Experimental Demonstration of Thermal Conductivity Reduction by Localized Phonon Resonances

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Thermoelectric materials convert heat into electricity through thermally driven charge transport in solids, or vice versa for cooling. To be competitive with conventional energy-generation technologies, a thermoelectric material must possess the properties of both an electrical conductor and a thermal insulator. However, these properties are normally mutually exclusive because of the interconnection of the scattering mechanisms for charge carriers and phonons. Recent theoretical investigations on sub-device scales have revealed that silicon membranes covered by nanopillars exhibit a multitude of local phonon resonances, spanning the full spectrum, that couple with the heat-carrying phonons in the membrane and collectively cause a reduction in the in-plane thermal conductivity—while, in principle, not affecting the electrical properties because the nanopillars are external to the pathway of voltage generation and charge transport [1]. Here this effect is demonstrated experimentally for the first time by investigating device-scale suspended silicon membranes with GaN nanopillars grown on the surface. The nanopillars cause up to 21 % reduction in the thermal conductivity while the electrical conductivity and the Seebeck coeffcient remain unaffected, thus demonstrating an unprecedented decoupling in the semiconductor's thermoelectric properties. The measured thermal conductivity behavior for coalesced nanopillars and corresponding lattice-dynamics calculations provide further evidence that the reductions are mechanistically tied to the phonon resonances. This finding breaks a longstanding trade-off between competing properties in thermoelectricity and paves the way for engineered high-effciency solid-state energy recovery and cooling [2].

References

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2. B.T. Spann, J.C. Weber, M.D. Brubakera, T.E. Harveya, L. Yang, H. Honarvar, C.-N. Tsai, A.C. Treglia, M. Lee, M.I. Hussein, and K.A. Bertness, *Adv. Mater*. **35**, 2209779 (2023).