Heat conduction at nano-interfaces and implications on thermomechanical interface properties

Localisation:

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PhD topic:

Nanotechnology and nanomaterials development in the field of energy allows now to envisage controlling heat transfer in solid materials at the length scales of energy carriers [1]. In non-metallic solids heat is carried by phonons (high-frequency acoustic waves). Structuration of the material can be done at various scales, in particular at the one of the mean free paths (MFP) of phonons, on the order of hundreds of nanometers in many materials, or at the at the one of the phonon wavelength(λ_{th}), on the order of few nanometers at ambient temperature (see Figure 1). At the largest scale, a phonon can be assimilated to a particle transported by diffusion, following the well-known Fourier law. At the mean free path scale, the transport is ballistic, and some original phenomena enter into play: temperature discontinuities at interfaces, flat temperature profiles, reduced dissipation in comparison to standard predictions. The effects of those phenomena on the thermomechanical behavior of the materials are currently unknown, while they are especially important in electronics. For instance, differential thermal expansion leads to cracks which are detrimental to the device performances. In addition, while the general picture of ballistic heat conduction is understood, the details for many materials are still elusive in spite of their significance.

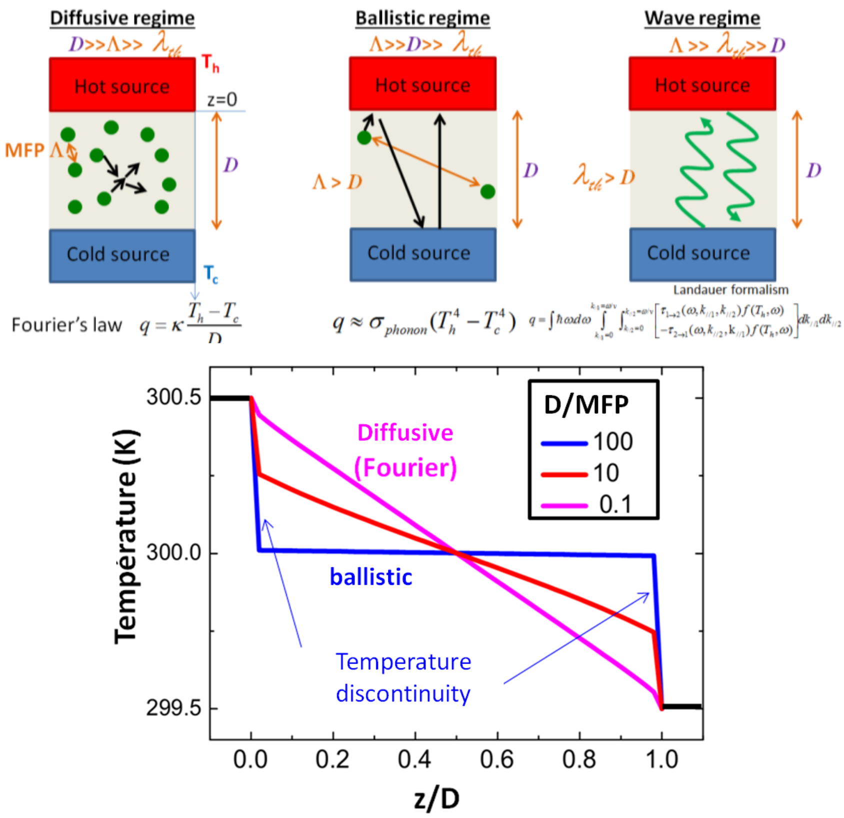


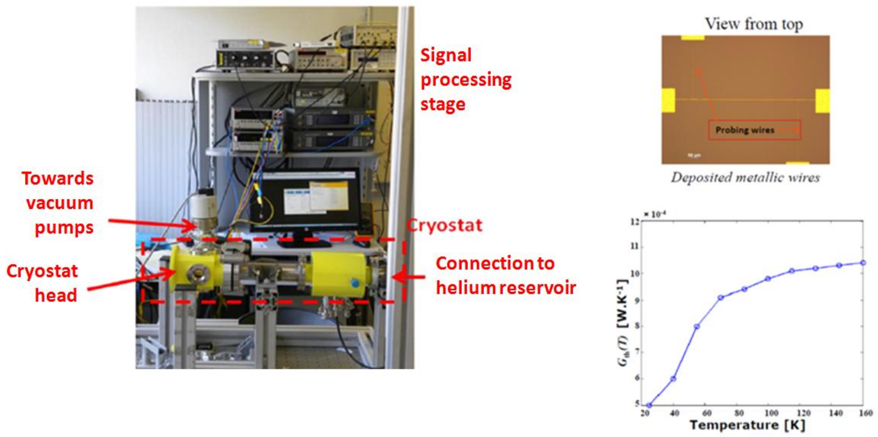
Figure 1. Heat conduction regimes, as a function of the thickness D of a layer

(a) Diffusive regime (Fourier law), when the thickness is much larger than the mean free path of the energy carriers (distance travelled between two collisions with other energy carriers) and much larger than the wavelength. (b) Ballistic transport, when the energy carriers are confined because the medium thickness is smaller than their natural mean free path. (c) Wave regime, when the medium is smaller than the mean free path and smaller than the wavelength.

The work to be performed will consist in an experimental study of various thin films as a function of their thicknesses, with the aim of observing a systematic transition between the different regimes [2]. These experiments will be performed in a temperature-dependent cryostat that allows electro-thermal measurements [3] of effective thermal conductivities of materials (or thermal conductances, depending on the geometry, see Fig. 2). Different materials of interest for the electronics or energy-harvesting fields will be considered. The objective will be to estimate the local discontinuities of ballistic temperature at the contacts between the materials. Particular attention will be devoted at interfaces [4]

Once these material parameters known, they will be compared to simulations based on the Boltzmann Transport Equation for phonon (similar to the Radiative Transfer Equation known in the field of thermal radiation), which allow to obtain local temperature profiles (similar to Fig. 1). These data will be used to determine effective parameters useful of thermomechanical analyses.

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.*



[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)

[4] *Native oxide limited cross-plane thermal transport in suspended silicon membranes revealed by scanning thermal microscopy*, A.M. Massoud, *et al.*, Applied Physics Letters 111, 063106 (2017)

Prerequisites : The candidate should have a strong background in mechanical engineering or in physical engineering.

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