Calculation of Terrestrial Cosmic-Ray Displacement Damage

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Abstract:
Terrestrial neutrons due to cosmic rays from the outer space are constantly striking electronic devices at ground level. Each neutron is likely to generate a cascade of atomic displacement, that can be referred to as Single Particle Displacement Damage. With device integration, these single cascades might impact the properties of integrated devices. This tutorial presents a comprehensive approach for the simulation of Single Particle Displacement Damage, from the incident particle interaction to the resulting electrical effect observed experimentally. The different steps of the global approach are presented, first describing the succession of phenomena at stake, and then identifying the corresponding simulation technique chosen for each step of the process, some outputs of one step being the inputs of the next. Combining different techniques allows covering large time scales, from the fs for the interaction itself to long-term evolution observed after seconds and more.

Monte Carlo simulation of the interaction between an incident particle and silicon, in the Binary Collision Approximation (BCA) is first performed. The next step is a classical Molecular Dynamics (MD) simulation of the trajectory of selected Primary Knock-on Atoms (PKA), with the detailed displacement cascade and the first steps of its evolution. To explore the long term evolution of this structure and reach time scales comparable with experimental data, a new technique called the kinetic Activation-Relaxation Technique (k-ART) is then used. Finally, first principles calculations are performed to calculate the electronics properties of the selected atomic damage structure. The output is, for each selected atomic damage structure, the energy levels introduced in the bandgap and the associated electronic activity. The originality of this comprehensive approach is to link these different types of simulations that are usually performed independently, to obtain realistic damage structures representative of what results

from the initial neutron-silicon interaction and to identify defect structures detrimental to the technology's performances.

Biographies:

Mélanie Raine received her PhD in Physics from Université Paris Sud in 2011 and her engineering degree in Micro-nano-biotechnologies and M.S. degree in Electrical Engineering from Ecole Centrale de Lyon in 2008. She is a research engineer at CEA, DAM-Ile de France, Arpajon. Her field of expertise is the Monte Carlo simulation of radiation interaction in matter, and the resulting effect on integrated electronic devices, studying in particular Single Event Effects (SEE) in nanometric devices. She currently manages the hardened circuits and technologies team responsible for the study of advanced microelectronics technology under radiation through radiation test campaigns and modeling. She has authored/coauthored more than 60 journal papers.

Nicolas Richard received his Ph.D. from the University of Marne-la-Vallée in 2001 and the Habilitation à Diriger des Recherches from the Université Paul Sabatier of Toulouse in 2014. He is currently researcher at CEA-DAM-Ile de France, Arpajon, France. His field of expertise is atomic scale simulation of materials and the studies of the impact of the point defects on materials properties, mainly related to microelectronic and optoelectronic technologies under radiation. He has participated to numerous studies on the simulation of the generation of defects during manufacturing processes and under irradiation in microelectronic, the characterization of defects in oxides and semiconductors and at oxide/oxide and oxide/semiconductor interfaces. He has authored or co-authored over 60 journal papers and has been supervisor or co-supervisor of around ten PhD and post-doctoral students.