A compact enhanced Fourier law for next-generation device thermal modeling

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Abstract:

In light of the findings of Johnson *et al.* that ballistic phonons with mean-free paths upto 500 microns carry a significant fraction of the total heat-flux in silicon at room temperature, it has become imperative to include ballistic transport effects in electronic and optoelectronic device thermal simulations even in the microscale. It would be impractical, in the short run at least, to shift to a fully numerical solution of the Boltzmann transport equation (BTE) for phonon transport. Coupling such a numerical solver with electron distributions and optical fields will be very time consuming, over and above the demanding computational requirements of the BTE solution itself. We present here an alternative, the “enhanced Fourier law”, which retains the mathematical brevity and simplicity of the Fourier law while including important ballistic transport effects. Rigorous derivation starting from the BTE lends clear physical meanings to various parameters in our equations, as opposed to so-called “phenomenological” models containing large numbers of essentially numerical fitting parameters. Two illustrative applications are considered: (a) deviations from the Fourier law reported by Johnson *et al.* using the transient gratings experiment, and (b) a serious difficulty in extracting the mean-free path accumulation function from frequency-domain thermoreflectance experiments - a difficulty that has not been pointed out until now. The enhanced Fourier law is expected to be of great promise to industrial device simulation because of the detailed information it yields about the heat-flux resolved according to the mean-free path, or in other words, according to the length scale of scattering.