Heat conduction in silicon thin film with black silicon nanostructures

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In order to improve the thermoelectric figure-of-merit ($ZT = S^2\sigma/\kappa$) of Si, many groups investigated a variety of approaches to increase σ/κ by nanostructuring, where phonons (main heat carriers) can be effectively manipulated by Si nanostructures, such as nanowires and phononic crystals (PnCs). Recently, nanopillars, another promising nanostructure has attracted increasing attention. For instance, nano- and micro-scale Si pillars fabricated on freestanding silicon films, also termed as "black silicon (B-Si)" have been highlighted in solar photovoltaic for decades. However, the thermal property of B-Si still remains unknown.

In this work, we fabricated B-Si nanostructures with 45 nm height on 50 nm-thick single crystalline Si membrane over 3 μm thick SiO_2 buried layer by inductively coupled plasma reactive ion etching (ICP-RIE), then used hydrofluoric acid to remove SiO_2 and suspend the whole structure (Figs. 1a, b and c). The heat transport in Si membrane with nanopillars was investigated by micro time-domain thermoreflectance (TDTR) method. The experimental results show that effective thermal conductivity is reduced by 45% at room temperature in Si membrane due to strong backscattering of thermal phonons by B-Si nanostructures compare to that in the membrane (Fig. 1d). At low temperature, where the ballisticity of phonon is stronger, B-Si plays a more important role in suppressing heat conduction (Fig. 1e). Being considered as external elements for reducing thermal conductivity, nanostructured pillars may provide the minimum impact on electrical properties within the host membrane, which makes B-Si nanostructures promising for enhancing the thermoelectric property of silicon.

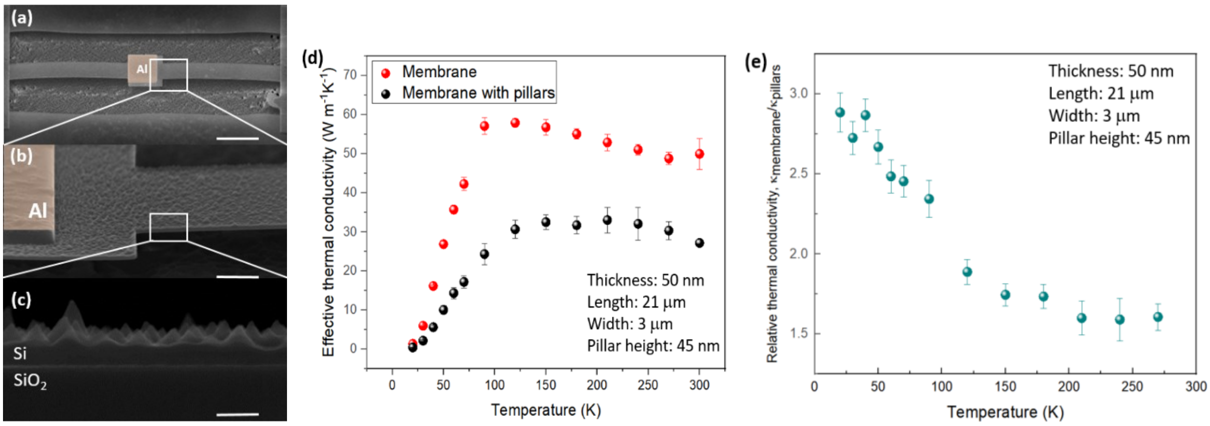

Fig.1 SEM images of (a) silicon thin film with black silicon nanopillars (suspended), (b) detail view of the structure and (c) cross-section view of black silicon nanopillars. Scale bars are (a) 5 μm, (b) 500 nm and (c) 100 nm. (d) Effective thermal conductivity as a function of temperature. (e) Relative thermal conductivity as a function of temperature.

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