Microstructural control of thermal transport in oxide materials

Primary supervisor: Dr Raymond McQuaid

In this PhD project, you will join a research team using cutting-edge nanoscale thermal mapping tools to investigate the physics of heat flow in materials with reconfigurable thermal properties, with the goal of improving fundamental understanding and fabricating prototype heat flow devices.

Project Introduction: Effectively minimising and recovering waste heat remains as one of the great challenges of our time, with a staggering 70% of primary energy estimated as ending up as waste heat released into the environment [1]. Part of the solution involves developing innovative ways to manipulate heat flow, ideally to the same level of sophistication as for electronic signals. However, there currently exist very few compelling ways to actively control heat flow in solid materials and after-the-fact solutions are still the norm, such as the use of fans and heat sinks for cooling microelectronics. For thermal conduction in solids, a popular research-level approach for controlling heat flow is by using microstructure to affect the transmission of thermal vibrations. In some exotic materials, where the microstructure can be dynamically configured using voltage signals, heat flow can therefore be modulated on command, giving rise to the possibility of thermal switch devices. Material solutions exhibiting large thermal conductivity switching ratios and fast switching response times are highly sought after [2]. Ferroelectric materials are promising candidates in this regard, since they support intrinsically microstructured features called domain walls that can both affect thermal transport and can be readily created or erased with applied voltage signals. This offers the possibility to manipulate the effective thermal properties of the ferroelectric material with a control voltage and therefore how easily heat passes through the material [3].

Project description: The core experimental methodology will involve thermal conductivity measurements made using a Frequency Domain Thermoreflectance (FDTR) setup [4]. FDTR is an optical pump-probe technique where the sample surface is locally heated by a high-frequency laser pulse and temperature induced variations in surface reflectivity are monitored and used to back-extract thermal transport properties. Recent advances have allowed for impressive microscopic spatial maps of thermal transport properties to be obtained, allowing for the microstructural effects on heat flow to be visualised directly. The material systems of interest will initially be domain-structured ferroelectrics with a view to later investigating other related materials, such as anti-ferroelectrics and phase change materials. What each of these materials systems have in common is the possibility to trigger changes in their microstructure *in-situ* while making thermal measurements. As part of the research program, these experiments will also be supported by nanoscale heat-flow experiments using the group's established Scanning Thermal Microscope (SThM) facility.

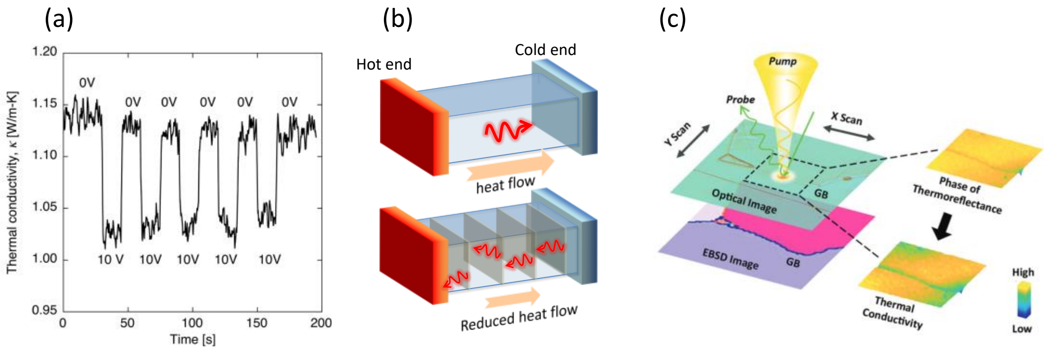

Figure 1 (a) Demonstration of a voltage controlled thermal switch, after Ihlefeld *et al*. [3]. (b) Schematic of ferroelectric domain switching and expected influence on phonon transport. (c) Using FDTR to spatially resolve the effect of sample microstructure on thermal conductivity, after Isotta *et al*. [4].

The PhD project is supported by the lead investigator's £950k UKRI Future Leaders Fellowship and will mainly comprise of fundamental research with an experimental focus. The broader ferroelectrics activity at Centre for Quantum Materials and Technologies is internationally renowned and the research features in high-impact journals and at international conferences. The student will work with Dr Raymond McQuaid as the primary supervisor and a crack team of established PhD students and post-doctoral researchers.

Applications should be made through the QUB system and informal discussions with Dr Raymond McQuaid are encouraged. Applicants should have a 1:1 or 2:1 MSci degree classification in a relevant discipline (e.g. physics, electrical engineering, materials science) and a strong personal motivation for PhD study in an experimental context.

References

[1] C. Forman *et al. Renew. Sustain. Energy Rev.* **57,** 1568, 2016 [link]
[2] A. Sood et al. *ITherm* 1396, 2018 [link]; J. Smoyer *Heat Trans. Eng.* **40,** 269, 2019 [link]
[3] J. Ihlefeld et al. *Nano Lett.* **15,** 1791, 2015 [link, link]
[4] J. Yang *et al. J. Appl. Phys.* **116,** 023515, 2014 [link]; J. Yang *et al. Rev. Sci. Instrum.* **84,** 104904, 2013 [link]; E. Isotta *et al. Adv. Mater.* **35,** 2302777 (2023) [link]