Master thesis proposal

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

Keywords : transmission electron microscopy, dopant characterization, electric properties, electric field, ptychography, iterative phase retrieval, automatization, high throughput

SCIENTIFIC DESCRIPTION :

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 valence band, 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. 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 streamline our data analysis approaches of 4D-STEM diffraction maps building on our acquired experience and make the data analysis pipeline as automated, user independent, fast and reliable as possible, allowing high throughput of data sets and potentially semi- automated reconstructions. Two kind of data analysis approaches will be considered: first the more classical Center-of-Mass (CoM) approach and second a more novel approach using iterative electron ptychography.

Then, these improved data analyses strategies will be compared on different experimental data to reconstruct electric fields and potentials, either in long range electric fields for example at a p-n junction or around single atoms. 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).

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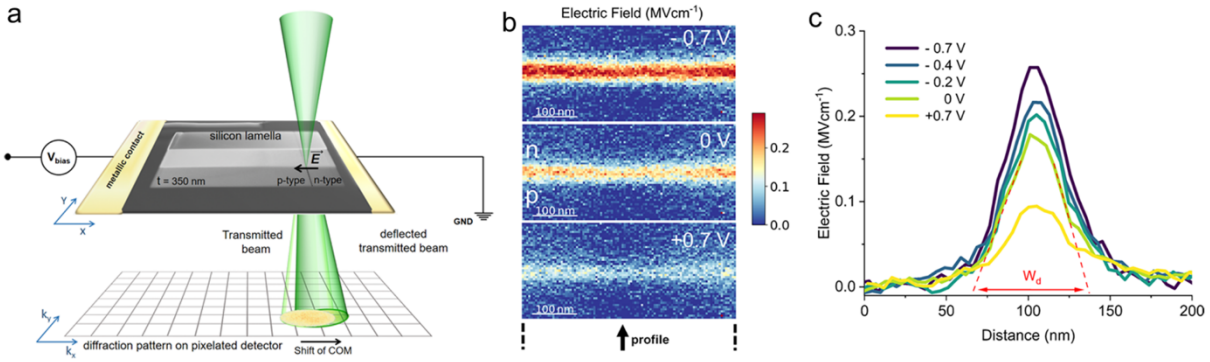


Figure 1a) Schematic of 4D-STEM on a p-n junction. b) Electric field maps on this sample with different values of applied bias. c) Profiles obtained from the maps in a.

Techniques/methods in use : In four-dimensional Scanning Transmission Electron Microscopy (4D-STEM) 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. Measuring the deflection of the beam allows for example to study the presence of internal electric fields in the sample. Data treatment approaches, automatization and streamlining will all be done using python code.

Budget description and use : Hiring the Master student, and if some funding remains, small consumables for the TEM smaple preparation.

Applicant skills : Skills in data treatment, signal analysis and python coding. Interest in solid-state physics, electrical and optical properties of semiconductors and advanced characterization techniques like transmission electron microscopy is a plus.

Industrial partnership : Collaboration with CEA Grenoble.

Internship supervisor(s) : Martien den Hertog, martien.den-hertog@neel.cnrs.fr & Alexis Wartelle, alexis.wartelle@neel.cnrs.fr, tel: 0476881045.

Internship location : Institut Néel – CNRS, 25 avenue des Martyrs - BP 166, 38042 Grenoble cedex 9

Possibility for a Doctoral thesis : Not granted in advance, but we support applications for a PhD grant.