Measuring Thermal and Thermoelectric Properties of Single Nanowires and Carbon Nanotubes

C. Dames, C.T. Harris, A. Muto, G. Chen (in coll. with M.S. Dresselhaus, MIT, Z.F. Ren, Boston College)
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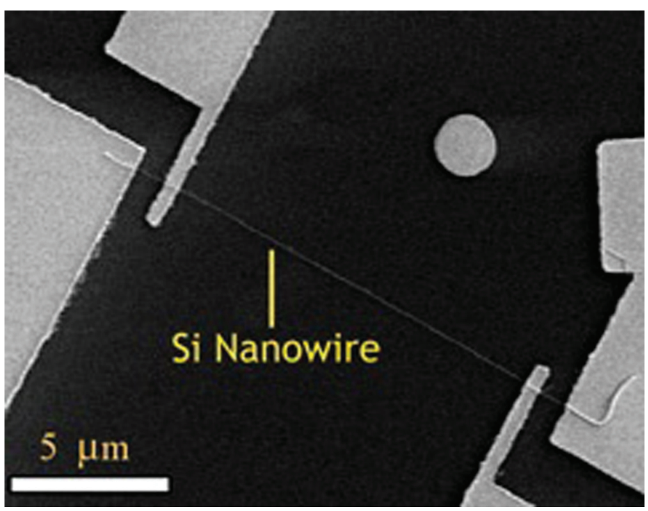
Knowledge of nanowire and carbon nanotube thermal and thermoelectric properties will be important for the thermal management of nanoscale devices that have recently been demonstrated (optoelectronic, sensing, and computing) and essential for the design of nanostructured thermoelectric materials. For nanowire diameters smaller than the bulk mean-free path of heat carriers (electrons and/or phonons), theory predicts that the thermal conductivity of these structures will be reduced when compared to similar bulk materials [1]. In order to experimentally verify these predictions, we are exploring several systems to measure the properties of single nanowires and carbon nanotubes.

Current work includes a basic platform to measure the thermal conductivity and specific heat of electrically conductive nanowires, such as the silicon nanowire shown below. Electron-beam lithography was used to pattern the leads of a four-point probe aligned to the ends of the nanowire. Joule heating of a suspended nanowire with thermally clamped ends results in a temperature rise of the nanowire due to its finite thermal resistance. This temperature rise can be measured by resistance thermometry (again using the nanowire) and used to calculate its thermal conductivity and specific heat. This technique is being adapted for an *in situ* TEM measurement, to enable high-throughput physical property measurements of many nanowires of various geometries and morphologies, and allow correlations with their atomic structure as determined by TEM.

Microfabricated metal lines can also be employed to measure electrically insulating nanowires. Using electron beam lithography, a metal heater line is fabricated such that a target nanowire crosses the center of the line. With the ends of the nanowire and heater thermally anchored, the nanowire removes a fraction of heat from the heater line, reducing the heater's temperature rise, and thus making it possible to calculate the thermal resistance of the nanowire.



▲ Figure 1: Contacts for a four-point probe measurement of a single silicon nanowire.

REFERENCES

[1] G. Chen, *Nanoscale Energy Transport and Conversion: A Parallel Treatment of Electrons, Molecules, Phonons, and Photons*, New York: Oxford University Press USA, 2005.