Power-law decay of quasidiffusive phonons

S. Tamura,[1] A. Sangu[1] and Y. B. Levinson[2]
[1]Department of Applied Physics, Hokkaido University, Sapporo 060-8628, Japan;
[2]Weizmann Institute of Science, 76100 Rehovot, Israel

Nonequilibrium, high-frequency phonons excited in nonmetallic solids are either transmitted ballistically or subject to both elastic and inelastic scatterings before they are detected. The propagation of acoustic phonons in the presence of both elastic and inelastic scatterings are called quasidiffusion.[1] One of the characteristic features associated with the phonon quasidiffusion is the presence of the exponentially decaying tail in the time-of-flight spectrum.[2] This tail and the magnitude of its decay rate are well explained by solving the integro-differential equation governing the phonon signal under perfect absorbing boundary condition at the detecting surface.[3] In the experiments of the nonequilibrium phonon propagation, samples are usually immersed in liquid helium and the above boundary condition corresponds to assuming that the liquid helium absorbs phonons perfectly. This assumption is supported in some sense by the presence of anomalous Kapitza conductance between solid and liquid helium. However, there should still exist (1) phonons coming back to the solid after traveling inside the helium and also (2) phonons reflecting back from the solid-helium interface. In this paper we theoretically consider the effects of the former phonons to the observed time-of-flight spectrum of phonons in the quasidiffusive regime.

More specifically, we study the simple model in which phonons are excited at the center of a spherical sample (of radius R) with a diffusion constant D surrounded by the medium with different diffusion constant D' [we tentatively neglect the presence of inelastic scatterings of phonons]. Then the time evolution of the phonon signal inside the sphere is found by solving the diffusion equation for several different values of D' / D. Analytical solutions (also the Monte Carlo calculations) predict the exponentially decaying signal in the limit of large D' / D and a power-law decay for D' / D=1. For intermediate values of D' / D we find the crossover from the exponential to power-law decays of the phonon signals. In the presence of both the inelastic scattering, or anharmonic phonon decay, i. e., in the quasidiffusive regime, the analytic solution is not available but the Monte Carlo simulation also predicts the crossover behaviors in phonon signals from the exponential to power-law decays. Such a crossover was found in the time-of-flight spectrum in glasses.[4]

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