Large scale instruments for characterization

Nanoelec's Characterization program is part of the institute's digital trust offering in support of the digital transition. Ennio Capria, Programme Director, sheds light on the achievements of 2022.

ENNIO CAPRIA, DEPUTY HEAD OF BUSINESS DEVELOPMENT AT ESRF AND DIRECTOR OF THE NANOELEC CHARACTERIZATION PROGRAM

Through the Nanoelec Characterization program, industrial firms and researchers have access to world-class tools to study the effects of ionizing radiation on electronic devices and systems, to characterize the properties of their materials and to inspect their components, contributing to the quality of their products and processes. Thanks to the high penetrating power of neutrons and synchrotron X-rays, these evaluations can be performed non-destructively, without the need to open or damage the objects, and in many cases while they are operating.

In 2024, the Characterization program continued to play a central role, offering innovative solutions and strengthening its collaborations with key partners, including STMicroelectronics, Soitec, Schneider Electric and Iroc Technologies. The year was marked by increased demand for non-destructive imaging (NDI) techniques at ESRF, driven by the spectacular advances made possible by the new EBS synchrotron source. •

AGENDA

Correlative Material characterization

The ESRF BM05 beamline, X-ray Beam Induced Current analysis brings correlations between charge collection efficiency and defects in the materials.

A new instrument capable of performing correlative analyses between XBIC (X-ray Beam Induced Current) and X-ray Diffraction Imaging is now available at the ESRF BM05 beamline. *"We successfully developed and implemented a new XBIC setup that allows characterization of semiconductors. This technique was shown to complement existing techniques (such as RCI, spectroscopy, XRF microscopy, etc.). The characterization of different diamond samples enabled us to identify the correlations between charge collection efficiency and defects like dislocations, growth boundaries and growth sectors, impurities, and color centers,"* explains Thu-Nhi Tran-Caliste, industrial liaison engineer at the ESRF, who is taking part in the study for the Nanoelec Characterization program.

Further investigations were conducted in 2024 with other semiconductors (GaN, SiC or CdTe) to fully evaluate the potential of this technique coupled with Bragg diffraction imaging.

Pierre Everaere, an engineer at ESRF, presented the first results obtained within Nanoelec on the international stage at NDNC 2024 Conference[1] and the French Japanese Workshop on Diamond Electronic Devices 2024[2].

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1. Everaere, P. (May 30, 2024). Coupling X-ray Beam Induced Current, ToF-XBIC and X-ray Diffraction Imaging to characterize diamond plates used as semiconductor-based detectors. Workshop NDNC 2024, Sydney (Australia)

2. EEveraere, P., Caliste, T. N. T., Baruchel, J., Benichou, S., & Dowek, R. (June 14, 2024). Coupling X-ray Beam Induced Current, ToF-XBIC and X-ray Diffraction Imaging for semiconductor characterization. French Japanese Workshop on Diamond Electronic Devices 2024, Cap Estérel

PROGRAM AT A GLANCE

- **Vision**
  The unmatched performance of large-scale instruments must be adopted by industrial users as a cutting-edge tool to perform advanced characterizations of electronic components and devices
- **Ambition**
  Develop a competence center for testing radiation hardness of electronic components
- **Mission**
  Continue to make unique scientific instruments & methodologies available to meet the new challenges of the electronics industry, for the serenity and sovereignty of the digital transition
- **Partners**
  CEA, CNRS/LPSC, ESRF, ILL, Schneider Electric, Soitec, STMicroelectronics, Iroc Technologies

SIMON BENICHOU AND THU NHI TRAN-CALISTE ARE OPERATING NANOELEC GIANT GONIOMETER FOR X-RAY REFLECTOMETRY AND DIFFRACTOMETRY AT ESRF BM05 BEAMLINE

AGENDA

Soft errors caused by neutron irradiation

Correlation between the sensor sampling frequency and the rate of SEU-induced mismatch failures in the case-study system.

A team from Telecom Paris, Tima laboratory (CNRS, Grenoble INP-UGA, UGA), and Institut Laue-Langevin revealed the impact of increasing the sensor sampling frequency on the reliability of a typical edge processing system operating under the effects of 14-MeV neutrons and thermal neutrons[3].

