Nanoscale Thermal Behaviors of Wide-bandgap Materials via Non-contact Deep-ultraviolet Transient Gratings

Brendan McBennett[1, S, C], Joshua Knobloch[1], Emma Nelson[1], Theodore Culman[1], Albert Beardo[1], Henry Kapteyn[1] and Margaret Murnane[1]

[1]*STROBE, JILA, University of Colorado Boulder, Boulder, CO, U.S.A.*
brendan.mcbennett@colorado.edu

Wide-bandgap materials such as gallium oxide, diamond and gallium nitride are poised to appear in next-generation semiconductor technologies, due to their high electron mobilities and breakdown strengths [1]. Their thermal behaviors on the sub-micron length scales of modern devices, where macroscale thermal diffusion breaks down, are critical for device performance. However, many traditional approaches to studying nanoscale thermal transport rely on ultrafast visible lasers. This often necessitates a contact metrology approach for wide-bandgap materials, complicating experimental interpretations due to the introduction of interfaces and boundaries [2]. Transient thermal grating experiments have long been capable of generating a microscopic, sinusoidal heating profile directly on a sample surface via the interference of two laser pulses. Without the added complexity of boundaries/interfaces, these experiments serve as an idealized testbed for nanoscale phonon transport theories. However, tabletop transient grating experiments are thus far limited to visible wavelengths, while recent free electron laser implementations face practical limitations [3,4]. We present a new tabletop deep ultraviolet transient grating experiment utilizing nonlinear upconversion of a Ti:sapphire amplifier to generate <300 fs pulses of 6.3 eV / 196 nm light for the investigation of nanoscale transport in previously inaccessible wide-bandgap substrates and films. The technique is validated using hypersonic acoustic waves launched by the laser-induced, impulsive thermal expansion. We further discuss ongoing measurements of phonon and electron transport in diamond at excitation periodicities ranging from microns to <300 nm. Because the shorter deep-ultraviolet wavelength enables the investigation of transport at length scales previously inaccessible to tabletop experiments, it is also possible to extend measurements of silicon and other common semiconductors deeper into the nanoscale. The deep-ultraviolet transient grating experiment provides a flexible tabletop platform to study non-diffusive transport behavior, from size effects to second sound [5], at reduced length scales and in a much-expanded range of materials.

References

1. Warzoha et al., *Journal of Electronic Packaging* **143**, 020804 (2021)
2. Jiang et al., *Phys. Rev. Mat.* **2**, 064005 (2018)
3. Johnson et al., *Phys. Rev. Lett.* **10**, 025901 (2013)
4. Bencivenga et al., *Science Advances* **5**, eaaw5805 (2019)
5. Huberman et al., *Science* **364** 375-379 (2019)