Position Description

1. General Information

Name of the position	**Artificial synapses for hardware implementation of neuromorphic networks**
Foreseen date of enrolment	1 July 2024
Position is funded by	• COFUND, Marie Skłodowska-Curie Actions (MSCA), Horizon Europe, European Union • École Centrale de Lyon (EC Lyon) • Royal Melbourne Institute of Technology (RMIT)
Research Host	École Centrale de Lyon (Institut des Nanotechnologies de Lyon)
PhD awarding institutions:	École Centrale de Lyon & Royal Melbourne Institute of Technology
Locations	Primary: Lyon, France Secondary: Melbourne, Australia
Supervisors	Bertrand VILQUIN (EC Lyon) Sharath SRIRAM (RMIT)
Group of discipline	Condensed matter physics, Nanoelectronics, Biomimetism

2. Research topics (only one of these projects will be funded)

Project 1: *Realization of ferroelectric artificial synapses for hardware implementation of neuromorphic networks*
After more than 40 years of continuous evolution, our computing systems are reaching their limits. Indeed, the architecture of Von-Neumann, on which our computers are based, physically dissociates the hearts of calculations from the memory. The sequential processing of information is thus confronted with a bottleneck, more commonly known as "Memory Bottleneck". One solution is to draw inspiration from the natural mathematical paradigms of the human brain, in which the data are massively parallel processed with high energy efficiency, realizing the hardware implementation of neuromorphic networks. The latter make it possible to bring the information storage sites (synapses) closer to the treatment sites (neurons). The major challenge of this bio-inspired approach is the realization of dense networks of artificial synapses to implement synaptic plasticity mechanisms. There are few man-made ferroelectric artificial synapses in the microelectronics industry to date. The aim of this project is to achieve the fabrication of such a device from transferable materials and processes in the semiconductor industry.

This project has received funding from the European Union's Horizon Europe research and innovation programme under the Marie Skłodowska-Curie grant agreement № 101081465

- The deposition of the ferroelectric $HfZrO_2$ must respect the CMOS processes, in particular at low thermal budget (<450 ° C).
- Since $HfZrO_2$ is a recent ferroelectric material, the influence of its thickness, stoichiometry, interfaces on ferroelectric properties is still poorly known today. This knowledge is essential in order to optimize the operation of the targeted devices.

Expected original contributions :

- Development and demonstration of artificial synapses based on ferroelectric $HfZrO_2$ using CMOS compatible methods
- Identification of the optimal deposition conditions (i.e. thickness, stoichiometry, temperature, etc.) of the functional oxide for the targeted application
- Realization of integrated synaptic matrices of "Crossbar" type

This project will be realized in the framework of common labs between INL and CEA-LETI and STMicroelectronics.

Supervisors: Bertrand VILQUIN (ECL), Sharath SRIRAM (RMIT), Laurent GRENOUILLET (CEA), Simon JEANNOT (STMicroelectronics)

Research Fields: Condensed matter physics, Nanoelectronics, Biomimetism

Project 2: *Operando characterizations of ferroelectric artificial synapses*

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- Charge related effects: The free charges of an electrode or substrate can help screening the polarization-induced surface charges which are detrimental to maintaining exploitable polarization in the ferroelectric thin film. With metallic oxide electrodes, an ionic displacement at the electrode/ferroelectric interface will also screen this depolarizing field.
- Depletion areas due to chemical and electronic reconstruction or defects at interfaces (semiconductor-insulating areas).
- Strain related effects that can rise from thermal expansion mismatch or lattice mismatch.
- Thickness dependent properties (space limiting effects for tunneling, ionic mobility).

Expected original contributions :

- to identify the best routes to optimize the properties in ferroelectric HfZrO2 thin films in order to obtain ferroelectric tunnel junctions answering the industrial requirements;
- to characterize the phase, local domain structure and chemistry, defect related electronic structure, the role of the interface and internal fields will be evaluated as a function of cycling, specially to obtain a unique material/structure chemical and physical characterizations evidencing the role of oxygen vacancies in wake-up, imprint and endurance;

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- to establish straightforward relationships between the ferroelectric stack composition and electrical performances and provide guidance rules toward stacks optimization thanks to both physical and compact model of Electrode-Ferroelectric-Electrode structures. Based on the chemical and electrical analyses, a physical model of Electrode-Ferroelectric-Electrode stacks, including interface layers and oxygen vacancies profiles will be realized.

This project will be realized in the framework of common lab between INL and STMicroelectronics.

