Ray phononics: Advanced heat flux manipulations using ballistic phonon transport

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Manipulation of thermal fluxes is essential in today's science and technology. Modern thermal phononics tries to achieve coherent control of heat conduction based on the wave interference of phonons that occurs in periodic nanostructures, called phononic crystals. However, the past decade of the research demonstrated that such a coherent control of heat is truly efficient either at sub-kelvin temperatures or in nanostructures with features at atomic scale.

Here, we propose an alternative concept of heat manipulation based on the particle picture of phonons and their ballistic transport. We call this concept ray phononics as a thermal analogy of ray optics. Our simulations demonstrate the formation of directional thermal fluxes in phononic crystals due to the stochastic phonon motion in phononic crystals (Fig 1a). We illustrate possible application of such directional fluxes for emitting directional heat rays (Fig. 1b-c), filtering the phonon spectrum, and even protecting a specific region from a thermal gradient (Fig. 1d). Finally, we show that the proposed concept is not bound to only low temperatures and can function in realistic nanostructures regardless of their surface roughness. This makes us believe that advances in material synthesis may soon enable creation of devices capable of thermal guiding, emitting, filtering, and shielding using the proposed concept of ray-phononics.

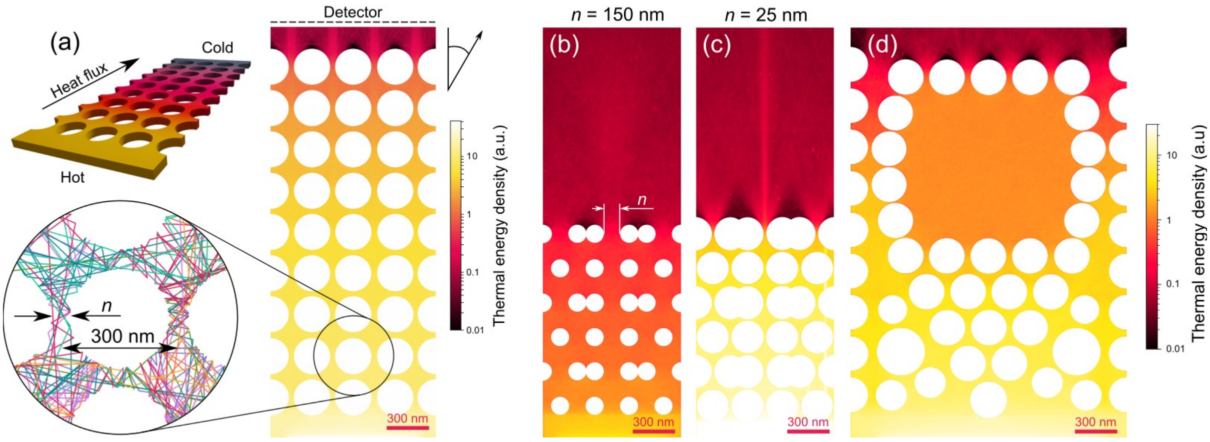

Fig. 1 (a) Illustration of the Monte Carlo simulation. (b-c) Heat-ray emmiting structures with the passage width of 150 and 25 nm. (d) Thermal shielding structure protecting the central region from the thermal gradient.

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Reference

[1] R. Anufriev and M. Nomura, Materials Today Physics 15, 100272 (2020).