

Internship/PhD topic: “Erasing chiral polar order with antiferroelectric switching of superlattices”

Lab: Structures, Properties and Modelling of Solids (SPMS)

Thesis supervisor: Cosme MILESI-BRAULT

Keywords: antiferroelectrics, epitaxial thin films, topological structures

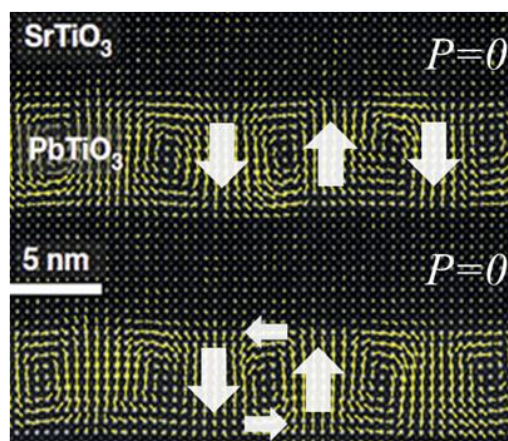
Topics: solid-state physics, ferroelectrics, material synthesis with physical deposition techniques, material characterisation: x-ray diffraction, electronic microscopy, atomic force microscopy, electrical measurements, spectroscopy...

Supervision: This thesis work will be co-supervised by Dr. Cosme Milesi-Brault, maître de conférences (expertise on synthesis and spectroscopy of ferroelectrics) and Prof. Pierre-Eymeric Janolin (expertise on structural and electrical properties of ferroics). This will be done in collaboration with other French labs specialized in PLD growth of oxide materials.

Quick summary of the internship/thesis project:

Antiferroelectrics are dielectric materials composed of an antipolar array of dipoles, which display no macroscopic polarisation. They can be switched to a polar ferroelectric phase by application of an electric field: this field-induced phase transition is called switching, which induces a so-called “double hysteresis loop” in its polarisation vs electric field curve.

Layering antiferroelectric and ferroelectric materials could also induce extremely rich topological physics, such as ferroelectric skyrmions [1, 2] or flux-closure domains, which could be useful for energy storage properties of multilayers [3, 4, 5], but also in other applications (e.g. extremely low-power computing). However, these topological objects remain hard to control in ferro/paraelectric superlattices.



Ferroelectric/paraelectric superlattice displaying flux-closure domains. Adapted from [1]

In this internship/thesis project, we will create and investigate such topological structures in ferro/antiferroelectric superlattices. Thanks to the possibility of controlling the polarisation of the antiferroelectric layers via an electric field, we will control the creation and destruction of such topological chiral structures, which would be completely novel in the field.

Materials of interest are inorganic perovskites such as PbZrO_3 , PbTiO_3 , (doped-) BiFeO_3 ... which are (anti)ferroelectric materials.

During this PhD, the candidate will:

- Design and synthesise antiferroelectric/ferroelectric superlattices
- Analyse in-depth the electrical, structural properties of these multilayers
- Study *in-situ* (anti)ferroelectric superlattices under the influence of electric fields and temperature change to elucidate their underlying mechanisms of their phase transitions

The first step of this PhD project is to **synthesise antiferroelectric epitaxial superlattices** by pulsed laser deposition (PLD) and study their basic electrical and structural properties. The

second step of this project is to **shed light on the electric-field induced switching mechanisms of these multilayers** to further improve our knowledge of these materials.

Main experimental techniques:

Pulsed laser deposition (PLD) for depositing multilayer thin film materials; x-ray diffraction (XRD), scanning electron microscopy (SEM), **transmission electron microscopy (TEM)**, **scanning probe microscopy (AFM/PFM)**; electron diffraction spectroscopy (EDS) for chemical analysis; electrical measurements (polarisation, capacitance, permittivity).

Bibliography:

- [1] Yadav, A. K. et al., Observation of polar vortices in oxide superlattices. Nature 530, 198–201 (2016).
- [2] Das, S. et al., Observation of room-temperature polar skyrmions. Nature 568, 368–372 (2019).
- [3] H. Aramberri, N. S. Fedorova, and J. Iniguez, ‘Ferroelectric/paraelectric superlattices for energy storage’, Sci Adv, vol. 8, no. 31, p. 4880 (2022)
- [4] T. Zhang et al., Superior Energy Storage Performance in Antiferroelectric Epitaxial Thin Films via Structural Heterogeneity and Orientation Control’, Adv Funct Mater, vol. 34, no. 4, p. 2311160 (2024)
- [5] Y. Zhang et al., ‘High Energy Storage Performance of PZO/PTO Multilayers via Interface Engineering’, ACS Appl Mater Interfaces, vol. 15, no. 5, pp. 7157–7164 (2023)