Thermal Conductivity of Si Thin Film with Nanopillars

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Thermal conductivity tuning is indispensable for improving the efficiency of Si-based thermoelectrics, while nanostructuring has been proved to be a promising route towards this direction. Recently, nanopillars have attracted increasing attention, which considered as external thermal conduction reducing elements and provide minimum impact on electrical properties within the internal body of the host.

In this work, we fabricated high-density nanopillars with 20 nm in height on 50-nm-thick single crystalline Si membrane via novel neutral beam (NB) etching technology in a damage-less and high-performance manner, then we used hydrofluoric acid to remove SiO_2 layer of the SOI wafer to suspend the structure, as shown in Fig. 1(a-c). We investigated thermal conduction in our samples by means of μ-TDTR method. Figure 1(d) indicates that at high temperatures, phonons are more likely to be localized and scattered by the nanopillars, which leads to the 16% reduction of thermal conductivity in samples with nanopillars. As temperature decreases, the range of phonon wavelengths increases from 0.5 to 6 nm at 300K to 10 to 100 nm at 4K [1]. Hence, long-wavelength phonons may ignore the nanopillars with the diameter of 13 nm and transport specularly, which results in the negligible contribution to suppressing phonon transport from nanopillar. To get a clearer understanding of how the nanopillars influence thermal conduction in Si thin film, we introduce nanopillars onto phononic crystals (PnCs), as shown in the insets in Fig. 1(e). The combination of nanopillars and PnCs offers an approach for tuning phonon transport more effectively at 300K. Herein, the nanopillars placed on top further increase the surface-to-volume ratio of PnCs and introduce more frequent phonon-surface scattering processes, which explains the significant reduction of thermal conductivity. Therefore, thermal conduction in silicon hosts can be effectively tuned by attaching additional nanopillars via NB etching, which makes our work promising and unique for effective Si thermoelectric applications.

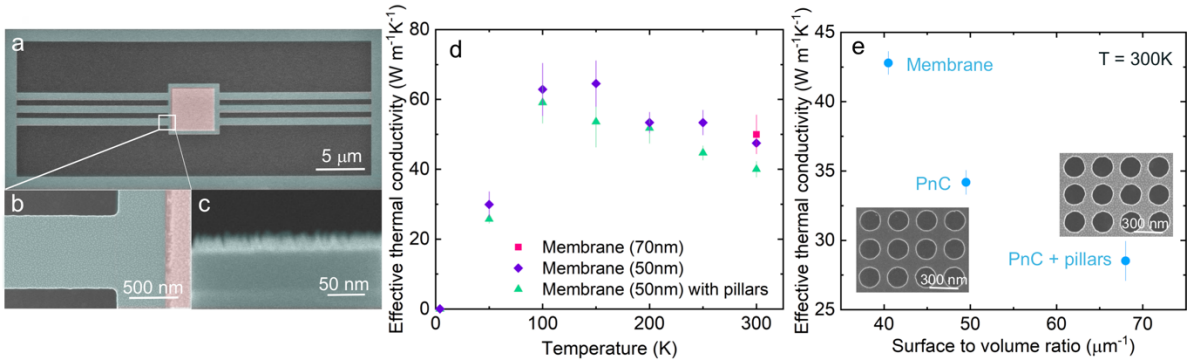

Fig. 1 SEM images of (a) top view of the Si membrane with nanopillars (suspended), detail view of the sample (b-c). (d) Effective thermal conductivity as a function of temperature for 70 nm-thick Si membrane without (pink square) nanopillars, 50 nm-thick Si membrane without (purple diamonds) and with (green triangles) nanopillars. (e) Effective thermal conductivities of unpatterned Si membrane, PnC structures with (inset at the right) and without (inset at the left) nanopillars as a function of surface-to-volume (S/V) ratio.

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Reference R. Anufriev, R. Yanagisawa, and M. Nomura, *Nanoscale* **9**, 15083 (2017)

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