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Novel techniques for phononic thermal conduction engineering: from phononic crystals to radial Casimir-limit

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For low-temperature bolometers and calorimeters, it is essential to be able to control thermal conduction in order to optimize sensitivity and response time. In many cases, thermal conduction is dominated by the phononic channel. Traditionally, phonon conduction has been engineered by fabricating structures with reduced dimensionalities, such as thin membranes and narrow beams. While this can lead to reasonable results, there have been indications of difficulties in meeting prediction targets, due to complications arising from control of surfaces and edges, transitions from ballistic to diffusive transport etc.
Here, we discuss two alternative and complimentary means of controlling phonon conduction: engineering of the phonon dispersion relations and thus group velocity in the ballistic limit by periodic nanostructuring [1] (using the so called phononic crystals), and by roughening the surface of the membranes to reach the limit of fully diffusive surface scattering. We find that orders of magnitude changes in the thermal conductance are possible with proper choices of the geometry in both cases, without having to resort to long narrow beams. For example in the case of two-dimensional Casimir- limit, we show computationally [2] that the thermal conductance G is a non-linear function of the membrane thickness, and it is possible to reach quite low values of $G < 10$ fW/K at bath temperatures ~50 mK with a 50 nm thick roughened membranes of fairly compact linear dimension ~20 μm. We propose that both mechanisms may be helpful for optimizing the operation of low-temperature detectors.

[1] N. Zen, T. A. Puurtinen, T. J. Isotalo, S. Chaudhuri, and I. J. Maasilta, Nature Communications 5, 3435 (2014).
[2] T. A. Puurtinen and I. J. Maasilta, AIP Advances 4, 124503 (2014)