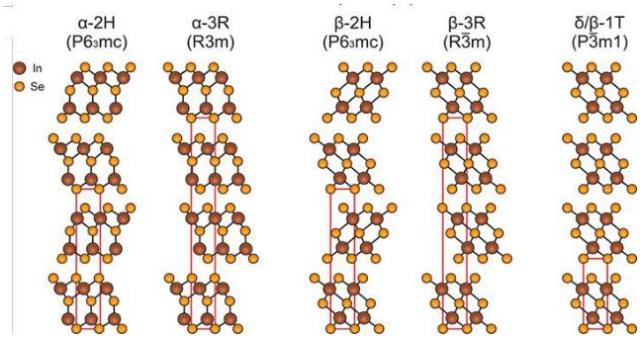
Master thesis proposal

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Title: **Symmetry engineering of two-dimensional In_2Se_3 semiconductors**

Keywords: 2d materials, condensed matter, sliding ferroelectricity, semiconductors



Scientific description: How do atomic stacking and ferroelectric polarization shape the properties of an atomically thin semiconductor? Layered In_2Se_3 provides a platform to address this question: its α and β phases exhibit distinct structures and electronic properties, while rhombohedral (3R) stacking introduces an additional source of inversion-symmetry breaking. Distinguishing structural non-centrosymmetry from switchable ferroelectric polarization is a central challenge for future non-volatile nanoelectronic devices.

This internship is part of RHOMBO2D, an ANR project accepted in 2026 bringing together C2N, MPQ, IPCMS and SPINTEC. The student will contribute to the growth and characterization of thin In_2Se_3 layers, with emphasis on phase identification, thickness and crystal symmetry. Chemical vapor deposition (CVD) growth at C2N will be combined with Raman spectroscopy and polarization-resolved second-harmonic generation (SHG). Comparing α- and β-phase samples, including before and after controlled annealing, will help identify optical signatures of phase changes and symmetry breaking.

The expected outcome is a comparative set of Raman and SHG measurements linked to thickness and growth or annealing conditions. This will provide a basis for selecting samples for electronic and ferroelectric investigations. A continuation towards a PhD within RHOMBO2D is envisaged, extending the work to electronic band structure, quantum confinement and the interplay between stacking and polarization.

Techniques/methods in use: The student will be trained in CVD growth, sample preparation, atomic force microscopy (AFM), micro-Raman spectroscopy and polarization-resolved SHG mapping. Reference exfoliated crystals and MBE-grown films from SPINTEC will support comparisons. Results will be discussed alongside first-principles calculations and complementary structural measurements within the consortium. The PhD would offer opportunities for X-ray and angle-resolved photoelectron spectroscopy (XPS/ARPES), including synchrotron experiments, and collaboration on ferroelectric and transport measurements. SHG will be used as a symmetry probe; polarization switching requires complementary ferroelectric measurements.

References

[1] W. Ding et al., "Prediction of intrinsic two-dimensional ferroelectrics in In_2Se_3 and other III_2–VI_3 van der Waals materials", Nature Communications 8, 14956 (2017).

[2] G. Kremer et al., "Mexican-Hat-Like Valence Band Dispersion and Quantum Confinement in Rhombohedral Ferroelectric α-In_2Se_3", Physical Review B 112, 155418 (2025).

[3] M. Rahimi et al., "Probing the Electric and Thermoelectric Response of Ferroelectric 2H and 3R α-In_2Se_3", Applied Physics Letters 124, 253503 (2024).

Applicant skills: Good students

Industrial partnership: No

Internship supervisor(s) Abdlekarim Ouerghi, abdelkarim.ouerghi@universite-paris-saclay.fr 0649956047

Internship location: C2N Univ. Paris Saclay

Possibility for a Doctoral thesis: Yes, By ANR Rhombo 2D