The results of two types of accelerated radiation tests indicate that the failure rates induced by soft errors caused by 14-MeV and thermal neutrons grow as a function of the sensor sampling frequency. The failure rates caused by 14-MeV neutrons rose by a factor of 2.2 by shifting the sensor sampling frequency from around 140 to 430 Hz. The results also suggest that the design and calibration of edge processing systems should consider the sensor sampling frequency as a parameter for adjusting the computing speed of the system in order to improve reliability in tolerating soft errors caused by neutrons..

RICHARD DAVIES, INDUSTRIAL APPLICATIONS SCIENTIST AT ILL & NANOELEC/CAR PROGRAM AND EMMANUEL ATUKPOR, ILL RESEARCH ENGINEER RESPONSIBLE FOR NANOELEC/TENIS

3. de Carvalho, M. M., Laurini, L. H., Atukpor, E., Naviner, L., & Bastos, R. P. (2024). Impact of Scaling Up the Sensor Sampling Frequency on the Reliability of Edge Processing Systems in Tolerating Soft Errors Caused by Neutrons. IEEE Sensors Letters, 8(9), 1-4. IEEE Sensors Letters. https://doi.org/10.1109/LSENS.2024.3435677

AGENDA

Neutron reflectometry for improved photolithography

Coatings on epoxy resin were investigated.

To protect polymer resins used in the semiconductor industry for patterning through photolithography, a hard coating can be applied to the polymer to prevent surface degradation.

Different coatings on epoxy polymer resin under ambient conditions have been investigated with in-situ neutron reflectometry in a vacuum and a D2O-saturated atmosphere. Results were published by authors from Institut Laue-Langevin and STMicroelectronics and Uppsala University (Sweden) collaborating within Nanoelec[4].

Emulating heavy ions irradiation on components through pulsed X-rays

Alternative to heavy ions testing of components.

Tynchrotron X-rays may be used to emulate the interaction between heavy ions and electronic devices for next generation space applications. The capability of synchrotron pulsed X-rays to deposit critical charges on electronic components has been demonstrated at the ESRF, in the frame of the PAC-G[5] driven, innovation led long term project for microelectronics industry. It can be used for fault injection, pre-screening and sensitivity characterization. As presented at GB-RADNext 2024[6] and IEEE Space Environment Workshop, also the possibility to characterize encapsulated components has been demonstrated, though the experiment should be carefully designed.

Reviewing potentially suitable facilities for pulse X-Ray irradiation, Françoise Bezerra (Cnes) presented at the Thematic Day of the RADECS2024 conference a selection of results collected at the ESRF ID09 beamline in the frame of the Nanoelec/PAC-G platform. *"More and more components are difficult or impossible to test under heavy ions, she said. Either because of limitation in the sample preparation/decapsulation (cost, delay, yields), or because the energy is not high enough to properly represent realistic conditions in space or because of strict conditions needed in the sample packaging, probing and conditioning close to the ion source."*

Results for several kind of components like Silicon based COTS (commercial Off the shelf), various diodes (Si, SiC or GaN) and finally power devices were presented at the RADECS2024 Thematic Workshop[7].

4. Chevreux, F., Letiche, M., Vorobiev, A., Wolff, M., & Chapelon, L.-L. (2024). Moisture Diffusion in PECVD a-SiOxNy:H and a-SiOx:H Coated on Polymer Resins : A Neutron Reflectometry Study. ACS Applied Electronic Materials, 6(7), 4864-4868. https://doi.org/10.1021/acsaelm.4c00239

5. Nanoelec/PAC-G provides a range of services, from consultancy work to executing sample characterization experiments and analysing data. This includes access to large-scale facilities, such as synchrotron and neutron sources, and offers a cost-effective and rapid service tailored to the micro- and nano-electronics industry. Through PAC-G, industry can gain access to cutting-edge characterization tools, without going through selection processes, and to some of the world's most knowledgeable experts in the field of material characterization

