MAR14-2013-020130

Abstract for an Invited Paper
for the MAR14 Meeting of
the American Physical Society

Phonon Mean Free Path Spectra Measured by Broadband Frequency Domain Thermoreflectance

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Nonmetallic crystalline materials conduct heat by the transport of quantized atomic lattice vibrations called phonons. Thermal conductivity depends on how far phonons travel between scattering events−their mean free paths (MFPs). Due to the breadth of the phonon MFP spectrum, nanostructuring of materials and devices can reduce thermal conductivity from bulk by scattering long MFP phonons, while short MFP phonons are unaffected. We have developed a novel approach called Broadband Frequency Domain Thermoreflectance (BB-FDTR) that uses high-frequency laser heating to generate non-Fourier heat conduction that can sort phonons based on their MFPs. BB-FDTR outputs thermal conductivity as a function of heating frequency. Through non-equilibrium Boltzmann Transport Equation models this data can be converted to thermal conductivity accumulation, which describes how thermal conductivity is summed from phonons with different MFPs. Relative to alternative approaches, BB-FDTR yields order-of-magnitude improvements in the resolution and breadth of the thermal conductivity accumulation function. We will present data for GaAs, GaN, AlN, Si, and SiC that show interesting commonalities near their respective Debye temperatures and suggest that there may be a universal phonon MFP spectrum for small unit cell non-metals in the high temperature limit. At the time of this abstract submission we are also working on measurements of semiconductor alloys and select metals that will be presented if completed by the conference.