Extending Characterization of Non-diffusive Thermal Transport in Silicon to <<1 µm Length Scales using Deep-ultraviolet Transient Gratings

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Managing nanoscale thermal transport in silicon is critical to developing next generation nanotechnology. Silicon transistors are manufactured with dimensions well below the average (~300 nm) mean free path of heat-carrying phonons. This leads to deviations from bulk diffusive thermal conduction that limit device efficiency and performance, notably capping computer clock speeds [1]. Fundamentally, phonon transport in nanostructured semiconductors is poorly understood, limiting our ability to engineer thermal properties of silicon components in nanoelectronics. Non-diffusive transport in silicon is commonly interpreted in terms of effective forms of Fourier's law with a reduced conductivity due to ballistic effects [2]. However, recent experimental evidence has shown that additional behaviors, including phonon hydrodynamics, appear unexpectedly on the nanoscale in semiconductors [3,4].

Previous measurements of thermal transport in silicon have either relied on fabricated transducers [4], or been limited to micron length scales [5]. To observe nanoscale transport without interfacial effects, we employ a deep ultraviolet (DUV) transient thermal grating (TTG) experiment. TTG experiments directly excite a sinusoidal thermal grating on the sample surface by interfering two laser pulses. Leveraging our short wavelength source, we measure TTG excitation periods down to 300 nm - nearly an order of magnitude below the shortest tabletop TTG previously measured on silicon [5]. We present observations of non-diffusive thermal transport from TTG excitation periods ranging between several microns and 300 nm, and reconcile our observations with previous microscale TTG measurements [5]. We discuss potential implications of our observations to discriminate conflicting theories of nanoscale thermal transport and to propose novel thermal management solutions in nanoscale devices.

References

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