Nanoscale Heat Transport and Phonon Hydrodynamics

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One of the most important limitations in electronic engineering is related with heat management at reduced length scales.

A phonon hydrodynamic model derived from the Boltzmann Transport Equation allows to use finite elements methods to describe heat transport in complex geometries at the nanoscale.

COMPUTATIONAL METHODS:
Weak form implementation analogous to Navier-Stokes equation.

Energy Conservation Equation

$$c\frac{dT}{dt} + \nabla \cdot \mathbf{q} = 0$$

Hydrodynamic Heat Transport Equation

$$\tau\frac{\partial \mathbf{q}}{\partial t} + \mathbf{q} + \kappa\nabla T = \ell^2(\nabla^2\mathbf{q} + 2\nabla\nabla\cdot\mathbf{q})$$

Slip Boundary Condition (implemented using Discontinuous Galerkin Method)

$$\mathbf{q}_t = -C\ell\,\nabla\mathbf{q}_t\cdot\mathbf{n} \qquad \mathbf{q}\cdot\mathbf{n} = 0$$

SILICON PHONONIC CRYSTALS

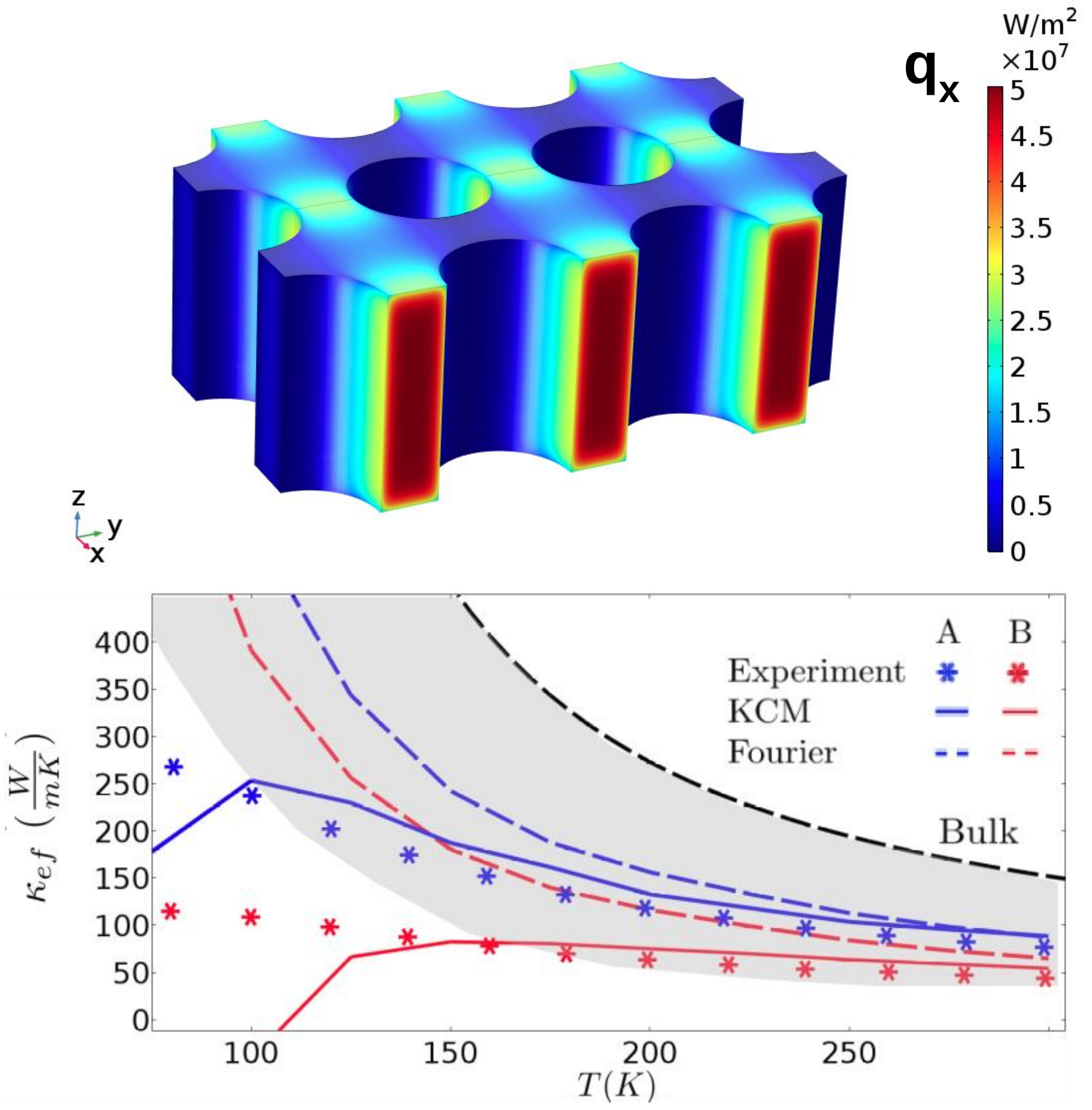

Figure 1. The effective thermal conductivity is predicted for different geometries and temperatures.

