Quasi-ballistic heat transport in silicon nanowires at different temperatures

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At nanoscale, heat can be conducted ballistically without actually heating the conductor. The ballistic heat conduction occurs because phonons can directly travel between scattering events for hundreds of nanometres without energy dissipation. However, the experimental demonstrations of this phenomenon in nanostructures are scarce and controversial. Here, we study ballistic heat conduction in silicon nanowires of different lengths and shapes using the micro time-domain thermoreflectance (μTDTR) and Monte Carlo phonon transport simulations.

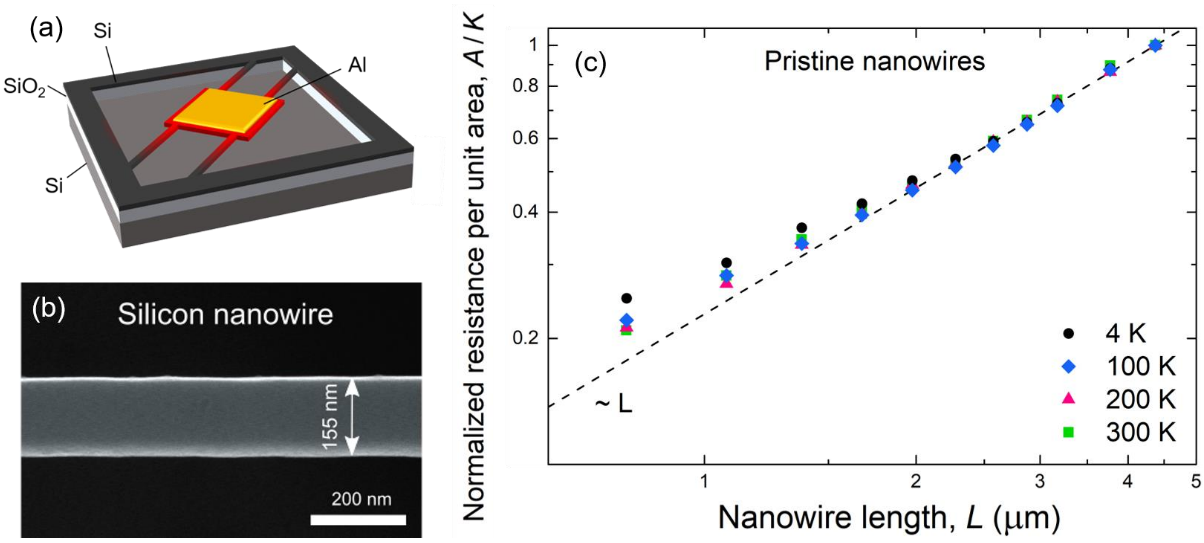

Fig. 1. (a) Schematic of a sample, (b) SEM image of a typical nanowire and (c) the thermal resistance per unit area, normalised by the value for the longest NWs at each temperature, showing nonlinear dependence on the nanowire length.

Figure 1 shows the thermal resistance per unit area measured at different temperatures for nanowires of different lengths. Whereas long nanowires (> 2.5 μm) follow a ~L linear trend typical for diffusive transport regime, the short nanowires deviate from this trend, thus indicating quasi-ballistic heat conduction. The effect is strongest at the temperature of 4 K and weakens as temperature is increased but remains visible even at room temperature. We attribute this non-diffusive heat conduction to ballistic phonon flights. Our Monte Carlo simulations show that phonon trajectories resemble Lévy walk with short travels between the nanowire walls mixed with long flights towards the cold side. Such quasi-ballistic heat conduction in silicon nanostructures opens new possibilities in thermal engineering in microelectronics.

Acknowledgements

Kakenhi (15H05869 and 15K13270), PRESTO JST, and the Postdoctoral Fellowship of JSPS.