Silicon Quantum Dot Superlattices for High Efficiency Thermoelectrics

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Project Overview

- Advantages of silicon as a thermoelectric material.
  - High abundance on the Earth.
  - Less toxic than other thermoelectric materials, e.g., Pb, Bi, Te.
  - Better integration with electric devices.

- Thermoelectric figure of merit

$$ZT = \frac{S^2\sigma}{\kappa}T, \quad Power\ Factor = S^2\sigma$$

$S-thermopower,\ \sigma-electrical\ conductivity,\ \kappa-thermal\ conductivity,\ T-temperature$

  - At room temperature, ZT of bulk silicon is only ~0.01.
  - Control *S*, σ and κ independently.

- Decrease the thermal conductivity using nanostructures.
  - As feature dimensions shrink to the phonon mean free path (~300nm), strong scattering of phonons should occur and κ decreases. In the meantime, the electrical conductivity is not heavily affected.

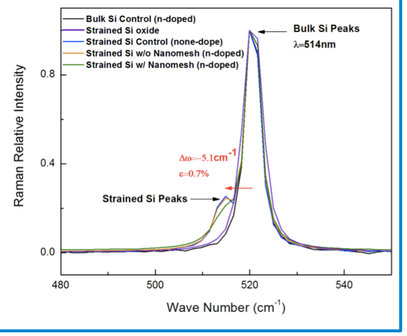
- Increase the electrical conductivity using crystal lattice strain.
  - Lattice strain affect the curvature of the energy band, resulting in lower effective mass of charge carriers and consequently higher mobility and conductivity.

- In this work, nanomesh structure was made on strained silicon thin films.
  - Thermopower values were enhanced for both strained silicon and normal silicon by adding nanomesh .
  - Strained silicon showed higher electrical conductivity than normal silicon. *ZT≈0.4 at 300K*

Raman Spectroscopy

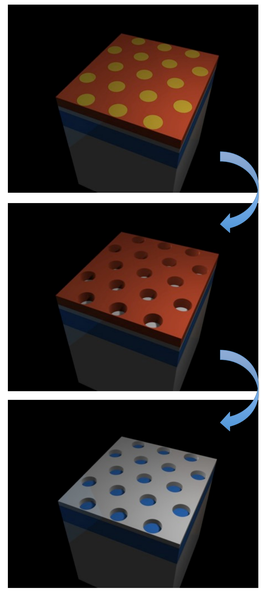
- Raman spectroscopy was conducted to verify that nanomesh didn't release all lattice strain in the strained silicon.

The green curve indicates that the nanomesh did release some lattice strain. However, most strain is still retained.



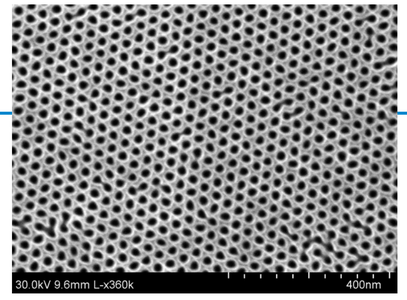
Device Fabrication

- Nanomesh is made on the strained silicon thin film on SiO_2 through steps as shown in the right schematics.
  - PS-PMMA block copolymer layer is first spincoated on top of the strained silicon.
  - After annealing and UV treatment, PMMA is removed by acetic acid.
  - Nanomesh is imprinted into strained silicon thin film by DRIE through the PS mask.
  - PS is finally removed by Piranha cleaning.



- SEM images show almost perfect hexagonal nanomesh on the strained silicon.

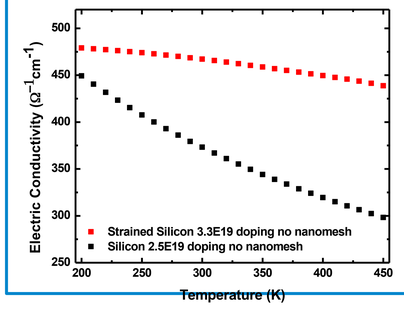
Top view.
nearly 20nm with pitches about 40 nm.

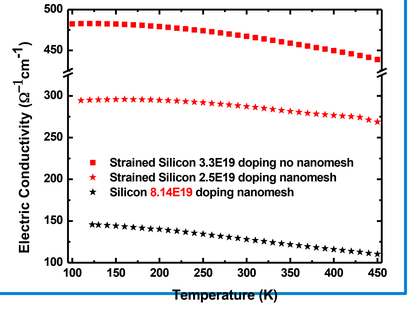


Electrical Conductivity Characterization

- Electrical conductivity were measured in a cryostat using a four-point setup.

- Strained silicon shows much higher electrical conductivity than normal silicon, both with and without nanomesh.

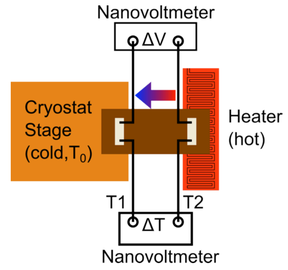




Thermopower Characterization

- All thermopower measurements were conducted in a cryostat using a LabVIEW interface.

A schematic of the experimental setup.



A screenshot of the LabVIEW program

- Thermopower is improved by adding nanomesh for both strained silicon and normal silicon.

Raw data *Linear fitting*