Master 2 Internship

Title: **Nanoscale Thermal Transport Beyond Fourier's Law in 2D Materials: Functionalisation Strategies and Ultrafast Optical Probing**

Type: experimental and theoretical

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PhD funding (if any):

Project: The rapid miniaturisation of electronic devices, coupled with the increasing demands of the energy transition, creates pressing challenges in nanoscale heat dissipation and thermal management. Two-dimensional (2D) materials such as graphene and hexagonal boron nitride (h-BN) have emerged as model systems due to their high thermal conductivity, mechanical robustness, and the possibility of probing their intrinsic thermal properties at the nanometre scale. While extensive research has characterised these materials in their pristine forms, the next frontier is to design strategies that actively control heat transport beyond the classical diffusive regime described by Fourier's law.

This project aims to develop and investigate advanced functionalisation and structuring methods — including controlled nanometric perforation, selective amorphisation, and partial encapsulation — in order to engineer the spatial distribution of phonon scattering centres on the scale of their wavelength (tens of nanometres at 300 K). Such approaches are expected to enable directional heat flow and to access non-classical transport regimes, notably ballistic and hydrodynamic heat conduction. The ultimate goal is to establish novel thermal building blocks — thermal guides, lenses, splitters, and rectifiers — that could underpin next-generation thermal management solutions for electronic and optoelectronic devices.

The internship will involve both theoretical and experimental aspects. From the fundamental side, the work will address heat transport at length and time scales where Fourier's law fails, requiring models that incorporate ballistic and collective phonon dynamics. On the experimental side, the project relies on advanced, non-contact optical techniques such as Time-Domain Thermoreflectance (TDTR) and Frequency-Domain Thermoreflectance (FDTR). These methods allow direct measurement of thermal transport with sub-picosecond temporal resolution and nanometric spatial sensitivity, making them ideal tools to probe the local thermal response of 2D materials under tailored nanostructuring.

This internship offers the opportunity to engage with state-of-the-art experimental nanophysics, to acquire expertise in ultrafast optical metrology, and to contribute to fundamental advances in nanoscale thermal transport with clear technological relevance for energy and electronics.

1. S. Grauby, B. Vidal Montes, A. Zenji, J-M. Rampnoux, and S. Dilhaire, How to Measure Hot Electron and Phonon Temperatures with Time Domain Thermoreflectance Spectroscopy? ACS Photonics, 9, 11, 3734–3744 (2022).
2. Zenji, A., Pernot, G., Lacroix, D., J-M. Rampnoux, O. Bourgeois, S. Grauby, and S. Dilhaire, Seeking non-Fourier heat transfer with ultrabroad band thermoreflectance spectroscopy. Commun Mater 5, 123 (2024).