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Phonons and their interaction with electrons in layered nanomaterials

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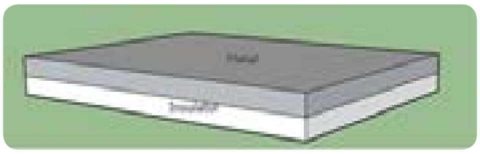
Vibrational excitations in nanomaterials are very sensitive to confinement and boundary conditions since both the typical wavelengths and mean-free-paths may easily exceed the size of a nanodevice. Then multiple reflections from the surfaces drastically modify the vibration properties as compared to bulk materials. These have major implications for the broad range of devices [1-3]. Thus, in ultrahigh sensitivity radiation detectors, electronic microrefrigerators or microcalorimeters [4,5] an essential part of the design is the coupling and energy exchange between vibrational modes (or their quantum version, phonons) and electron excitations in ultrathin quasi-two-dimensional structures: It has been shown both experimentally and theoretically that in such devices the transfer of energy per unit time (or energy flux) between electrons and phonons (in a stationary case, for instance, electrons may thermalize at a higher effective temperature than phonons, or inverse) can be engineered to vary in orders of magnitudes depending on the specific requirements [6-8]. The problem becomes more complicated for a layered structure composed of materials with significantly different acoustic characteristics when the interface effects cannot be neglected (e.g., Copper film deposited on Silicon Nitride membrane). Unlike the composite materials with layer stacking along the direction of propagation of excitations, the "lateral" symmetry with respect to this direction in our case is absent. This difficulty, however, can be viewed as an opportunity for a new kind of behavior. For a better understanding of this situation a new theoretical approach is proposed that allows to substantially simplifying the description of the governing equations and in, some cases, to obtain analytical expressions for both the spectra and amplitudes of the normal modes. These are shown to become gapped when the system is sufficiently thin for the physically relevant wavelengths to reach the nanometer range. The only truly acoustic waves which account for the low energy – low temperature properties in a composite system are the Lamb compressional (dilatational) and flexural (bending) modes. These modes are described in an analytical form. An additional possibility to engineer the behavior of phonon modes and their coupling to electrons is revealed by the possibility to localize the vibration amplitudes in one or another layer, near to the surfaces or the interface, depending on the thickness of the layers and material parameters.



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Biography

Sergiu Cojocaru is a senior researcher at the Department of Theoretical Physics of the National Institute of Physics and Nuclear Engineering, Romania. He authors over 100 scientific publications in several areas of Condensed Matter Theory. His current interests are in Nanophysics and, in particular, the physical effects of confinement on the properties of nanomaterials, https://scholar.google.ro/citations?hl=en&user=BIRSbiwAAAAJ&view_op=list_works&sortby=pubdate.

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