Exploring Thermal Transport and Electrocaloric Effects in Ferroelectrics using Scanning Thermal Microscopy

Raymond McQuaid

School of Mathematics and Physics, Queen's University Belfast, Belfast, BT7 1NN, U.K.

Scanning Thermal Microscopy (SThM) is a valuable Atomic Force Microscopy technique for mapping the thermal properties of materials at the nanoscale [1]: surface temperature distributions can typically be mapped out with temperature resolution on the order of 10 mK and with spatial resolution of sub-100nm. In this talk, I will discuss how SThM could be a powerful tool for studying the role of microstructure on heat flow in ferroelectric materials, specifically for (i) mapping the thermal properties of domain walls and (ii) understanding the microscopic behaviour of electrocaloric effects for solid state cooling.

Domain walls are nanostructured interfaces that occur in ferroelectric materials and emerge naturally as part of their polar domain microstructure. They can be created and removed with applied voltages and are in this sense reconfigurable. Interest in using ferroic domain boundaries to enable voltage control of heat flow has been steadily growing over the last decade. On one hand, it is well established that domain walls can inhibit thermal transport through phonon scattering [2] but, on the other hand, the fact that domain walls can exhibit enhanced electrical conductivity [3] means that enhanced thermal transport within the wall is also a possibility. However, direct, local measurements of either of these domain wall thermal behaviours have yet to be reported. In this regard, I will describe our SThM approach for locally mapping variations in thermal transport associated with microstructural heterogeneity. Proof-of-principle imaging in a multilayer ceramic capacitor will be discussed as well as exploratory measurements in $LiNbO_3$ thin films with domain wall microstructures.

The electrocaloric effect is a well-known phenomenon whereby rapid application of an electric field to a ferroelectric material can result in a sudden cooling. While the electrocaloric effect can be well described macroscopically through a thermodynamic approach and is understood to arise from changes in dipolar configurational entropy, the effect at the microscopic scale is not as well characterised. To this end, we developed an SThM based approach for mapping local electrocaloric response with sub-micron spatial resolution, here demonstrated in a multilayer ceramic capacitor [4]. From this data, the electrocaloric heating and cooling can be extracted to create 2D spatially resolved maps of the electrocaloric response. We intend to further use this technique to elucidate the influence of microstructural inhomogeneity on electrocaloric response in other material systems.

[1] S. Gomes, A. Assy, P.-O. Chapuis *Phys. Status Solidi A* 212, 477 (2015)
[2] J. Ihlefeld *et al. Nano Lett.* 15, 1791, (2015)
[3] J. Seidel *et al. Nature Mater.* 8, 229 (2009)
[4] O. Baxter, A. Kumar, J. M. Gregg, R. McQuaid *J. Phys.: Energy* 5, 045009 (2023)