6. Capria, E. (June 13, 2024). The use of synchrotron X-rays to emulate the interaction between heavy ions and electronic devices for next generation space application. GB-RADNEXT 2024, Didcot (United Kingdom). https://indico.cern.ch/event/1353707/

7. Bezerra, F., Dubos, S., Coic, L., Guillermin, J., Levantino, M., & Capria, E. (2024, September). Perspectives and Current Status on SEE Testing with Pulsed X-rays. Mas palomas, RADECS2024 Thematic Workshop

NANO-FOCUSING ON ID01 BEALINE AT THE ESRF DEDICATED TO MICRODIFFRACTION IMAGING

Testing hard coating for resins in photolithography

Since the 1970s, polymer resins have been widely utilized in the semiconductor industry for patterning through photolithography. In state-of-the-art image sensors, permanent resins are used in arrays of microlenses to optimize the path of light and increase its yield.

The variety of resin compositions, their tunable refractive indices, and their shapes allow them to meet the high standards required in microelectronics manufacturing. Moreover, the polymer layer is moisture-resistant and prevents water from penetrating into the sensor. Unfortunately, polymers have soft surfaces and are easily damaged by mechanical stress. A hard coating can be applied to the polymer to prevent surface degradation. In a paper published in ACS Applied Electronic Materials[8], a team from STMicroelectronics, Laue Langevin Institute and Uppsala University, supported by Nanoelec, used X-ray photoelectron spectroscopy (XPS) and ToF-SIMS to study the uptake of water by thin films of SiOxNy and SiOx hard coatings as-deposited on epoxy polymer resin by PECVD.

8. Chevreux, F., Letiche, M., Vorobiev, A., Wolff, M., & Chapelon, L.-L. (2024). Moisture Diffusion in PECVD a-SiOxNy:H and a-SiOx:H Coated on Polymer Resins : A Neutron Reflectometry Study. ACS Applied Electronic Materials, 6(7), 4864-4868. https://doi.org/10.1021/acsaelm.4c00239

Optical transceivers under heavy ions

SEE sensitivity and testing constraints

Latest generation high data-rate optical transceivers are considered innovative and strategic products for future space missions.

A team from TRAD Tests & Radiation and Cnes, partially supported by the Nanoelec/Carac program, investigated heavy ion SEE sensitivity and testing constraints using various test facilities for such products, including synchrotron focused pulsed X-rays. This work, presented at RADECS 2024[9], reinforces the interest in these products and shows that even high-frequency optical transceivers can be tested, with minimal preparation. In the end, the data shows that the products tested as part of this study can be of interest for telecoms missions.

9. Aubry, Laborde, Coic, L., Garcia, P., Dubos, S., Guillermin, J., Dufour, & Mekki. (September 16, 2024). Study of the heavy-ions sensitivity of latest generation high data-rate optical transceivers. Actes RADECS 2024, Mas Palomas (Spain)

AGENDA

Single-Event Upsets Induced by Thermal Neutrons in SRAMs

No need for a very large amount of nitride to cause a substantial number of upsets in SRAMs.

Investigations of single-event upsets (SEU)[10] induced by thermal neutrons continued in 2023 at the Thermal and Epithermal Neutron Irradiation Station (TENIS ILL/Nanoelec beamline)[11]. Thermal neutrons are an important contributor to any radiation environment where spallation reactions and neutron moderation are involved. This is the case in the atmosphere (ground level to flight altitudes) as well as in high-energy physics accelerators. Thermal neutrons can trigger single-event upsets (SEUs) in memory-based devices through indirect ionization following their nuclear absorption in 10B atoms that may be present within or near sensitive cells.

Combining experiments at Tenis, as part of the Nanoelec/Carac program, with simulations, a pan-European collaboration was published in the IEEE Transactions on Nuclear Science Review[12]. *"We introduce the possibility that thermal neutron SEUs may not only be caused by the interaction with 10B in the proximity of the SV, but also by the interaction with 14N that may result in the release of low-energy protons (LEPs)[13],"* explains Andrea Coronetti (Cern) as first author of the paper.

