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Holey silicon as an efficient thermoelectric material

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Harvesting waste heat for electrical power generation is one of the important clean energy resources that could significantly impact future trends on environmental contamination and energy security. Solid-state thermoelectric (TE) modules recently have drawn extensive attention due to the great potential of electricity generation by recycling waste heat from power plants, automobiles, and building heating systems. The major challenge is to improve the heat-to-electricity conversion efficiency, which is mainly dictated by the TE material quality, defined as the figure of merit, $ZT=S^2\sigma T/\kappa$, where S is Seebeck coefficient, σ is electrical conductivity, T is the absolute temperature, and κ is thermal conductivity.

From the last decade, studies have mainly focused on nanoengineering conventional TE compounds (such as Bi_2Te_3) in order to improve ZT by enhancing the Seebeck coefficient and/or reducing the thermal conductivity. Additionally, thin and rough silicon nanowires show a surprisingly good ZT (~0.5 at 300K), making silicon a viable candidate for future large-scale TE applications. However, the inconsistent ZT, highly dependent on diameter/detailed surface morphology, as well as the weak mechanical strength remain as big challenges for practical implementations. In this seminar, I will present the TE properties of thin silicon membranes decorated with a highly dense nanoscopic holey array. These “holey silicon” membranes were fabricated by either nanosphere lithography or block-copolymer lithography, both of which are scalable for practical device realization. By a pitch of the hexagonal holey array=55 nm with a porosity=35%, the thermal conductivity of holey silicon (1~2 W/mK at 300K) is reduced by two orders of magnitude from bulk silicon (148 W/mK at 300K), and approaches the amorphous limit. The overall ZT ~0.4 at room temperature, comparable to the best value recorded in the silicon nanowire system, is consistently obtained. The reliable TE performance and its excellent mechanical strength make holey silicon an attractive TE material for future large-scale heat-to-electricity conversion.