



UNIVERSITÉ DE MONTPELLIER

FACULTÉ DES SCIENCES

COMMISSARIAT A L'ENERGIE ATOMIQUE ET
AUX ENERGIES ALTERNATIVES

**Report of the Alternance program for the Masters
second year in Computational Physics**

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June 2024

Acknowledgements

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1 Introduction

The continuous miniaturization of microelectronic components, driven by Moore’s Law, has led to a significant reduction in transistor size and increased chip complexity. This rapid advancement has presented new challenges in the field of metrology, the science of measurement. Existing metrology techniques, such as Optical Critical Dimension (OCD) and Critical Dimension Scanning Electron Microscope (CDSEM), are reaching their limits in terms of resolution and accuracy as feature sizes shrink to the nanometer scale.

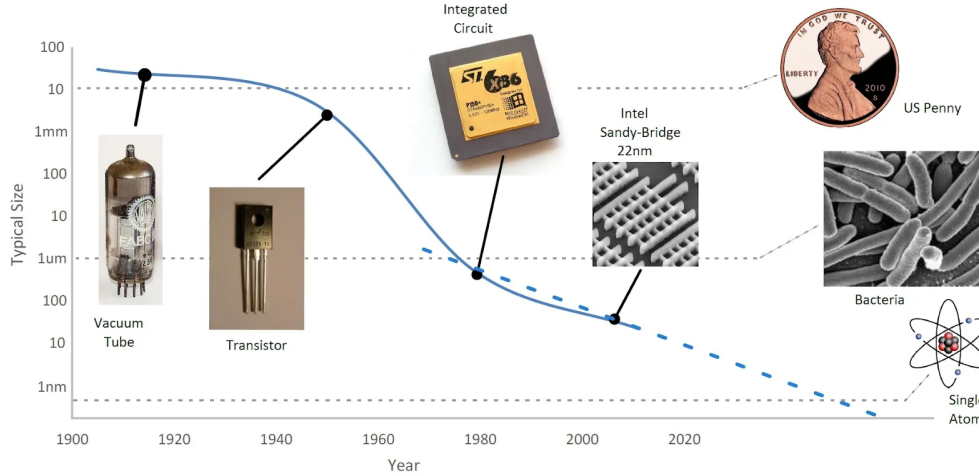


Figure 2: Evolution of microelectronics and the need for advanced metrology techniques [1].

To address these challenges, a new metrology technique called Critical Dimension Small Angle X-ray Scattering (CDSAXS) is being developed. CDSAXS utilizes short-wavelength X-rays ($\lambda \approx 0.05 - 5nm$), to probe the internal structure of materials, providing high-resolution measurements of critical dimensions (CDs) with greater accuracy than conventional methods. CEA-Leti, a leading research institute in microelectronics, is actively involved in the development of CDSAXS technology.

This work-study project focused on the development of a coherent software for the fit and analysis of CDSAXS data. The software aims to streamline the data processing workflow and enhance the accuracy of CD measurements. The project involved a comprehensive understanding of CDSAXS theory, data collection procedures, and fitting algorithms.

The report begins with an overview of the context of the project, highlighting the evolution of microelectronics and the need for advanced metrology techniques. It then delves into the CDSAXS technique, explaining the principles, data collection, fitting, and analysis. Then the subsequent section describes the software development process, outlining the software’s functionalities and design. Finally, the report concludes with a summary of the project’s achievements and outlines potential future directions.

2 Context

2.1 Host organisation

The French Alternative Energies and Atomic Energy Commission (CEA) stands as a cornerstone of the nation’s research landscape. Its multifaceted expertise encompasses a broad spectrum of fields, including nuclear energy, renewable energy, technological research for industry, material sciences, health and life sciences, and defense and security. The CEA’s network of research centers spans across France, each with its unique specializations and areas of excellence. Among these, CEA Grenoble holds a prominent position, where I have the privilege of pursuing my work-study program. I am part of the Leti Institute, a research center dedicated to microelectronics and nanotechnologies. More specifically, I was with “Materials and Structures Properties Laboratory” (MSPL) which is under “Technology Platforms Department” (TPFD), one of six different departments of Leti.

2.1.1 History

The French atomic energy commission, CEA, was born in 1945 after World War II. Its mission was to develop nuclear expertise for France. Pioneering scientists like Frédéric Joliot-Curie and Francis Perrin led the way in building research reactors and nuclear power plants.

