Directional heat flow engineering by phononic nanostructures

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Recently, ballistic heat transport has been demonstrated experimentally in the bulk, thin-films and various nanostructures. Yet, a practical use of this phenomenon remains challenging, because thermal phonons tend to travel chaotically. We used μ-TDTR experiments and Monte-Carlo (MC) simulations to show the in-plane ballistic heat transport in silicon phononic crystals (PnCs) and a possibility to use such PnCs to guide and emit of heat flux with well-defined directionality.

First, we fabricated and measured PnCs with aligned (Fig. 1a) and staggered (Fig. 1b) lattices of 5 different periods, and demonstrated that significant difference in thermal decay times (τ) appears in the structures with small period (Fig. 1c). We attributed the faster heat dissipation in the samples with aligned lattice to the presence of ballistic heat transport in the passages between the holes.

Next, we fabricated samples of PnCs coupled with nanowires (NWs) (Fig. 1d), in *coupled* (Fig. 1e) and *uncoupled* (Fig. 1f) configurations and observed a significant difference (Δ) between them in the samples with short NWs at 4K, due to the enhancement of ballistic transport in the coupled configuration. As the NWs lengthen or temperature were increased, the effect gradually disappears (Fig. 1g and 1e), because heat transport becomes diffusive.

Finally, we showed that the observed effect can be used, for example, to create thermal lenses focusing thermal energy into a spot of about 200 nm (Fig. 1k).

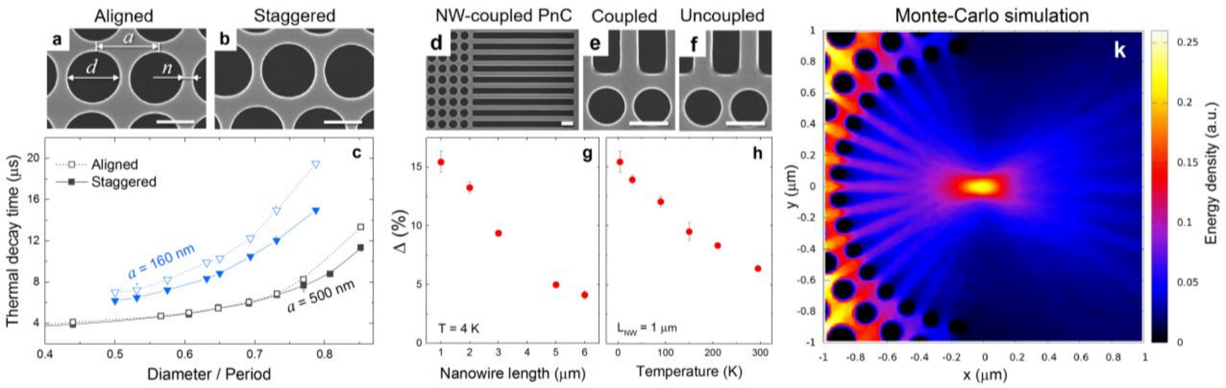

Fig.1: SEM images of (a) aligned and (b) staggered PnCs and (c) measured τ. SEM images of (d) a NW-coupled PnCs sample with (e) coupled and (f) uncoupled configurations, and difference between their decay times as a function of (g) NW length and (h) temperature. (k) MC simulation of a thermal lens.

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