Engineering Phonon Thermal Transport by Nanostructuration: From Fundamentals to Applications

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The use of thermoelectric devices for energy harvesting at room temperature has a lot of advantages. Indeed harvesting thermal energy, which is present all around us, could ensure a real autonomy to connected objects (Internet of Things IoT) when low power consumptions are required. However conventional thermoelectric modules are not well fitted to fulfil this task. Indeed even if they can be miniaturized, their 3D geometry implies a very bad thermal exchange with their environment. That is why nanostructured systems carries on exciting opportunities.

Since two decades, engineering the thermal properties of materials by nanostructuration has made significant progress. The phonon engineering is based on an approach of phonon blocking to reduce the lattice thermal conductivity of a material through decreasing the scale or introducing nanostructures. Once the distances between scattering center are comparable to the phonon mean free path within the material the phonon transport can be much more diffusive resulting in a somehow prohibited heat transport.

Since numerous years, the Thermodynamic of Small System (TPS) group is working on the influence of nanostructuration on phonon transport, from low temperature to room temperature. Several ways of manipulating and inhibiting heat flow have been studied in specific structures under the form of thin films, membranes and nanowires. Here, we will review the recent achievements of our group in thermal transport measurements going from low temperature in the quantum regime to possible applications for room temperature thermoelectricity. It includes measurements and understanding of phonon transport in different kind of membranes and nanowires (Si_3N_4, Si) and optimization of specific "electron-crystal phonon-glass" thermoelectric thin films (like GeMn inclusions in Ge matrix, where the size distribution goes from 5 and to 50 nm).

All along, we will detailed the adapted thermal methods that has been used for the thermal measurements of each nanostructures. Then, for each of these systems, we will describe the best thermal model that gives good account for peculiar phonon transport (from fully ballistic to diffusive). As a conclusion, we will give various possible applications of nanostructured materials for thermoelectricity and energy harvesting at low dimensions where phonon engineering is used to reduce the thermal transport.