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Discovering New Properties of MoS2: An Emerging Technologically Important Material

ABSTRACT

With a growing need for miniaturization of devices in the electronics industry, due to being close to reaching the limit of conventional silicon-based transistors, extensive studies have been conducted on utilizing two-dimensional (2D) materials as replacements for silicon to avoid size restrictions and quantum effects. However, as a key limiting factor of device performance, the energy transport (i.e., heat dissipation) in these materials is yet to be fully understood. The recent development of ultrafast electron microscopy (UEM) has enabled the direct visualization of nanoscale energy transport in the form of coherent crystal lattice vibration called phonon in semiconductors. This opens up more possibilities in advancing the study of nanoscale energy dissipation. My research focuses on studying nanoscale phonon dynamics in molybdenum disulfide (MoS2), a well-understood 2D material in terms of its electronic and optical properties. My experiments are conducted by shining ultrafast laser pulses onto the material and capturing the structural responses on the picosecond timescale. The material responds rapidly to the optical excitation and emits phonon to release energy. Phonon plays an important role in nanoscale heat transfer in condensed matter and can modify material properties such as thermal conductivity. My dissertation work focuses on understanding the fundamentals of energy transport in MoS2 with UEM. I made the first observations on nanoscale phonon dynamics along different crystallographic directions as a result of the highly anisotropic nature of the material. I performed detailed analysis and characterization of the emission and propagation of phonon that matched the speed of sound. Ongoing work includes studying of the structural-properties relationship of layered materials and the effects of unique structural morphology on phonon dynamics. The results of these studies have advanced our knowledge in understanding the fundamentals of energy transfer in 2D materials and provide insight in the design of next-generation electronics.