Simulations and conception of innovative cooling nanodevices based on III-V heterostructures

Marc Bescond [a,b], Xiangyu Zhu [b], Nicolas Cavassilas [a], Fabienne Michelini [a], Guéric Etesse [a], C. Belabbas [a], Chloé Salhani [b,c], Kazuhiko Hirakawa [b,c]

[a] Faculté des Sciences de Saint Jérôme, IM2NP, UMR CNRS 7334, Aix-Marseille Université, Case 142 (13397 Marseille Cedex 20, France)

[b] Institute of Industrial Science, University of Tokyo, 4-6-1 Komaba, Meguro-ku (153-8505, Tokyo, Japan)

[c] LIMMS-CNRS, IRL 2820, 4-6-1 Komaba, Meguro-ku (153-8505, Tokyo, Japan)

Corresponding author email: marc.bescond@cnrs.fr

Thermoelectric devices are based on the diffusive phonon and electron transport, and operate in close to equilibrium regime, where their produced power is obviously limited. The scenario is significantly different in nanostructures where carrier transport can be assumed as strongly ballistic. In this non-equilibrium regime, electron temperature may significantly differ from the lattice one, raising the opportunity to obtain devices with better performances than conventional thermoelectric structures [1]. In particular, we theoretically and experimentally demonstrated that an asymmetric double-barrier GaAs/AlGaAs heterostructure can act on both the electronic and phononic bath's refrigeration due to a remarkable evaporative cooling process [2-4].

We subsequently studied the operating principle of a "Quantum Cascade Cooler", a multiple quantum well structure whose cooling capabilities rely on combined resonant tunneling and thermionic emission filtering. We experimentally and theoretically demonstrated that such device exhibits bias dependent electron temperature oscillations emerging from electron-phonon interactions and inter-subband transitions. The actual potential for such structure to overcome the performances of the double-barrier device is discussed [5,6].

Finally, based on a non-equilibrium Green's Function quantum transport code, we theoretically showed that electrons in III-V heterostructures, are also subject to an unexpected revolving effect when applying a temperature gradient. This effect, while it does not (almost) transport electrons, transfers a high energy flux from a hot area to a colder one. It could then provide simple technological solutions in the semiconductor industry to electronically control the temperature in nanostructures [7].

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