Exploring the extremes of thermal transport in emerging semiconductors by photothermal microscopy (MicroTherm)

Electronic devices use only a portion of the supplied energy for useful operation, with the remainder lost as heat. Significant efforts have been directed towards developing devices that are either more energy-efficient or better at dissipating residual heat, thereby extending their operational lifespan. **With the development of next-generation semiconductors promising exciting applications, it is crucial to address the thermal management challenges posed by their often-unusual structures and distinct properties compared to industry-ready materials.** Overcoming these challenges is essential for advancing electronics that can withstand overheating.

In this project, we propose **systematic investigations into the extremes of thermal transport properties in emerging classes of electronic materials**, focusing particularly on hybrid perovskites (known for recent achievements in photovoltaics) and two-dimensional layered semiconductors similar to graphene.

We hypothesize that **by using rapidly switchable lasers we will achieve temperature modulation dimensions comparable to the optical resolution of microscopes**, enabling mapping of thermal properties and revealing the potential influence of material heterogeneity. Some materials exhibit differences in heat dissipation ability depending on their crystallographic orientation, known as anisotropy. This effect is particularly strong in layered semiconductors, where individual atomic layers are separated by van der Waals forces, much weaker than typical atomic bonds. Despite the significance of such behaviour for structures made of very thin (sub-micron) material layers, this topic remains largely unexplored for many materials, especially low-dimensional perovskites.

Our ultimate goal is to reveal the reasons behind the observed limits of thermal parameters using laser-induced acoustic wave generation and conducting experiments at various temperatures. Acoustic wave speed is a fundamental parameter linked to a material's thermal properties, making its determination at the microscopic scale without attaching sound transducers highly valuable. It can also provide insights into potential deviations from the fundamental Fourier's law of heat energy transfer, recently documented for nanomaterials. Experiments conducted at both cryogenic and typical operating temperatures will help us identify the dominant energy scattering processes and the influence of potential phase transitions (changes in atomic arrangement of crystals) on thermal properties.

To achieve these objectives, we will implement a range of **microscopic photothermal methods**, leveraging major advancements made in the field over the past decade. Thermoreflectance (TR) measurements, which rely on optically generated heat pulses in materials, have opened unprecedented possibilities for non-contact investigations of heat transfer in solids and led to significant discoveries. **Within our project, we will develop complementary TR configurations targeting different ranges of thermal conductivity, spatial resolution, and extreme conditions, paving the way to addressing key questions in the field.**

The proposed studies will shed new light on the microscopic landscape of heat dissipation in materials with promising applications in next-generation electronic devices. We hope that the successful completion of these tasks and the establishment of a state-of-the-art experimental base will attract the attention of the broader research community.