Typically, nitrogen is used in thin barrier layers made of TaN or TiN or even as an insulator in the form of Si3N4. The presence of nitrogen in these thin barrier layers can be enough to justify the experimentally observed thermal neutron SEU cross-section for a static random-access memory (SRAM). Nevertheless, the expected SEU cross-section from thermal neutrons is usually a few orders of magnitude lower than that of high-energy particles, and does not therefore represent a major threat in atmospheric applications. At the same time, for high-energy accelerators, the contribution to the total soft error rate could become substantial, although easy to handle by means of margins.

"The devices that may be affected are therefore only those showing a marked sensitivity to LEPs. At the same time, there is no need for a very large amount of nitrides (TaN, TiN, or Si3N4) to cause a substantial number of upsets in these kinds of devices," warns Andrea Coronetti.

10. The terms single-event upset (SEU), single-event effect (SEE) or single-event latch-up (SEL) refer to the highly localized deposition of energy by single particles or their reaction products causing adverse effects in a sensitive node of a microelectronic device

11. In 2023, ten external experiments took place on the TENIS instrument (Thermal and Epi-Thermal Neutron Irradiation Station), although the ILL reactor did not deliver any neutrons from October 2021 to March 2023, due to a major maintenance and upgrade program

12. Coronetti, A., Alía, R. G., Lucsanyi, D., Letiche, M., Kastriotou, M., Cazzaniga, C., Frost, C. D., & Saigné, F. (2023). An Analysis of the Significance of the 14N(n, p) 14C Reaction for Single-Event Upsets Induced by Thermal Neutrons in SRAMs. IEEE Transactions on Nuclear Science, 70(8), 1634-1642. https://doi.org/10.1109/TNS.2023.3239407

13. When a capture of thermal neutrons releases low-energy protons into the material

AGENDA

French reliability center

Nanoelec joins the national community of reliability experts.

Since the end of 2023, Nanoelec has been a member of the French Reliability Center (CFF), a grouping of reliability experts for electronic systems and components. The CFF is a national body and includes academic and industrial entities, laboratories and research units, large groups and SMEs/mid-caps.

A VIEW OF THE DEUTERIUM IONS SOURCE ON THE GENESIS ACCELERATOR[14]. A NEUTRON BEAM (14 MEV) IS GENERATED BY THE NUCLEAR REACTION OF DEUTERIUM NUCLEI ON A TRITIUM TARGET. THE GENESIS INSTALLATION IS MAINLY USED TO TEST THE EFFECTS OF A SINGLE EVENT IN THE FIELD OF MICROELECTRONICS, ON DIAMOND OR SILICON WAFERS. ACCESS TO THIS UNIQUE INSTRUMENT IS INCLUDED IN THE PAC-G SERVICE FOR INDUSTRIAL STAKEHOLDERS.

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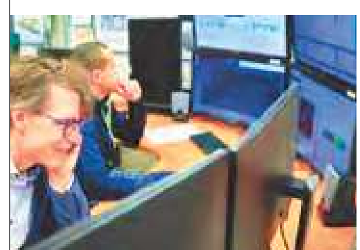
PAC-G provides a single access point to large-scale facilities such as synchrotron and neutron sources through a cost-effective and rapid service tailored to innovation in electronics.

PAC-G provides the electronics industry with quick and easy access to some of the world's most advanced characterization facilities. Under the Nanoelec/Carac program, PAC-G also provides an extremely broad portfolio of individual but complementary characterization techniques.

A dedicated pipeline has been established to ensure that all proofs-of-concept validated within the program are successfully transferred and adopted by the relevant R&D partners.

"The partnership between Schneider Electric and PAC-G is vital, whether for service design— such as quality control or methodology development—or to bring our research and technology initiatives forward with the right expertise," comments Damien Bachellerie, Ph.D, Global Insulation & Dielectrics Technical Leader in the Innovation & Technology division at Schneider Electric.



PAC-G IS A DEDICATED GATEWAY GIVING THE MICRO- AND NANO-ELECTRONICS INDUSTRY QUICK AND EASY ACCESS TO SOME OF THE WORLD'S MOST ADVANCED CHARACTERIZATION FACILITIES

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14. At the subatomic physics and cosmology laboratory in Grenoble (CNRS – UGA)