Thermal Transport in Mesoscale, Heterogeneous Systems

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Key thermal engineering challenges for integrating new nanostructured materials into devices include development of low-cost fabrication methods for nanostructured materials and rapid, accurate, and reliable experimental and analytical techniques for thermal characterization of nanostructures. We address these challenges by integrating the material synthesis with thermal property measurements and physics-based analysis. Additionally, development of new methods for simultaneous characterization of multiple types of properties (thermal, mechanical, electrical, etc.) gives additional insight into the physics governing the heat transfer.

Often to achieve the desired functionality, multiple materials are combined to form heterogeneous composites. For example, thermal interface materials (TIMs) and phase change materials (PCMs) for passive thermal management often rely on high thermal conductivity filler particles to increase thermal transport, while the matrix provides mechanical flexibility, fills gaps, and for PCMs, the latent heat of the matrix (often wax) provides an effective energy storage mechanism. Controlling the structure, composition, and arrangement of the filler particles is crucial to improving the performance of such composites. In current lithium ion batteries, the electrode materials consist of micro- and nano-structured components infiltrated with a liquid electrolyte, and current research focuses on integrating solid polymeric electrolytes. In all these systems, the combination of components with features spanning multiple length scales with vastly different properties leads to challenges in predicting and controlling thermal transport.

Here, we use a combination of experimental and numerical approaches to evaluate thermal transport in such systems. Experimentally, we use a high resolution infrared microscope to interrogate the thermal conductivity, interface resistances, and thermal transport pathways in heterogeneous composite systems focusing. Numerically, we use granular mechanics simulations coupled with thermal transport models interrogate the impact of stress and filler particle arrangement on transport. Ultimately, these studies enable rational design and development of new materials with unique combinations of properties.

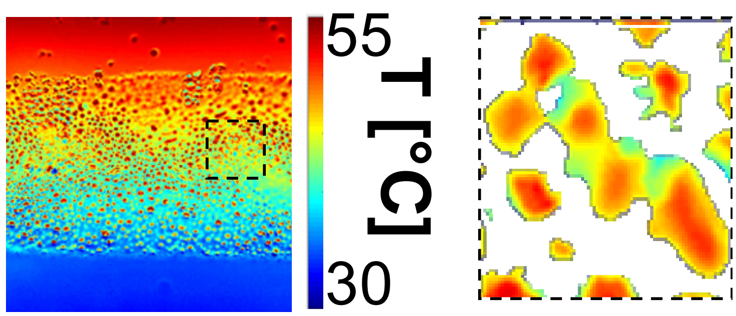

Fig. 1: (left) Thermal map of a packed bed of granular particles sandwiched between a hot and cold reference layer of known thermal conductivity. (right) High magnification thermal map of a cluster of particles.