Harnessing Wave and Particle Properties of Phonons for Enhanced Control over Lattice Thermal Transport

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In the past decade, the dual nature of phonons, embodying both wave-like and particle-like characteristics, has received significant attention alongside their extensively investigated particle nature. Notably, we have witnessed the phenomenon of ballistic transport of coherent phonons within superlattices, a revelation observed through both experimental and atomistic simulations. These coherent phonons, arising from the intricate interference of backscattered phonon waves at densely packed interfaces, challenge conventional assumptions and significantly impact the transport of phonons traditionally considered particle-like.

In this invited presentation, we embark on an exploration of these intriguing behaviors and their relationships with conventional incoherent phonons. Our first focus lies in the precise manipulation of the overall thermal conductivity of multilayered structures and holey structures. This control is achieved through intentional localization, scattering, or channeling of phonons, resulting in the reduction of thermal conductivity, even below the limits of random alloy materials. Machine learning techniques have proven to be particularly helpful to this objective. Our second endeavor is dedicated to understanding the complex interplay between coherent and incoherent phonons within the same material. This interaction leads to intricate temperature and length-dependent thermal conductivity phenomena in superlattices. We have developed and employed theoretical and modeling approaches to elucidate these phenomena. Our final segment delves into the feasibility of engineering coherent and incoherent phonons independently. We highlight our experimental and modeling results on the control of thermal conductivity in superlattices and nanocomposites, showcasing the potential to tailor thermal properties through the decoupling of these two phonon types.