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# Net Heat Current at Zero Mean Temperature Gradient

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Thermal waves generated by the periodic fluctuations on time of a temperature field are widely used to determine thermal properties of macro-, micro-, and nanomaterials via standard photothermal techniques (thermoreflectance, radiometry, 3w, photoacoustics, and resonant cavity), and they usually do not carry a net heat flux in materials with constant thermal properties. By contrast, in materials whose thermal properties do depend strongly on temperature, the material thermal response is driven by the temperature values at each instant of time and therefore the thermal waves are expected to carry a net heat flux. However, this thermal wave heat current is not quantified yet.

In this work, we theoretically demonstrate the existence of the conductive heat shuttling, a net heat current generated by thermal waves that shows up even in the absence of a mean temperature gradient. This heat shuttling is generated by the temperature-dependent thermal conductivity of materials excited with a thermal excitation periodically modulated in time. We show that this modulation gives rise to a heat current superimposed on the one generated by the mean temperature gradient, which enhances the heat transport when the thermal conductivity increases with temperature. By contrast, if the thermal conductivity decreases as temperature increases, the thermal wave heat current inverts its direction and reduces the total heat flux. The reported shutting effect is sensitive to the amplitude of the periodic thermal excitation, which can facilitate its observation and application to harvest energy from the temperature variations of the environment.

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