Thermal Conductivity Measurement of Microwires and Nanowires Using Three Omega Method and Scanning Probe Microscopy

by

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ABSTRACT

Low thermal conductivity nanostructured materials have the potential of increasing the thermoelectric figure of merit. In order to characterize the thermal properties of nanowires grown by oblique angle deposition (OAD) and template-assisted electrochemical deposition, a novel technique based on the widely used three omega (3ω) method was proposed. In this technique, a conductive scanning probe microscope (SPM) tip is in contact with one end of the nanowire and serves as one of the electrodes in the 3ω method. The other electrode is the conductive substrate. Taking the advantage of the small size of SPM tips, the 3ω method could be extended to various nanostructures.

Theoretical simulations were conducted for the OAD nanowires using the well developed one dimensional 3ω model. Using a power of 10^{-9} W, the 3ω voltage signal was between 10^{-9} V and 10^{-11} V, depending on the extent of the sizing effect on the thermal conductivity and the electrical resistivity. This is beyond the detection limit of our current instruments (2 nV smallest). Raising the power could increase the magnitude of the 3ω voltage signal. However, the power is limited by the amount of heat that the tips and the nanowires can sustain. In order to extract the thermal conductivity from the 3ω voltage versus frequency curve, a frequency range must be chosen so that the 3ω voltage signal is sensitive to the frequency change. The sensitive frequency range of the above simulation was 10^7-10^9 Hz, which is beyond the highest frequency that our current instruments could measure (100 kHz).

For the nanowires embedded in the template, conduction heat loss in the radial direction must be considered. The existing model was modified in order to include the radial heat loss and simulations were conducted based on the modified model. The results showed that the magnitude of the 3ω voltage signal and the sensitive frequency range have strong dependence on the boundary thermal resistance. Therefore, besides raising the power level, increasing the boundary thermal resistance could also increase the magnitude of the 3ω voltage.

Preliminary experiments raised several challenging issues. The stability of the electrical contact between the AFM tip and the nanowires was particularly studied. The contact stability could not be maintained with a temperature change of 10K. It is hoped

that STM will show advantages compared to AFM, mainly because the STM tips are metallic and the electrical conductivity is not affected by the quality of the conductive coating.