Master internship (M2)

Thermal properties measured by resistive thermometry
(Propriétés thermiques mesurées par thermométrie résistive)

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Context: Heat transfer at the micro and/or nanoscale is strongly modified in comparison with usual laws known at macroscopic scale, *i.e.* Fourier's diffusive law of heat conduction, Planck's law of thermal radiation and Newton's law of convective exchange between solids and fluids. In addition, surface effects can become predominant when small objects are involved, which further modifies the apparent thermal properties. All the associated phenomena provide interesting opportunities for designing interesting new nanomaterials and devices with improved thermal management or energy-harvesting capabilities, which is highly required in order to reduce the carbon footprint of many activities such as nano-electronics. Figure 1 summarizes some of the effects that enter into play: rarefaction of energy carriers, sizes becoming smaller than characteristic lengths associated with heat transfer (mean free path, wavelength, boundary layer), geometrical effects, etc.

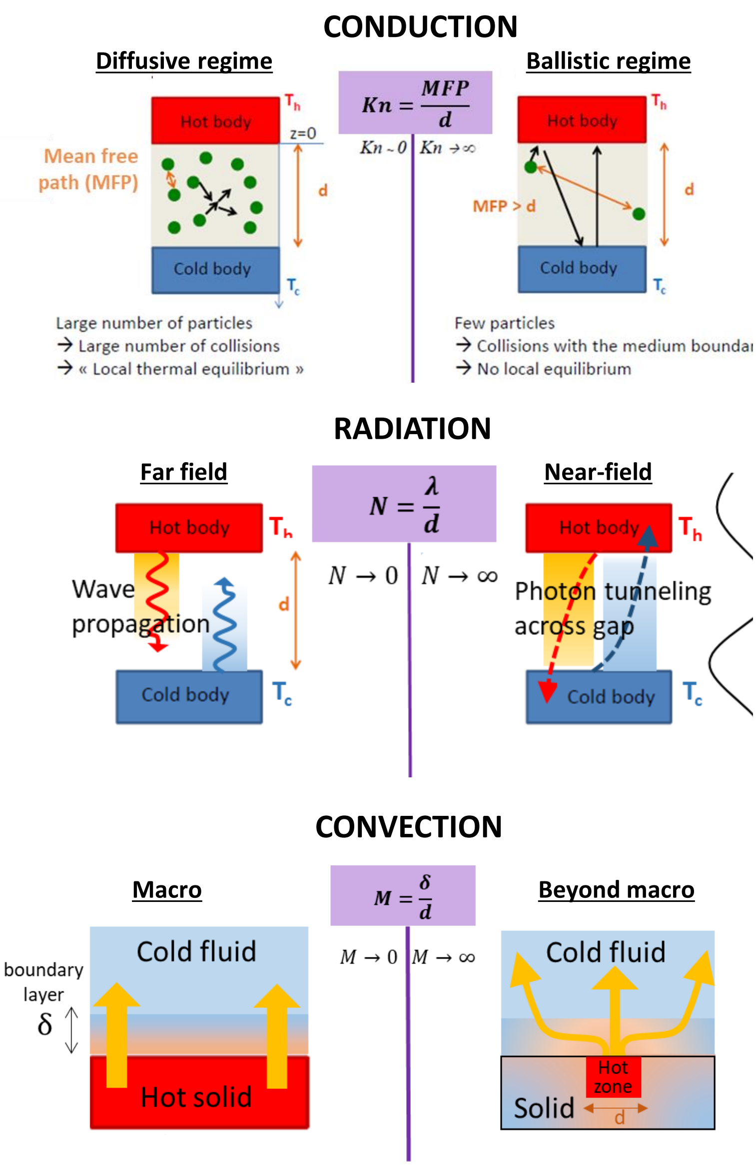

Figure 1. *Transition from macroscopic-scale to microscale heat transfer.*

Goal of the project: The goal is to study experimentally some of these effects during the internship by means of resistive thermometry, i.e. the fact that electrical resistivity depends on temperature. For metallic resistors, the electrical resistance writes:

$R(T) = R(T_0).(1 + \alpha(T - T_0)),$

where $\alpha = 1/R.dR/dT$ is known as the temperature coefficient of electrical resistivity (TCR). By means of metallic lines or serpentines deposited on top surfaces, used as tiny thermometers, we will analyse heat dissipation in solids in order to observe deviations to Fourier usual heat diffusion, the impact of heater size on the convective coefficient, and possibly analyze thermal radiation as a function of size.

Work to be performed
- Understanding the project goals; modifications of the numerical code
- Experimental measurements of already-existing samples and devices at CETHIL with an experimental setup which is well established.
- Design of few novel samples and characterization of such samples
- Comparison with numerical simulations

- Final report/oral defense

Framework: Collaboration with other laboratories: INL (INSA Lyon), where sample fabrication properties are available in the frame of the NanoLyon platform. Possible collaboration with IEMN (Lille), which hass fabricated devices for CETHIL in the past.

Required background: Knowledge of thermal physics is mandatory. Solid-state physics and electronics will also be useful.

Possibility of PhD thesis after the internship: Yes. A funded PhD thesis offer is available from September 2021 on a slightly different topic, in the frame of a project financed by the French National Research Agency (ANR).

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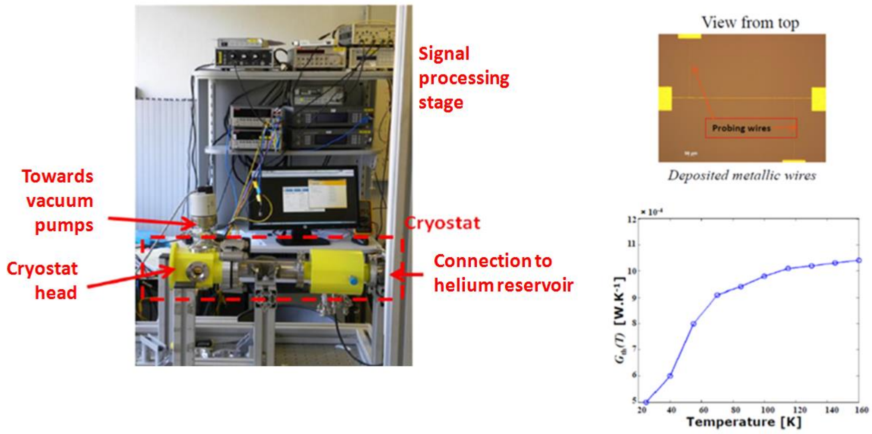
Figure 2. Electro-thermal measurements for determining the effective thermal conductivity. *(a) Experimental setup. (b) Top view of a metallic line deposited by lithography (c) Exemple of result: temperature-dependent thermal conductance.*



Possible references

[1] *Introduction to heat transfer at nanoscale*, P.-O. Chapuis, in "Thermometry at the nanoscale: Techniques and selected applications", RSC Publishing, F. Palacios and L. Carlos ed., 2015. http://pubs.rsc.org/en/content/ebook/978-1-84973-904-7#!divbookcontent

[2] *Thermal transport phenomena beyond the diffusive regime*, P.O. Chapuis, *et al.*, Proceedings of MIXDES (Mixed Design of Integrated Circuits & Systems) conference, Lodz (Poland), 2016.

[3] *Non-idealities in the 3omega method for thermal characterization in the low- and high-frequency regimes*, W. Jaber and P.-O. Chapuis, AIP Advances 8, 045111 (2018)