Stage N° : 15

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Title

Electron holography for the high-resolution imaging of magnetic nanotubes for spintronics

Keywords
Transmission electron microscopy, magnetic imaging, nanotubes, simulation, micromagnetism

Summary
The objective of the internship is the study by transmission electron microscopy (TEM), of magnetic nanotubes synthesized by a chemical method. We are studying these as models objects to explore the concept of information storage in 3D magnetic media, based on the propagation of magnetic walls along one-dimensional structures. Physico-chemical study of the material and magnetic imaging at the nanometer scale will be used to explore and understand the arrangement of domains and domain walls in these systems, whose synthesis has been achieved recently.
The experimental techniques used are the chemical and structural analysis by electron diffraction and high-resolution imaging, and high-resolution and sensitivity magnetic imaging by electron holography, in a transmission electron microscope. The student will perform sample preparation for electron microscopy, will participate in the imaging, and will have a key contribution in the image processing needed to analyze the data. .
The work also includes participation in micro-magnetic simulations to support the physical understanding of the measurements. These will be done in collaboration with the joint simulation group SPINTEC / NEEL.

Full description of the subject

To perform the structural and magnetic microscopy we benefit from the latest and world-leading equipment for chemical analysis, images of matter at the atomic scale and also to visualize magnetic fields. The work will be largely experimental:
- The chemical and structural analysis by electron diffraction
- The high-resolution images
- The magnetic imaging and electron holography with a resolution and sensitivity of a few nanometers.

The experimental systems are under control, and will be made available, under the collaboration with chemist experts and also by physico-chemists at Institut NEEL. In recent experiments with photoelectron microscopy (PEEM, experiments with synchrotron radiation) we evidenced azimuthal domains (magnetization curling around the perimeter of the tubes), thus with flux-closure. This closure is very interesting in the context of a 3D memory because it minimizes the effects of long-range dipolar fields, and thus cross-talk between elements. However it is unexpected with respect to the axial direction. Following this, in this internship we will try to clarify the reason for this orientation, in connection with the microstructure. Moreover, thanks to our high spatial resolution we will seek to clarify the type of magnetic walls occurring between the domains, which have a crucial impact on their dynamics expected in a magnetic field or spin-polarized current.

The student will handle the sample preparation for electron microscopy (dispersion of tubes initially in solution, possible use of etching by focused ion beam), will participate in the experiments in the TEM microscope, under static conditions and possibly under magnetic field or elevated temperature, for the study of the magnetization pattern inside matter and magnetic stray field around the tubes. A key task of the student will be to take part in processing steps and its analysis with micromagnetic simulation.

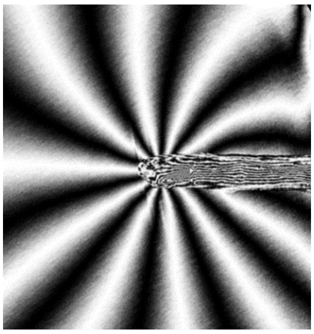
In the framework of a PhD work, the topic would be enlarged, to progressively shift from a nanomagnetics focus, to spintronics objectives. We will consider tubes connected electrically, to control their magnetization state under polarized current in the microscope, and in particular move domain walls. We will also consider core-shell shell structures, as multilayered systems is a requirement to develop spintronic effects such as giant magneto-resistance and efficient spin injection through the spin-Hall effect. A perspective will be dynamic studies with a nano-device operation (eg polarized current flow inducing precessional dynamics) in the microscope.
Finally, efforts will be made on simulated images and simulations micromagnetism. These calculations will be performed in collaboration with the joint SPINTEC / NEEL simulation group, to interpret our results.

Requested skills

Experimental physics, understanding of condensed matter physics, computer skills

Possibility to follow with a PhD

YES



Iso-lines of magnetic phase arising from a Ni nanowire in a magnetic state close to saturation. The dense lines within the nanowire are indicative of magnetization, while the lines in vacuum pertain to the stray field of dipolar origin created by the wire.