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Unusual Size Dependence of Acoustic Properties in Layered Nanostructures

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Compared to symmetrically stacked layered structures, e.g., sandwich-like, much less is known about acoustic properties in a more general configuration lacking such a symmetry. Structures composed of layers with different characteristics (e.g., metal-insulator) are ubiquitous in nanotechnologies harnessing finite size and quantum effects. Explicit analytic expressions describing acoustic waves in a representative two-layer system are derived and analyzed in the full space of material parameters. An unusual behavior of the spectrum is revealed in the dispersive (long wavelength) region where size effects are most prominent. Velocity of the lowest frequency branch, which becomes the Rayleigh surface wave at shorter wavelengths, is shown to depend in a strongly non-monotonous way on the thickness of the layers in contrast with the expected monotonous evolution of higher frequency branches. The wave pattern of different mode types is discussed in detail. Connection between long (including resonances of the composite plate) and short wavelength (bulk-like, surface and interface guided) regions of the spectrum is established. It is shown that the peculiar behavior of the low energy phonon spectrum induces similar effects in the electron-phonon relaxation and heat transport in composite nanomaterials at low temperatures.