NÉEL INSTITUTE Grenoble

Topic for Master 1 internship – Academic year 2025-2026

Nm scale characterization of p-n junction electrical properties by 4-dimensional Scanning Transmission Electron Microscopy

General scope:

Semiconductor p-n junctions are basic building blocks for devices like solar cells, avalanche photodetectors or light emitting diodes. To implement the junction, the electrical properties of semiconducting materials are engineered by adding dopant atoms that donate or accept an electron from conduction or band valence, respectively. In this way the density of mobile charges can be tuned over several orders of magnitude. It is very well known that a transition from one type of dopant to the other kind will generate a so-called p-n junction, giving rise to rectifying current-voltage characteristics and potentially light emission, for example in light emitting diodes, when a quantum dot or well is inserted inside the junction. These properties depend on the electric field present at the junction. However, challenges remain to control and measure the electrically active doping levels and related electric field in semiconducting materials with nanometer-scale precision, especially in wide bandgap materials with high dopant activation energies.

Research topic and available facilities:

The aim of this internship is to contribute to the study of p-n junction semiconducting materials regarding their electrical properties studied at nm length scales, by contributing to the data treatment of four-dimensional Scanning Transmission Electron Microscopy (4D-STEM) results. In these experiments, a focused electron probe is raster-scanned over the sample, and a diffraction pattern is acquired at each probe position. The presence of an electric field in the sample results in a deflection of the transmitted beam as well as a phase change, see Fig. 1a. Different methods exist to calculate the phase and amplitude map from such a four-dimensional data-set. The student will assist with the 4D-STEM experiments and data acquisition on a state-of-the-art corrected TEM present at Institut Néel, equipped with a new very fast camera. The core of the project is to compare different data treatment methods on these 4D data: the Center-of-Mass approach and electron ptychography, building on our experience. We will both consider simple p-n junctions, electrically contacted nanowires containing a p-n junction, as well as nanowires containing a quantum dot insertion inside the p-n junction to better asses their electrical properties. If needed, the student will adapt the data treatment and use numerical simulations as point of comparison. The student will integrate a multi-institute, multi-disciplinary research group, including researchers of both CEA Grenoble and CNRS Institut Néel.
An example of electric field maps calculated from 4D-STEM diffraction maps by the Center-of-Mass approach is shown in Fig. 1b-c at different applied bias values, accompanied by the electric field profiles (1c).

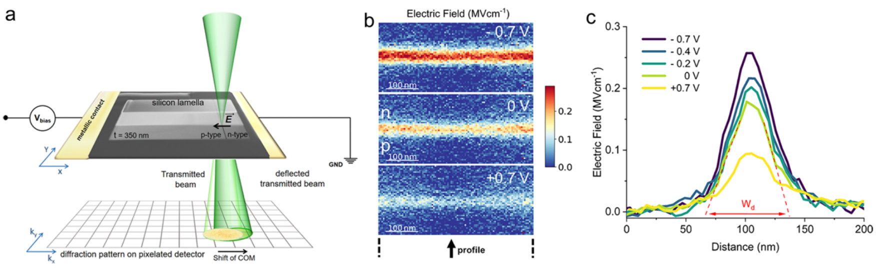

Figure 1a) Schematic of 4D-STEM on a p-n junction. b) Electric field maps on this sample with different values of applied bias. c) Profiles obtained from the maps in a.

Possible collaboration and networking: The internship will be in collaboration with Alexis Wartelle & Julio Cesar da Silva, and in collaboration with colleagues from CEA.
Possible extension as a PhD: Not granted in advance, but we support applications for a PhD grant.
Required skills: Interest in solid-state physics, electrical and optical properties of semiconductors and advanced characterization techniques like transmission electron microscopy.
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