Probing Nanoscale Heat Dissipation Away from 1D- and 2D-Confined Heat Sources with Coherent EUV Light

Jorge Nicolas Hernandez-Charpak [C, S], Kathy Hoogeboom-Pot, Travis Frazer and Damiano Nardi
JILA, University of Colorado Boulder, Boulder, CO, U.S.A.
nico.hernandez@jila.colorado.edu

weilun Chao and Erik Anderson
CXRO, Lawrence Berkeley National Laboratory, Berkeley, CA, U.S.A.

Xiaokun Gu and Ronggui Yang
Mechanical Engineering, University of Colorado Boulder, Boulder, CO, U.S.A.

Margaret Murnane and Henry Kapteyn
JILA, University of Colorado Boulder, Boulder, CO, U.S.A.

How is thermal transport affected by spatial confinement in nanoscale systems? The answer to this question is at the forefront of current efforts to build a fundamental understanding of nanoscale thermal transport. While past work has shown that Fourier's law for heat conduction dramatically over-predicts the rate of heat dissipation from isolated heat sources with dimensions smaller than the mean free path (MFP) of the dominant heat-carrying phonons [1], we have recently demonstrated that heat source size is not the only important dimension to consider [2]. A new regime of nanoscale thermal transport dominates when the separation between nanoscale heat sources is small compared with the dominant phonon MFPs: the collectively-diffusive regime. In this case, close proximity between neighboring heat sources can counteract the reduction in nanoscale heat dissipation from individual sources due to ballistic effects. This finding not only has consequences for thermal management applications and for the fundamental understanding of thermal transport, but also provides a new exciting tool to extract the phonon MFP spectra of materials. In order to probe nanoscale thermal transport, we explore this regime in different sample geometries, in particular heat dissipation away from 1D- and 2D-confined heat sources. We use a pump-probe setup to directly observe the dynamics of periodic arrays of metallic nanostructures (nanolines and nanodots) as small as 20nm and with varying periodicities on dielectric and semiconductor substrates. The structures absorb a 25fs infrared pump pulse; the resulting thermal expansion and relaxation is probed using the diffraction of femtosecond pulses of coherent extreme ultraviolet (EUV) light centered at 30nm, created by tabletop high harmonic generation [3]. Use of such short probe wavelength in an interferometric diffraction measurement allows for an extremely precise contact-less thermometer, sensitive to thermally-generated picometer-scale deformations in the surface profile.

References

[1] Siemens et al., *Nature Mater.* **9**, 26 (2010).
[2] Hoogeboom-Pot et al., s*ubmitted,* arXiv1407.0658 (2014).
[3] Popmintchev et al., *Science* **336**, 1287 (2012).