The CEA didn’t stop at just nuclear energy. In the 1960s, they began to diversify into new areas like renewable energy, micro and nanotechnologies, defense, and healthcare. This diversification led to the creation of specialized research centers, including the future innovation hub, CEA Grenoble.

CEA Grenoble was founded in 1956 by Nobel laureate physicist Louis Néel. He saw the scientific potential of the Grenoble region and his vision proved to be true. The center grew rapidly in the following decades, attracting talent and investment from around the world.

It came to be known as France’s ”atomic capital” due to its research reactors. However, their influence went far beyond nuclear. They developed their first integrated circuit in 1965, launching their journey into micro and nanotechnologies. They also played a key role in creating Minatoc, the first European hub for excellence in this field. In addition, they became a leader in renewable energy research with the Institut national de l’énergie solaire (Ines).

Today, CEA Grenoble is a research powerhouse with over 2,500 researchers and technicians. Their campus houses specialized institutes in various fields, from healthcare to digital technologies. It’s also the headquarters for CEA Tech, the technological branch of the CEA with over 4,500 researchers across France.

2.1.2 Sectors of activity

CEA Grenoble plays a pivotal role in the nation’s economic and technological advancement through its groundbreaking research and innovations across diverse fields.

- **Energy and Sustainability:** Supporting current and future nuclear power, exploring solar, hydrogen for carbon neutrality (2050), researching SMRs and thermonuclear fusion.
- **Digital Technologies:** Contributing through the SPIN program for spintronics (frugal, agile, sustainable computing) aligned with France 2030 plan.
- **Healthcare:** Distinguished research in biology and biotechnology for health, addressing current and future challenges. (e.g., Laboratoire de biologie et biotechnologie pour la santé)
- **Defense:** Traditionally significant role, developing cutting-edge technologies for national security and defense (less documented for Grenoble).

CEA Liten for example also serves as an innovation hub for new energy technologies and nanomaterials, emphasizing energy diversification and renewable energy integration. Their research encompasses solar photovoltaics, energy storage, and transportation (hydrogen and fuel cells).

2.1.3 Future and orientation strategy

The French Alternative Energies and Atomic Energy Commission (CEA) stands as a powerhouse for innovation in France. Spanning energy, healthcare, defense, and digital technologies, the CEA pushes boundaries by collaborating with universities and industry on ambitious R&D projects.

Their focus is clear: develop transformative solutions for global challenges. This includes renewable energy sources, innovative healthcare systems, advanced defense solutions, and disruptive digital technologies. Sustainability is paramount, with research prioritizing energy efficiency and minimizing environmental impact.

The CEA partners with leading institutions to accelerate technology transfer and create open innovation ecosystems. These partnerships combine expertise, resources, and networks, leading to breakthrough technologies with significant economic and social value.

CEA Grenoble exemplifies this innovative spirit. They focus on cutting-edge technologies like AI, advanced materials, nanotechnologies, and quantum technologies. Their research aims to revolutionize industries and improve lives, from developing next-generation batteries to creating innovative medical devices and advancing digital technologies.

The challenges they tackle are vast: climate change, the energy transition, emerging diseases, cybersecurity, and technological sovereignty. The CEA goes beyond just solutions; they strive to influence public policy and raise awareness. Their research is guided by a long-term vision, anticipating future challenges and preparing for them through innovation.

The CEA is a vital force in shaping a sustainable future. Their commitment to innovation promises clean energy sources, advanced healthcare, robust national security, and a cutting-edge digital landscape. By working collaboratively and addressing global challenges head-on, the CEA positions itself as a leader in the global scientific and technological landscape.

2.2 Project description

2.3 Objectives

3 CD-SAXS

3.1 Introduction

3.2 Theoretical background

3.3 Experimental setup

3.4 Fitting Algorithm

3.5 Analysis of the reconstructed structure

4 CD-SAXS Python Application

4.1 Introduction

4.2 Conception

4.3 Simulation Models

4.4 On the fly uncertainty estimation

4.5 Future Prospects

References

- [1] Soham Chatterjee. *Beginner's Guide to Moore's Law*. URL: <https://medium.com/@csoham358/beginners-guide-to-moore-s-law-3e00dd8b5057> (visited on 07/01/2021).