCs. These types of commercial off-the-shelf (COTS) devices are increasingly being used in space and other radiation environments due to their high performance, low cost, and rich features. However, these devices are subject to various single-event effects (SEEs) and total ionizing dose (TID) effects, which can manifest as silent data corruption, system crashes and hangs, and permanent damage. The complexity of these devices makes it difficult to model and predict their radiation response, as the devices typically contain substantial internal state and complex interactions between components. Radiation testing of such systems requires substantial effort, time and expertise in developing appropriate test frameworks. This course will discuss both the radiation effects in these systems, as well as different strategies and lessons learned in how to effectively test and characterize these devices. In the second half of this course, **Prof. Fernando Fernandes** from INRIA, with the support of **Prof. Paolo Rech** from the University of Trento, will discuss the reliability challenges of adopting emerging post-Von Neumann architectures in safety-critical applications and space missions. While existing hardware architectures offer high computational performance, the memory bottleneck remains a limiting factor for energy efficiency and scalability since, in most applications, including AI, most of the power is wasted on data movement. New technologies such as processing in-memory and neuromorphic computing are emerging as alternatives to existing ones. Unfortunately, characterizing radiation effects and fault models on emerging hardware is challenging as conventional evaluation methods are not suitable for the task. The challenges include not only fault identification and correction but also designing radiation tests and qualification methodologies for emerging architectures.