Phonon scattering mechanisms in suspended nanostructures from 4 to 40K

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We report on our investigations of thermal conductance of n-doped and intrinsic (undoped) mesoscopic GaAs wires from 4 to 40 K. Thermal conductance of the doped wires is measured directly, while that of the undoped wires is determined from subtractive comparison of two specially configured devices (Figure 1a,b). We find that surprising result that heat is transported more efficiently in the undoped wires than the in doped wires, despite the fact that in the latter case heat can be conducted by both electrons and phonons. We analyze the possible role of various scattering mechanisms using the Callaway formula to model bulk conductivity in terms of a single relaxation time that depends on frequency and temperature but not on wave vector or polarization. This indicates that boundary phonon scattering, phonon-phonon, electron-phonon, and defect scattering are all significantly stronger in these nanostructures than in bulk.

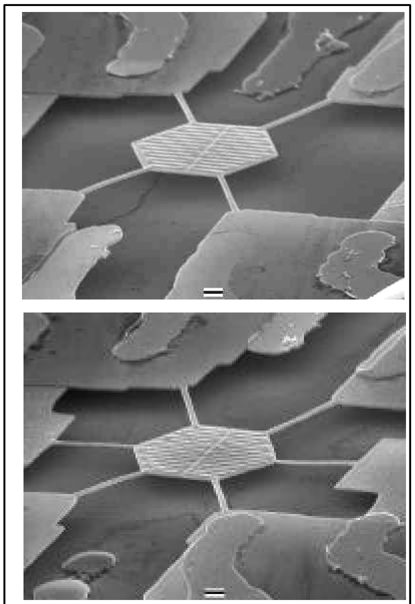

Figure 1 a,b. Suspended four- and six- conductor devices.

Phonon transport in suspended semiconductor nanostructures is dominated by the effects of surface scattering and reduced dimensionality. At very low temperatures (~ 100mK) for a short constriction, dimensionality reduction prevails and 1-D transport results in the quantization of thermal conductance. At higher temperatures, the scattering of phonons becomes important. But the scattering mechanisms are currently not very well understood. Our study offers some insight to the problem.

Electron micrographs of nanoscale samples are shown on the left. The devices are made from single-crystal GaAs heterostructures grown by molecular beam epitaxy. The central “reservoir” is suspended and thermalized by either four or six narrow bridges (width ~200nm) that radiate outward. These terminate on structures that are thermally clamped to the substrate. In both devices four of the thermal conductors include electrically-conducting top layers providing electrical contact to the meandering transducers. Separate transducers on each device, serving as heaters and thermometers provide a local measurement of phonon temperature.