Call for applications – PhD candidate

Lyon Institute of Nanotechnology
INSA Lyon, 1 rue Enrico Fermi
696922 Villeurbanne, FRANCE
http://inl.cnrs.fr

Fabrication and in-depth study of advanced ferroelectric capacitors based on $HfZrO_2$ for ultra-low power and secured edge applications

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The proliferation of edge devices has witnessed an exponential surge in recent years, with an ever-expanding array of applications ranging from smart sensors and wearable devices to industrial IoT deployments. The number of connected devices is anticipated to surpass tens of billions, transforming the way we interact with the digital world **[1]**. In this context, there is a crucial need for secured and ultra-low power technologies such as non-volatile memories to meet the stringent requirements for edge-devices applications.

Ferroelectric memories have regained significant interest over the last decade after the discovery of ferroelectricity in hafnium oxide [2]. Ferroelectric NVM (FE-NVM) based on $HfZrO_2$ (HZO) are highly appealing because of their ultra-low power consumption (< 0.1pJ/bit), high endurance ($>10^{14}$) as compared to other competing technologies.[3] In addition, the intrinsic stochasticity of ferroelectric switching at a nanoscale makes them suitable to implement security primitives such as True Random Number Generator.**[4]**

However, despite the strong interest in FE-NVM over the last years, **some technological challenges still require considerable research efforts among which wake-up and fatigue** (progressive opening and closure of the programming window along cycling) and **imprint** (shift of the Polarization-Voltage curve along voltage axis with time). While wake-up/fatigue would mostly affect the sensing margins, **imprint raises a major issue regarding security applications**, since it opens a breach to retrieve the stored data even after safety erase operations but also by altering security primitives during their life cycle. The root causes for imprint are still intensely debated in literature but can be categorized into three mechanisms **[5]**: (1) redistribution of mobile charges in the interfacial dead (*i.e.* non-FE) layer due to depolarization field (2) charge trapping/detrapping in the interfacial layer. (3) FE domains pinning caused by oxygen vacancies (V_O). Recent works have proposed imprint mitigation strategies based on **interface engineering** and **adjusting the Hf/Zr ratio in HZO capacitors [6]**.

This thesis will address the following objectives: (i) bringing a comprehensive understanding of imprint mechanism in FE capacitors through **advanced physical characterization and modeling** and (ii) deploying technological approach in order to tackle imprint in FE device based on **thin film and interface engineering**.

This thesis falls in the framework of the French ANR research project **ECHOES** (**E**dge se**C**urity wit**H** ferr**O**electric Devic**ES**) for which the Electronic group at INL will work in collaboration with CEA-SPEC (Saclay) and IM2NP (Aix-Marseille Université). In this context we are currently looking for a **PhD student** for a **3-year** contract to be supervised by Damien Deleruyelle (electrical characterization and modelling), Bertrand Vilquin (thin film deposition and XRD analysis) and Jordan Bouaziz (device integration).

Job description

The Ph.D. thesis is structured in the following main tasks:

1. **Literature survey on advanced ferroelectric devices and physical mechanisms (M1 to M6)**
    - The purpose of this task is to acquire state-of-the-art knowledge regarding the physical properties of ferroelectric hafnium-zirconium oxide (HZO) and gaining insights on the physics of ferroelectric devices. In alignment with the thesis objective, particular attention will be dedicated to understanding the physical origins of imprint at the microscopic level, along with exploring technological approaches to mitigate this phenomenon.
2. **Ferroelectric device engineering (M2 to M28)**
    - This task will consist in the fabrication of ferroelectric capacitors (FeCap) using NanoLyon technological Platform of INL. Various technological options will be explored and evaluated in order to improve the performance of FeCap in connection with the thesis objectives such as : employing different deposition techniques for HZO (PVD, ALD), varying the composition of HZO thin-films through Hf/Zr ratio adjustment

and evaluating the impact of different interface layers and electrodes. The goal of this task is to provide a technological route enabling imprint mitigation without sacrificing any major performance metrics.

3. **Advanced physical characterization of ferroelectric devices (M3-M30)**

    - In this task we will perform the electrical characterization of ferroelectric capacitors in order to evaluate their electrical performances (programming voltages, cycling endurance, leakage current, imprint,…). To this aim, electrical measurement under probe stations (PUND measurements, IV, CV…) will be conducted in order to extract the main performance metrics and physical parameters. In addition to this, physical characterization (XRD, XPS, HAXPES) will be conducted in collaboration with CEA-SPEC (operando measurements) to gain insights on the physical composition of the memory stack and interfaces (HZO crystallographic phases and composition, interface analysis, VO profile…). Combining both electrical and advanced physical analysis will be a key point to establish connections between the microstructural properties and electrical performances in order to bring technological options to imprint.

4. **Physical modeling (M12 – M30)**

    - In order to assess the different assumptions on the origin of imprint and other mechanisms affecting reliability a pre-existing physical model of ferroelectric capacitor will be exploited **[7]**. To this aim, the model will be fed with physical parameters gathered along the previous task and confronted to electrical data obtained on ferroelectric capacitors. The goal of this task is to provide a unified frame connecting electrical performances observed at the device level to physical properties collected through advanced physical analysis.

5. **Evaluation and Dissemination (M6-M36)**

    - Scientific papers, conference abstracts and thesis manuscript preparation.

Profile

You have or are about to obtain an MSc in Nanotechnology / Electrical Engineering / Physics / Material Science with strong experience in at least one of the following areas: Device physics, Material Science, Functional thin films. Excellent written and verbal communication skills in English together with good programming skills (e.g. Python). Fluency in French is also a plus but is not mandatory.

About INL

INL is a 200+ research institute based in Lyon, France, carrying out fundamental and applied research in electronics, semiconductor materials, photonics and biotechnologies. The Electronic group is a leader in the area of advanced nanoelectronic design, with research projects and collaborations at both national and European level. Recent highlights include the fabrication, analysis and modeling of emerging ferroelectric devices for new computing paradigms **[7,8,9]**.

Dates:

Ph.D. position is available from January 2024.

Environment:

The Ph.D. thesis will be supervised by the INL team in Lyon. The Ph.D. salary will follow standard French rates.

References:

[1] https://www.statista.com/statistics/1017863/worldwide-iot-connected-devices-data-size/
[2] T. S. Böscke et al., Applied Physics Letters, 99, p. 102903, (2011).
[3] A. I. Khan et al., Nature Electronics, 3, pp. 588–597, (2020).
[4] T. Liu et al., IEEE EDTM, pp. 1–3, (2021)
[5] P. Yuan et al., Nano Research, 15, pp. 3667–3674, (2022)
[6] H. Shin et al., Applied Physics Letters, 122, p. 022901, (2023)
[7] G Segantini et al., physica status solidi (RRL), 16, 2270019, (2022)
[8] B. Manchon et al., physica status solidi (RRL), 16, 2100585, (2022)
[9] K. Alhada-Lahbabi et al., ACS Appl. Electron. Mater., 5(7), 3894-3907, (2023)

Send CV and statement of purpose (in English or French) to:

Damien Deleruyelle / INL - Lyon Institute of Nanotechnology - INSA Lyon – email: damien.deleruyelle@insa-lyon.fr
Bertrand Vilquin / INL - Lyon Institute of Nanotechnology - Ecole Centrale Lyon – email: bertrand.vilquin@ec-lyon.fr
Jordan Bouaziz / INL - Lyon Institute of Nanotechnology - Ecole Centrale Lyon – email: jordan.bouaziz@ec-lyon.fr