INSTITUT NEEL Grenoble

PhD grant

Imaging the mechanical and thermal properties of nanowires in an electron microscope

Context :

A major challenge in studying nanoscale objects is that many of their inherent physical properties are out-of-reach. Typical examples are semiconductor nanowires developed based on many materials for various applications. One important driving force in studying nanowires is their large thermoelectric figures of merit. These can be extracted directly but only after electronic devices are fabricated. However, when prototyping and optimizing the growth process, this method is costly, time-consuming and therefore not sufficient to build statistical measures based on numerous nanowires.

In this project, we develop a method for evaluating the mechanical and thermal properties that is fast, minimally invasive and works for rapid and statistical diagnosis prior to device integration. We shall use the electron beam from a conventional scanning electron microscope (SEM) as a local probe. The beam plays a dual role. First, it heats the nanowire locally. Second, the natural mechanical vibrations of the nanowire (Brownian motion) modulate the secondary electron (SE) current and can be detected[Nigues-2015]. The electron beam has typical waist of ~1 nm, which is much tighter than that available with light. In preliminary results, we have demonstrated that it is possible to address the mechanical properties of free-standing nanowires [Nigues-2015],[Pairis-2019] and nanotubes [Tsioutsios-2017]. The mechanical modes appear as peaks in the frequency spectrum of the SE signal. The sensitivity of this technique cannot be achieved by any other techniques. For example, we can detect the vibrations of tiny nanowires (20 nm in diameter and 700 nm long) as grown, whereas optical schemes are not suitable at this scale, on top of requiring suitable procedures in order to isolate the sample of interest.

In parallel, we have worked on a theoretical framework based on the extension of the fluctuation dissipation theorem that accurately describes the Brownian motion of a resonating beam subject to a heat flux. We have experimentally showed that within this framework, using interferometry, one can probe the local properties (temperature, mechanical damping) of a silicon cantilever within various settings (e.g. bare or coated), by coupling the mechanical modes to the laser-driven temperature field [Geitner-2017]. At the intersection of those approaches, **this project proposes to exploit electro-mechanical coupling inside an SEM in order to evaluate the thermal and mechanical properties of nanowires.**

Objectives and means available :

Within this project, the PhD thesis objectives are twofold. First, the student will determine the global mechanical properties of nanowires (elastic moduli, mechanical damping) using electro-mechanical coupling inside the microscope in a minimally invasive configuration. Then, he/she will study the effect of the microscope settings on the nanowire mechanical response in order to understand the refined interaction between the electron beam and nanoscale oscillators. This will enable the development of thermal maps of the nano-objects heated by the beam with nanometer scale resolution.

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Nanowires will be available at the beginning of the thesis and the student will participate in growth campaigns. The PhD student will have access to a scanning electron microscope to perform the experiments. In addition, measurement campaigns will take place in a cathodoluminescence setup at low temperature to correlate the mechanical properties with the optical properties.

The PhD takes place within the ANR IMAGIQUE (granted in 2022). The different partners (material scientists, theoreticians and experimentalists) exchange regularly during meetings and research visits.

Possible collaboration and networking :

ANR IMAGIQUE partners: LUMIN, ENS-Lyon, IRIG-PHELIQS
Research Networks: GdR MecaQ, GdR Matepi

Required profile :

We are looking for a student interested in experimental research, statistical analysis and programming. Knowledge in materials science and physics are mandatory. We are looking for a person curious with organizational skills and with ability to perform delicate experiments.

Foreseen start for the grant : as soon as possible

Amount : 2135 € per month brutto

Duration : 36 months

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