Offset Nanoslot Patterns as an Effective Way to Reduce the In-Plane Thermal Conductivities of Thin Films

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Nanostructures have been widely used to improve the thermoelectric performance of materials and new applications can also be found for heat guiding and focusing. The introduced nanostructured boundaries or interfaces can strongly scatter phonons and thus reduce the lattice thermal conductivity. One challenge here is to minimize the characteristic length of the structure to better suppress the phonon transport, while charge carriers usually with a much short mean free path are slightly affected to enhance the thermoelectric figure of merit. Along this line, thin films with circular or rectangular nanopores have been intensively studied for thermoelectric applications. As one extreme case for rectangular nanopores, nanoslots with a narrow neck width between adjacent nanoslots can effectively cut off the phonon transport, as indicated in both experimental and computational efforts. For fundamental studies, the phonon mean free path spectral distribution can also be reconstructed from the thermal conductivities of nanoslot-patterned thin films with varied neck widths.

As a variant, the offset nanoslot pattern is expected to achieve an even larger thermal conductivity reduction compared with the aligned nanoslot configuration. In this work, silicon thin films are suspended with offset nanoslot structures of different sizes and periods. The in-plane thermal conductivity is then measured with the 3-Omega method and compared between the aligned and offset nanoslot configurations. The measurement result is further compared to an analytical model for thin films with aligned rectangular nanopores and the more advanced phonon Monte Carlo simulation. In simulations, the rounded nanoslot corners due to the etching process can also be considered for more accurate predictions. The offset configuration allows further reduction of the thermal conductivity, without increasing the overall porosity and requirements for better spatial resolutions of nanofabrication techniques. The observed large anisotropy of thermal conductivity is desired for heat guide applications within thin-film-based devices.