Thermal transport in Single Nanowires and Nanowire Arrays

Deyu Li, Alexis Abramson, Scott Huxtable, Li Shi[1], Arun Majumdar
Department of Mechanical Engineering
University of California, Berkeley

The potential for achieving high values of thermoelectric figure of merit for semiconductor nanowires has recently been recognized. This is now driving research towards two directions, namely: (i) understanding the mechanisms of thermal transport in nanowires; (ii) synthesis of nanowire arrays and measurement of their thermal properties. Phonons in nanowires can be different from that in bulk semiconductors mainly because the dispersion relation could be significantly modified due to confinement in two directions. In addition, the presence of a surface can introduce surface phonon modes. These result in many different phonon polarizations other than the two transverse and one longitudinal acoustic branches found in bulk semiconductors. Such changes in the dispersion relation can modify the group velocity and the density of states of each branch. The phonon lifetime also changes and this arises from two sources. First, the phonon-phonon interactions can change because selection rules based on energy conservation and wave-vector relations depend on the dispersion relation. Second, boundary scattering can be much stronger in nanowires (5-50 nm diameter) than in bulk semiconductors. While there have been some theoretical studies on phonon conduction in nanowires, there are still several open questions regarding phonon transport in 1-d nanostructures: What are the phonon-phonon relaxation times and the selection rules? How does the phonon gas couple to the electronic one? What is the role of individual defects in a nanowires on phonon transport and do presence or absence of single defects alter overall thermal transport? How can nanowires be designed for very high or low thermal conductivities? It is envisioned that these questions can only be answered by a combination of experimental studies of single nanowires and theoretical and computational (molecular dynamics and Monte Carlo simulation) studies of phonon transport in 1-d nanostructures.

In this paper, we will present experimental results of thermal measurement of individual nanowires. We have developed a unique way to bridge suspended microheaters using a nanowire, which allows one to measure its thermal conductivity. We will present thermal conductivity measurements of single carbon nanotubes as well as silicon nanowires. In addition, we will also present results on a new technique of synthesizing nanowire arrays. Arrays are particularly important for building nanowire-based thermoelectric devices. We will present results of thermal conductivity of polymer-matrix composites containing nanowires.

[1] Currently at IBM Austin Research Lab.