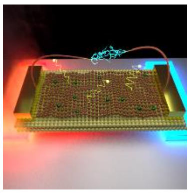
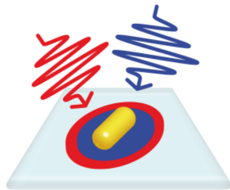
Proposition de Stage M2 pour l'année 2020/2021

Thermal transport in nanostructured thin films: the challenge of a microscopic understanding





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Project title **Thermal transport in nanostructured thin films: the challenge of a microscopic understanding**

Keywords thermal transport, nanocomposite, phonons, picoacoustics

One of the main challenges for our modern society consists in reducing the heat losses associated with energy consumption: indeed, about two thirds of produced energy is lost as heat, whatever the energy source and processing. Optimizing materials and processes for reducing heat dissipation, increasing thermal insulation, and converting heat into other forms of energy is at the focus of an intense research effort. In this context, nanostructuration has arisen as a most promising approach: the presence of interfaces and the intertwining of different materials at the nanoscale has shown to effectively act on the quasi-particle responsible for heat transport – phonons – and not on other functional properties. Phonons are strongly diffused by the interfaces and their mean free path, i.e. the distance over which they efficiently transport heat, is reduced. As a result, thermal conductivity can be greatly limited[1].

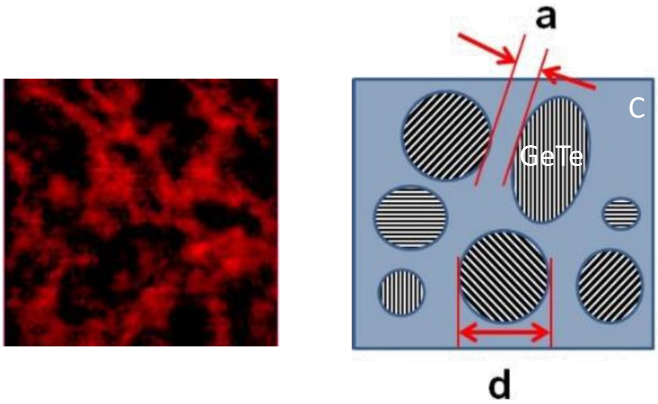

Fig. 1. (left) HRTEM image (60 nm side). Red: Carbon, black: crystalline GeTe and (right) sketch of C-GeTe. The parameters tuned in the project (inter-distance a and particle size d) are highlighted

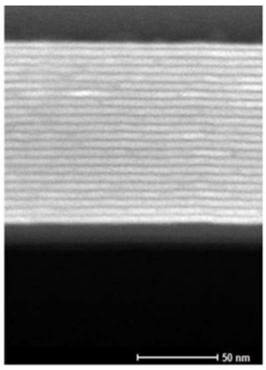

Fig. 2. STEM image of GeTe (light gray)/C (dark gray) multilayer after crystallization

We propose in this internship to investigate nanostructured thin films, which are expected to show a reduction of the effective thermal conductivity. Specifically, we will investigate nanocomposites made of nanocrystalline GeTe surrounded by amorphous carbon (Fig. 1), for which nanostructuration has been reported to reduce the thermal conductivity by a factor of 6 compared to non nanostructured GeTe thin films and multilayers made of nanocrystalline GeTe alternating with amorphous carbon (Fig. 2). By tuning the size of GeTe nanocrystals (sample 1) and layers (sample 2) and the amount of amorphous carbon, we expect to observe different regimes of thermal transport.

For characterizing these effects, we will combine the macroscopic measurement of thermal conductivity with microscopic measurements of the mean free path of acoustic phonons, which are the main heat carriers. This will allow to track modifications of individual properties of phonons due to the nanostructuration and understand how such modifications influence material thermal transport.

The individual properties of the phonons in a frequency range of ~10 GHz will be investigated by means of time-resolved ultrafast optical spectroscopy, based on femtosecond lasers, a technique which is at the heart of the activity of FemtoNanoOptics group. In this technique an acoustic wave is coherently excited by a femtosecond laser pulse and its propagation in the solid is investigated by optical methods[2]. Thermal conductivity will be measured with a thermoreflectance equipment available in the Energy group. In this technique a nanosecond pump laser is used to impulsively heat a metallic coating on the material under study. The reflectivity of the coating strongly depends on temperature. Its time dependence after the impulsive heating is followed in the nano-second scale: its characteristic decay time is related to the thermal diffusivity of the material under study towards which heat flows from the coating[3].

The Trainee will participate to experiments with ultrafast optical spectroscopy and thermoreflectance and to the analysis of the signals and their interpretation. Numerical modeling for connecting the time-resolved optical signals to the physical properties of specific phonons will also be carried out in the FemtoNanoOptics group.

This internship is part of a funded project (MAPS) where the thermal optimization of these materials for memory and thermoelectric applications is investigated[4,5], gathering experts from CEA-LETI in materials fabrication, Institut Néel (Grenoble) in thermal measurements, Lamcos and Cethil in theoretical modeling and the Energy and FemtoNanoOptics groups at ILM for phonon investigation. The trainee will interact with this large and rich consortium during her/his internship.

This internship can last 4 to 6 months and can be extended into a PhD thesis.

Bibliography

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