Supervisors: Bertrand VILQUIN (ECL), Sara GONZALEZ (CNRS), Sharath SRIRAM (RMIT), Nick BARRETT (CEA), Simon JEANNOT (STMicroelectronics)

Research Fields: Condensed matter physics, Nanoelectronics, Operando measurements, Spectroscopies, Surface and interface science

Project 3: *Prototyping and testing the learning capabilities of ferroelectric synaptic network*

After more than 40 years of continuous evolution, our computing systems are reaching their limits. Indeed, the architecture of Von-Neumann, on which our computers are based, physically dissociates the hearts of calculations from the memory. The sequential processing of information is thus confronted with a bottleneck, more commonly known as "Memory Bottleneck". One solution is to draw inspiration from the natural mathematical paradigms of the human brain, in which the data are massively parallel processed with high energy efficiency, realizing the hardware implementation of neuromorphic networks. The latter make it possible to bring the information storage sites (synapses) closer to the treatment sites (neurons). The major challenge of this bio-inspired approach is the realization of dense networks of artificial synapses to implement synaptic plasticity mechanisms. There are few man-made ferroelectric artificial synapses in the microelectronics industry to date. The purpose is to analyse the physical mechanisms that govern the dynamic switching behaviours and highlight how these properties can be utilized to efficiently implement synaptic and neuronal functions. Prototype system that can be used in machine learning and brain-inspired network implementations will be fabricated and simulated. The final challenge is to propose large scale implementations and opportunities for building bio-inspired, highly complex computing systems.

Expected original contributions :

- Theoretical and practical design requirements of $HfZrO_2$ based ferroelectric artificial synapses
- Modelling of $HfZrO_2$ based ferroelectric artificial synapses
- Characterization of integrated synaptic matrices of "Crossbar" type
- Prototyping and testing the learning capabilities of the synaptic network

This project will be realized in the framework of common labs between INL and CEA-LETI and STMicroelectronics.

Supervisors: Bertrand VILQUIN (ECL), Sharath SRIRAM (RMIT), Laurent GRENOUILLET (CEA), Simon JEANNOT (STMicroelectronics)

Research Fields: Condensed matter physics, Nanoelectronics, Modelisation, Biomimetism

3. Employment Benefits and Conditions

Ecole Centrale Lyon offers a 36-months full-time work contract (with the option to extend up to a maximum of 42 months). The employment contract includes a probation period of one month, which may be renewed once for a period not exceeding the initial duration. The total working hours per week is 35h.

The remuneration, in line with the European Commission's rules for Marie Skłodowska-Curie fellows, will consist of a gross monthly salary of EUR 2,142 in 2024. Of this amount, the estimated net salary to be received by the researcher is EUR 1,720 per month. However, the final amount to be received by the Researcher is subject to national tax legislation (approximately EUR 100 /month). This salary will increase during the thesis and should reach, on average, EUR 2,340 gross (i.e. EUR 1,870 net) per month.

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Benefits include

- Becoming a Marie Skłodowska-Curie fellow and be invited to join the Marie Curie Alumni Association.
- Access to all the necessary facilities and laboratories at EC Lyon (INL) and RMIT University.
- Tuition fees exemption at both PhD awarding institutions.
- Yearly travel allowance to cover flights and accommodation for participating in AUFRANDE events.
- 10,000 EUR allowance to cover flights and living expenses for up to 12 months in Australia.
- 27 days paid holiday leave.
- Sick leave.
- Parental leave.

4. PhD enrolment

Successful candidates for this position will be enrolled by the following institutions and must comply with their specific entry requirements, in addition to AUFRANDE's conditions.

Applicants must hold a Master's degree that includes a research component comprised of at least 25% of a full-time academic year (or part-time equivalent) with an overall high distinction or a master degree without a research component with at least a high distinction average.

Applicants will also need to meet English proficiency requirements: https://www.rmit.edu.au/study-with-us/international-students/apply-to-rmit-international-students/entry-requirements/english-requirements.

More information on EC Lyon's requirements

Foreign degrees are examined by the doctoral schools to determine whether they are equivalent to a Master's.

Important: the authorisation of the Defence Security Officer may be required before admission. In case of denial, the enrolment will not be carried out.

Visit the website: https://www.ec-lyon.fr/en/research/doctorate/admission-enrolment-doctorate

RMIT University

Visit the website: https://www.rmit.edu.au/research/research-degrees/how-to-apply

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