Observation of Ballistic Thermal Transport across 2D Nanoscale Interfaces

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Thermal transport is generally depicted as a diffusive process in which the flow of energy is driven by a temperature gradient, as described by the Fourier theory of thermal transport. However, experiments have demonstrated that this picture fails for length scales smaller than the mean free path of the energy carriers in a material. The breakdown of conventional Fourier heat conduction has been observed in a variety of nanostructured materials such as thin films, superlattices, and nanowires. In recent work, we observed size-dependent ballistic thermal transport for heat dissipation from a nanoscale line heat source into the bulk, and reported the first systematic observation and quantitative measurements of the transition from diffusive to ballistic heat dissipation. We observed a significant decrease in thermal transport away from one-dimensional metallic nano-gratings into a sapphire substrate compared with Fourier law predictions. In this work, we study thermal transport from two-dimensional hot spots. Monitoring heat transfer dynamics from two-dimensional nano-gratings into the substrate by using time-resolved diffraction of extreme ultraviolet light, we observe significantly stronger ballistic contributions to thermal transport in two-dimensions compared with one-dimension. This is consistent with the theoretical expectation that stronger ballistic effects are anticipated as nanostructures shrink in size, or acquire higher dimensional confinement. These experimental studies not only significantly advance the understanding of heat transfer fundamentals at the nanoscale, but also have direct implications in the thermal management and reliability of nanoelectronics, photovoltaics and nanomedicine.