PHONON TRANSPORT IN PERIODIC MICRO-POROUS SILICON THIN FILMS

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The purpose of this work is to obtain a fundamental understanding of phonon transport in micro and nanoscale periodic porous structures through experimental study on the thermal conductivity of periodic microporous silicon membranes over a wide temperature range. The understanding of phonon heat conduction in a periodic and porous media can be greatly simplified: (1) if the solid phase in the porous media is single-crystalline with very few other defects, and (2) if the pores have uniform dimensions and are periodically arranged. Such structures are possible with microfabrication, which provide control over the pore size, shape, spacing, and alignment. With pore diameters and pore spacing of the order of microns, we expect to observe size effects on thermal conductivity near the liquid nitrogen temperature. The small thickness of the pore walls can result in the domination of pore-surface scattering over the internal phonon scattering and a low effective thermal conductivity of micro-porous silicon. Silicon is chosen for microfabrication, because the processes for creating micro- and nano-scale structures into single crystal silicon is well established [1-7] and because the phonon mean free path in silicon is relatively long. In addition, there have been studies on the thermal conductivity of random porous silicon [1,2]. In addition to the attainment of the fundamental understanding, the thermal conductivity characterization of periodic porous silicon would be of interest to optoelectronics and integrated circuits.

To measure the in-plane thermal conductivity of the periodic micro-porous freestanding silicon thin film, an adaptation of a steady-state method [8] is used. The experimental structure is shown in Fig. 1. A metal wire runs lengthwise on top of the long and narrow silicon thin film to serve as a heater-thermometer. When a DC current is passed through the metal heater, it will heat up the membrane and the resulting average DC temperature rise experienced by the heater—a function of membrane's in-plane thermal conductivity—is recorded in the form of the change in the heater's resistance. Because the membrane is long and narrow, the heat from the metal heater can be assumed to flow only in the direction perpendicular to the axis of the heater with reasonable accuracy (~5%). The radiation heat loss from the membrane has been estimated to contribute less than 1% error to the measured in-plane thermal conductivity.

The thermal resistance at the boundaries of the membrane can be significant in a silicon-on-insulator structure, where the low-thermal conductivity silicon oxide bridges the top silicon film

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and the underlying silicon substrate. To remedy this situation, aluminum heat sink is employed to replace oxide and bridge the silicon film and the substrate along the thin film boundaries.

The microfabrication steps is a three-mask process, which features deep-reactive ion etching for drilling periodic pores and a thick photoresist layer for liftoff patterning of the thick Al heat sinks. The resulting micro-porous silicon membrane is released from a silicon-on-insulator wafer by wet-etching of the underlying silicon oxide, as shown in Fig. 1. The heater is placed along the central strip of the membrane which does not contain pores.

To isolate the phonon size effect on the in-plane thermal conductivity of the periodic porous silicon thin films, two strategies could be used. One is to measure the thermal conductivity of a single porous membrane in the low temperature range such that the phonon mean free path is comparable or larger than the core characteristic thickness. Another strategy is to measure at the same temperature several porous membranes that have the same pore volume fraction but different pore sizes. Both strategies are being pursued and experimental results will be reported at the conference.

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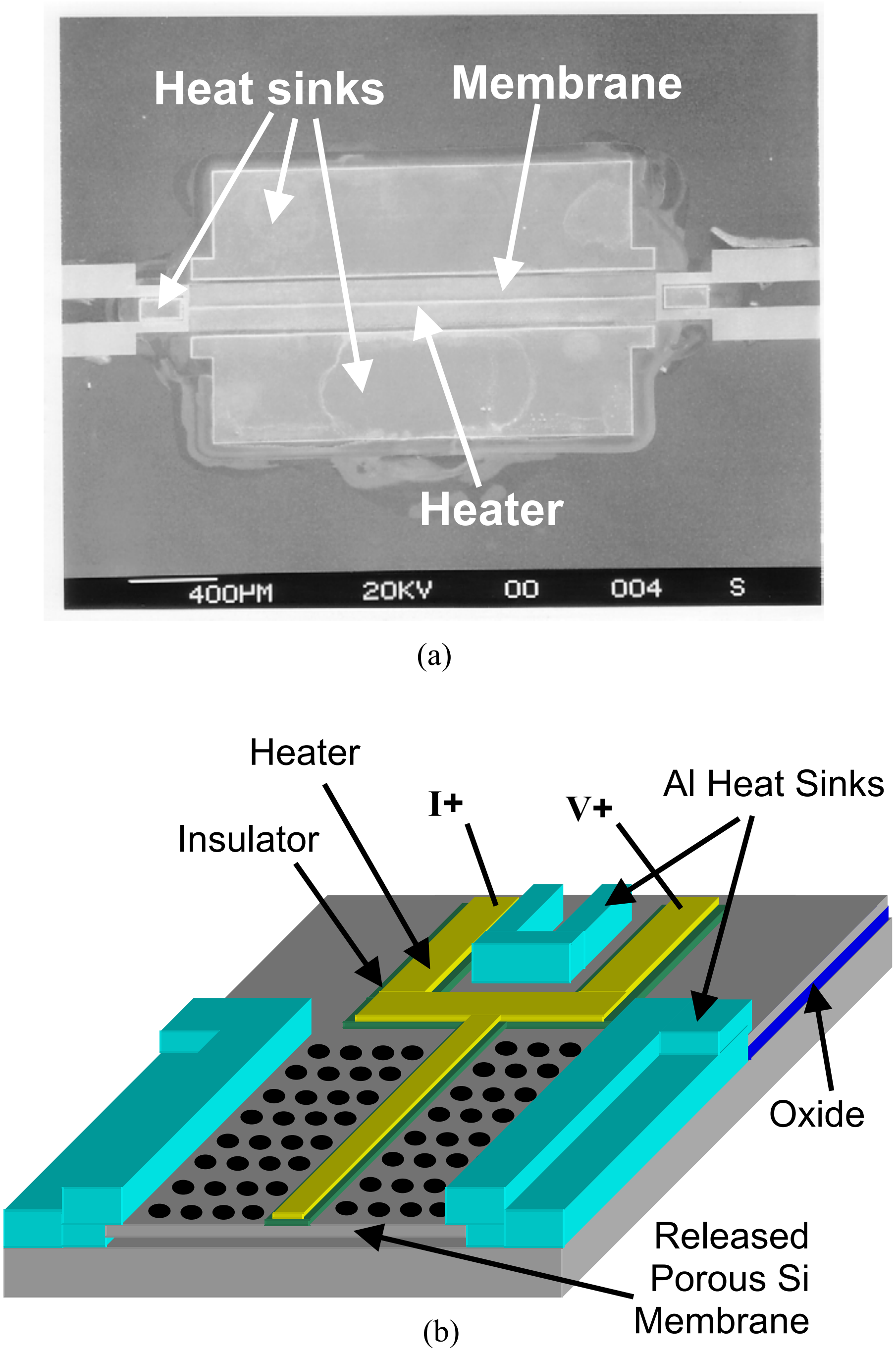

(a)

(b)

Fig. 1. (a) SEM of fabricated sample, (b) schematic cross-sectional diagram of the membrane