Olivier Bourgeois*, Christophe Blanc, Adib Tavakoli, Yanqing I. Liu, Dimitri Tainoff

olivier.bourgeois@neel.cnrs.fr

Institut Néel, CNRS & Univ. Grenoble Alpes, F-38042 Grenoble, France

Low Temperature Nanophononics: manipulating heat at the nanoscale in the regime of ballistic phonon

Nanophononics is an emerging field of condensed matter that deals with transport of thermal phonons at very small length scales. Here we particularly focus our interest towards low temperature experiments where ballistic transport of phonon is dominating.

When a waveguide becomes smaller than the mean free path or the phonon wavelength ($\ell < 100$ nm at low temperature), heat transfer are strongly affected. Here, I will present the results we obtained by ultra-sensitive measurements of thermal conductance of suspended nano-objects (nanowires and membranes) using the 3ω method. This experimental set-up allows the measurement of power as small as a fraction of femtoWatt (10^{-15} Watt) [1, 2]. These experiments show that the concepts of mean free path and dominant wavelength are crucial to understand the phonon thermal transport below 10K. The phonon transport, at this temperature, is well described by the Casimir-Ziman model used here to treat the data. Thanks to the fact that the nanowires are made out of monolithic single crystal, we first demonstrate that the contribution of the thermal contact between a nanowire and the heat bath to the global thermal balance is negligible [3].

Strong reduction of thermal conductance has been obtained in serpentine nanowire where the transport of ballistic phonons is blocked [4]. Moreover, in corrugated silicon nanowire, we showed that the corrugations induce significant backscattering of phonon that severely reduces the mean free path (up to a factor of ten), beating in some cases, the Casimir limit. These experiments demonstrate the ability to manipulate ballistic phonons by adjusting the geometry of thermal conductors, and hence manipulate heat transfer at low dimensions. We will also discuss future thermal measurements at subkelvin temperature on individual suspended nanowire and membrane deeply in the ballistic regime where the 3 method has to be abandoned. New experimental techniques are developed to address the question of nanoscale thermal transport below 0.1K, especially concerning quantification of thermal conductance, phononic crystal and thermal rectification in the ballistic regime of phonon transport [5].

Finally, the use of these new concepts of engineering heat transfer at the nanoscale allows considering the development of new nanostructured materials for thermoelectrics at room temperature, opening exciting prospects for future applications in energy harvesting.

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