Uncovering Nanoscale Heat Transfer from Periodic Heaters using Extreme Ultraviolet Light

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At the nanoscale, the expected thermal behavior has previously been shown to deviate from the macroscopic diffusive prediction, specifically when the characteristic dimensions (CD) of the transport are comparable to the dominant phonon mean free paths (MFPs) in the material. As there is no fully predictive theory for the interplay between nanoscale geometry and non-diffusive thermal transport, there is a great need for reliable metrology tools to probe dynamics at these length scales. Using our unique nanometrology technique, we observe heat transfer away from nanoscale 1D and 2D periodic heat sources. These metallic nanostructures, which have a CD ranging from 1 mm down to 20 nm, are deposited on top of dielectric or semiconductor substrates. An infrared femtosecond laser pulse preferentially heats the nanostructures, causing them to impulsively thermally expand. Then, the gratings relax to their equilibrium surface profile as the heat is transferred to the substrate. These dynamics are probed by tracking the diffraction efficiency of an extreme ultraviolet (EUV) probe beam diffracted from the nanostructures. This EUV light comes from high harmonic generation, an extreme non-linear process which provides coherent ultrafast pulses of 29 nm wavelength. In previous work, our group showed that quasi-ballistic thermal transport dominates for isolated 1D nanostructures whose CD is below the average MFP in both silicon and sapphire substrates. We also uncovered a new surprising regime where this quasi-ballistic transport is partially reversed when the spacing between the heaters is comparable to the dominant MFPs in the substrate. Here, we will show a further validation of this regime by probing varying period independent of linewidth and using fused silica as a control. In addition, we will present how thermal transport from 2D confined heat sources exhibits similar geometry dependence as the 1D confined case together with the cooling dynamics on new complex materials.