Thermal conduction engineering in Si membranes by phononic nanostructures

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Thermal phonon engineering using ballisticity and wave nature of phonons brought new possibility to thermal conduction engineering. We introduce characteristic heat transfer in Si phononic nanostructures including heat focusing and counter intuitive heat transfer based on wave nature of phonons.

We fabricated 145-nm-thick single-crystalline Si porous membranes by conventional top-down approach using electron beam lithography and measured thermal conduction in the nanostructures by a custom built micro-time-domain thermoreflectance system [1]. We found that thermal phonons show clear ballistic transport within a few micrometers in Si nanowires with a diameter of 100 nm at 4 K [2]. We demonstrate that heat flow can be focused by using the ballisticity of thermal phonons within the mean free path. Figure 1 (a) shows energy distribution in a phononic structure with holes which aligned in a radial fashion. The fabricated structures have a slit centred at the focus or shifted by x. The heat dissipation times were compared among these structures and showed strong position dependence of the slit; the fastest heat dissipation was observed when the slit was located at the focus. The difference can be observed even at room temperature due to long thermal phonon MFP is Si. This result is the first demonstration of heat focusing using tailored phononic structures [3]. In the presentation, thermal conduction tuning by short-range order control of phononic crystal structures will be also presented.

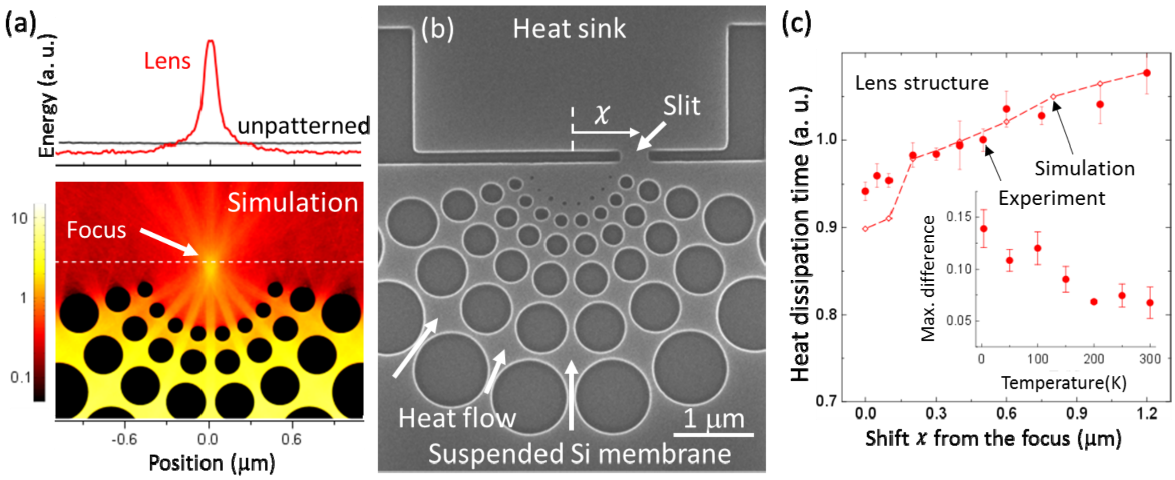

Fig. 1: (a) Simulated energy distribution in the lens structure at 4 K. (b) SEM image of the lens structure with a slit. (c) Heat dissipation time for the lens structure: demonstration of heat focusing.

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[3] R. Anufriev, A. Ramiere, J. Maire, and M. Nomura, Nature Communications **8**, 15505 (2017).