Time-Resolved Quasi-Ballistic Heat Transport at Nano-Interfaces

Mark Siemens [C, S], Qing Li, Margaret Murnane and Henry Kapteyn
University of Colorado at Boulder and JILA, Boulder, CO, U.S.A.

Ronggui Yang
Department of Mechanical Engineering, University of Colorado at Boulder, Boulder, CO, U.S.A.

Keith Nelson
Massachusetts Institute of Technology, Cambridge, MA, U.S.A.

Erik Anderson
Lawrence Berkeley Labs and Center for X-Ray Optics, Berkeley, CA, U.S.A.

Coherent Extreme Ultraviolet (EUV) beams from high harmonic generation (HHG) are a sensitive probe of nanoscale dynamics, including thermal transport and surface acoustic wave propagation. We have used the change in diffraction from a nanostructured grating to measure heat transport across sub-micron interfaces and to observe he changes in between diffusive and ballistic heat transport. In HHG, an intense ultrafast laser pulse is focused onto gas atoms, generating high-frequency light up to and beyond the EUV (~100-10nm) region of the spectrum. EUV holography has been used to measure thermal surface displacements of less than 1pm, and can resolve femtosecond dynamics. These features make HHG an exciting source for metrology, surface science, and nanomaterials research.
We used EUV diffraction from nanostructured nickel lines on sapphire to study acoustic and thermal processes at the interface. The nano-lines were impulsively heated by a ~50fs near-IR pulse and we observed two responses: high-frequency surface acoustic waves generated by impulsive, spatially periodic stress at the nano-bulk interface, and a slow thermal decay as heat flowed from the nano-lines into the substrate. By varying the base temperature before heating and the nanostructure dimensions, we observed heat transport in both the diffusive and quasi-ballistic regimes. Understanding of heat flows in the sub-micron regime (where features are on the order of a phonon mean free path) is critical in nanoelectronics design, where heat management is a limiting constraint.