NANOSCALE HEATER IN INGAAS SUBSTRATE

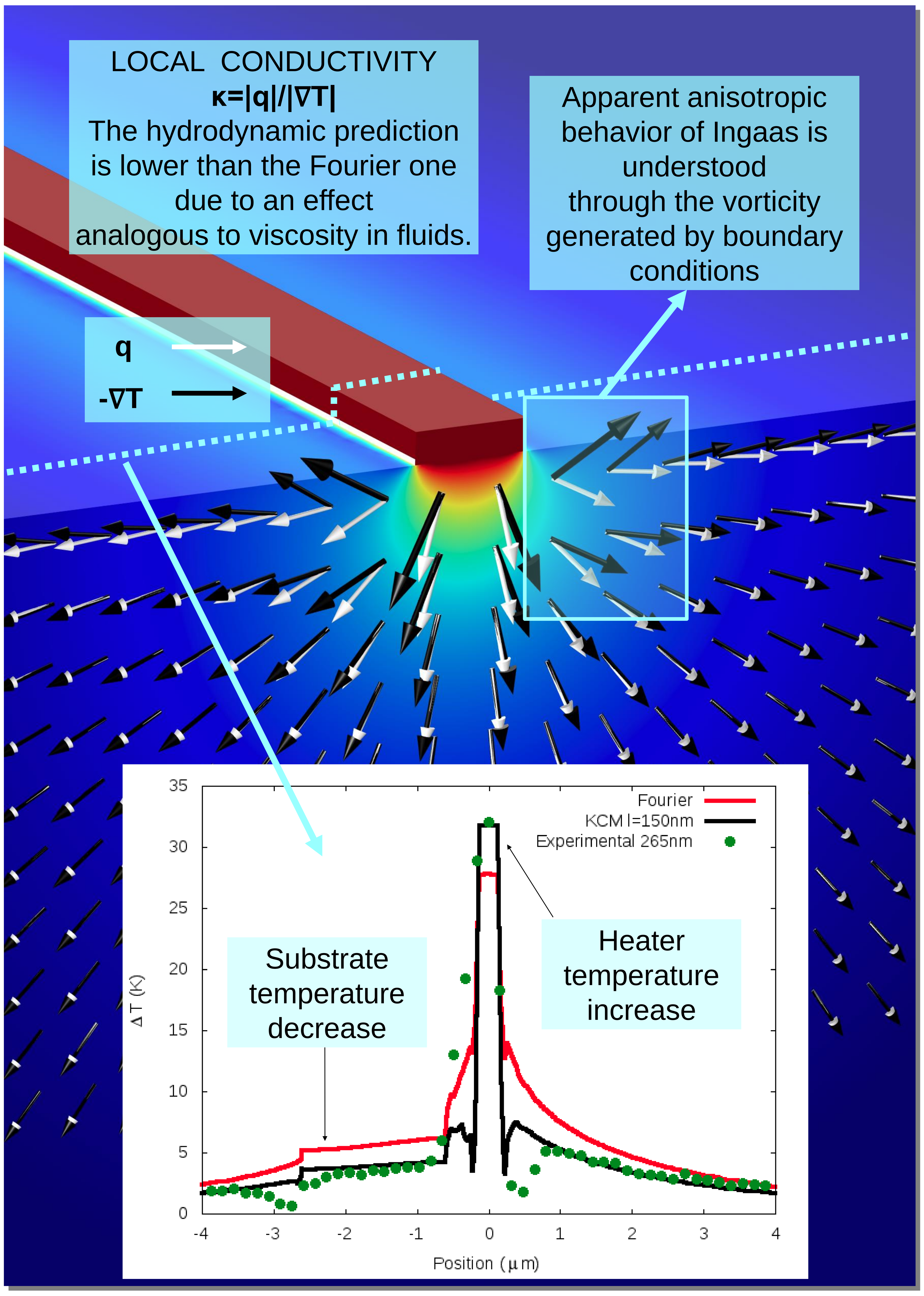

Figure 2. Color map correspond to temperature.
The temperature profile along the dashed line is reproduced by the hydrodynamic model.

CONCLUSIONS

A COMSOL® interface is under development to describe heat transport phenomena at the nanoscale.

This tool is an improvement of current approaches based on the use of an effective Fourier law, that can not be used in complex geometries.

REFERENCES:

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