24. Measuring the Thermal Properties of Single Nanowires

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Knowledge of nanowire thermal and thermoelectric properties will be important for the thermal management of nanowire devices (optoelectronic, sensing, and computing) and essential for the design of nanowire thermoelectric materials. For nanowire diameters smaller than the bulk mean free path of heat carriers (~1 μm in undoped Si at 300 K), theory predicts that the thermal conductivity of nanowires will be reduced when compared to similar bulk materials. To experimentally verify these predictions, we are exploring several systems to measure the thermal properties of single nanowires.

Our current work includes a basic platform to measure the thermal conductivity and specific heat of electrically conducting nanowires, such as the microfabricated metal lines shown below. Joule heating of a suspended nanowire with thermally clamped ends results in a temperature rise at the center of the nanowire due to its finite thermal resistance. This temperature rise can be measured by resistance thermometry (using the nanowire itself) and used to calculate the nanowire's thermal conductivity and specific heat. The metal lines shown below are typically 100 nm thick, 300-500 nm wide, and 10-50 μm long. They are patterned with scanning-electron-beam lithography (SEBL) and a lift-off process on a Si substrate coated with oxide. Some of the oxide is removed in a wet etch to suspend the lines above the substrate for thermal isolation.

Microfabricated metal lines can also be employed to measure electrically insulating nanowires and nanotubes. Exploiting the direct-write capabilities of SEBL, a metal heater line is fabricated such that a target nanowire crosses the center of the heater. With the nanowire and heater both thermally anchored at their endpoints, the nanowire removes a fraction of heat from the center of the heater. This reduces the heater's temperature rise, and thus makes it possible to calculate the thermal resistance of the nanowire.

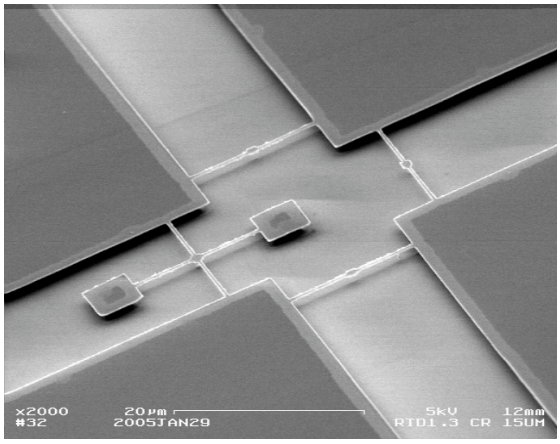

Figure 1: Microfabricated metal heater lines suspended 1.0 μm above the substrate, for thermal property measurements.