M2 Internship proposal, March-Septembre 2020

Heat dissipation in microelectronics-related configurations: ballistic stress

(French version of this Offer available upon request)

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Context:
Hot spots are one of the main causes of limitations in microelectronic devices, since they have impacts on performances (*e.g.* temperature limits the speed at which operations can be performed) and mechanical properties (*e.g.* cracks due to variation of temperature in a device can appear and lead to device destruction). Unfortunately, it is not easy to determine the temperature field below a nanometer-scale heat source. Indeed, heat transfer through conduction is mediated by heat diffusion at macroscopic scale (Fourier's law), but not at nanometer-scale: it is instead mediated by *ballistic* heat conduction, governed by the Boltzmann equation. This regime takes place when energy carriers (air molecules, electrons in metals, collective atomic vibrations called phonons in crystalline solids) move freely between domain boundaries and do not interact between each other through collisions in the volume (the mean free path is larger than the domain size). It is crucial to study the transition between the diffusive and the ballistic regimes, when energy carriers interact weakly with each other (few collisions) and with the domain boundaries. In addition, the impact of thermal boundaries at surfaces is critical in some microsystems since the surface-to-volume ratio becomes larger.

The goal of the internship is to analyze how ballistic heat dissipation can lead to a different type of strain than the one usually considered in standard simulations tools based on the Fourier heat equation. First results (Master internship results in 2019) have underlined that the error usually committed can be significant. This internship will provide an opening towards nanotechnologies and is based on numerical work. The student will be able to learn many novel concepts during the internship and is not expected to be an expert of the field at the beginning.

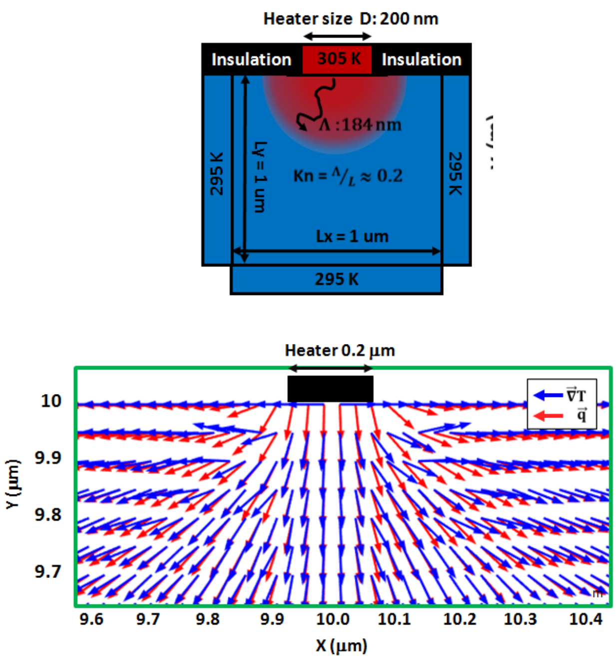

Figure: (a) Heat dissipation below a Joule-heated metallic wire of width close to the heat carrier mean free path (200 nm), *i.e.* in the ballistic regime. (b) Zoom below the heat source, highlighting an example of phenomenon linked to ballistic heat dissipation: the flux and the gradient temperature are not aligned.

References :

- Quasi-ballistic thermal transport and temperature jumps in nanostructures, A. Alkurdi et al., E-MRS Fall Meeting Symposium "Nanomaterials thermal transport properties and nanothermodynamics", Warsaw (Poland), September 18-22, 2019
- Thermal transport phenomena beyond the diffusive regime**,** P.-O. Chapuis, T. Nghiem, C. Abs Da Cruz, E. Nefzaoui**,** Special session on Nanoscale Thermal Modeling and Measurement, 23rd International Conference on Mixed Design of Integrated Circuits and Systems – MIXDES, June 23-25, 2016, Lodz (Poland), 'Invited lecture'

For more information, see website.

Work to be performed:

- Understanding of the concept
- Adaptation of the numerical code for the new configuration
- Comparison with previous numerical data
- Final report

Dates: March-September 2020

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