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Thermal Conductivity Manipulation in Lithographically Patterned Single Crystal Silicon Phononic Crystal Structures

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Background, Motivation and Objective

The thermal conductivity of many semiconductor materials has shown dramatic reductions via micro/nano-scale structuring. In such materials, the dominating heat transfer mechanism is through lattice vibration (phonons). As the dimensions of thermal pathways becomes comparable to the phonon mean-free-path, phonon scattering increases, leading to reduction in heat transfer.

Statement of Contribution/Methods

In this work, we demonstrate thermal conductivity manipulation via lithographically defined phononic crystals in single crystal silicon. Figure 1 shows fabricated bridge-shaped test structures consisting of sub-micron diameter through-holes patterned in a 500nm-thick Si membrane. Heat is supplied via an aluminum serpentine in the membrane center and its temperature change was measured to extract the thermal conductivity.

Results

Figure 2 shows the measured thermal conductivity of phononic crystal samples which were much lower than Maxwell-Eucken predictions which model the volume reduction effect in porous materials. This discrepancy increases as the minimum feature size decreases likely due to enhanced phonon scattering as the size of the thermal pathways shrinks. The device with a limiting dimension of 0.25um showed the highest reduction in thermal conductivity, ~30W/mK, which is half that of the Maxwell-Eucken prediction.

Discussion and Conclusions

Thermal conductivity can be effectively controlled via phonon-scattering enhancement from lithographically defined sub-micron features. This has potential to enhance many micromachined devices. For example, reducing thermal conductivity with much less alteration in electrical conductivity can significantly improve the performance of micromachined thermoelectric coolers, energy harvesters, and ovenized devices.

Fig1. SEM image of a test structure with phononic crystals

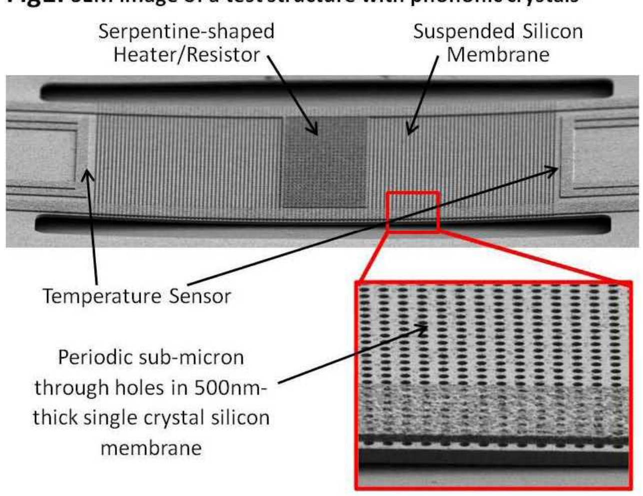
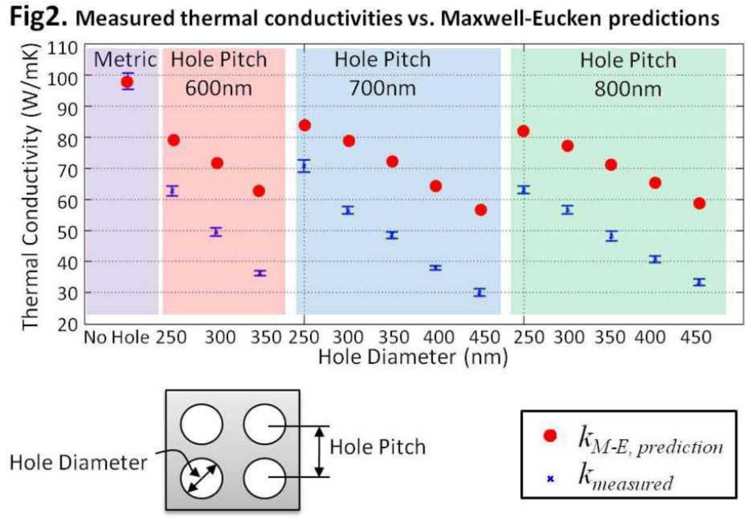


Fig2. Measured thermal conductivities vs. Maxwell-Eucken predictions



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