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Heat Transport along Nanofilms and Nanowires due to Surface Phonon-Polaritons

The blossoming of nanotechnology involving the miniaturization of devices with enhanced rates of operation requires a profound understanding and optimization of their thermal performance. This is particularly critical in nanomaterials, due to the significant reduction of their thermal conductance as their size is scaled down. Surface phonon-polaritons (SPPs) have shown wide potential to enhance the energy transport through these materials. The mean free path of these energy carriers can be much longer than that of phonons, however their contribution to the heat transport is not well understood to date, especially in absorbing nanomaterials.

In this work, the SPP contribution to the heat conduction along nanofilms and nanowires of different polar materials is investigated in detail. Based on the Maxwell equations, Boltzmann transport equation and Landauer formalism, it is shown that: (1) a small difference between the permittivities of the two media surrounding a nanofilm can generate large propagation lengths in the order of a few centimeters and therefore enhance remarkably the SPP thermal conductivity [1]. (2) The thermal conductivity of a set of nanolayers can be described as the one of a single layer with an effective permittivity, which does not ordinarily appear in nature, and it allows us to optimize the SPP energy transport by decreasing the film thickness, increasing the film length and raising the temperature [2]. In these two cases, the SPP thermal conductivity can be higher than the one of phonons. (3) The SPP thermal conductance of polar nanowires is independent of the material characteristics and is given by $\pi^2 k_B^2\ T/3h$, where k_B and h are the Boltzmann's and Planck's constants, respectively and T is the temperature. This universal quantization holds not only for a temperature much smaller than $1\ K$, as is the case of electrons and phonons, but also for temperatures comparable to room temperature [3]. The experimental measurement of the SPP thermal conductivity and SPP thermal conductance is also explored by using infrared microscopy. The obtained results could have great applications in the thermal management of nanoscale phononics and photonics.

References:

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