Thermoelectric Effect in Nano Ribbons

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Abstract

Topological insulators promise to be highly efficient thermoelectric materials with high Seebeck coefficients and high electrical conductivity through doping. Waste heat produced from cars or in industry can be good resources to harvest electrical energy by thermoelectric materials. To thermoelectric properties, nano-scale materials are made for which electrical conductivity stays high, while thermal conductivity is decreased significantly by boundary effects.

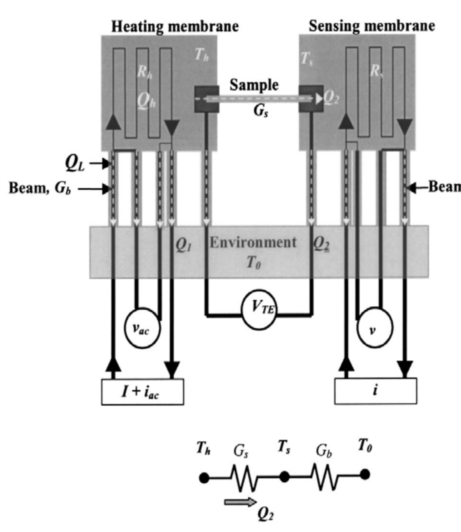
To evaluate thermoelectric conversion efficiency, a figure of merit, ZT, is used, where ZT= (Seebeck squared * elect conductivity /thermal conductivity)*T

$$ZT = \frac{S^2\sigma}{k}T$$

This work explores nanoscale Bi_2Te_3, Bi_2Se_3 with the goal to improve ZT of these materials.

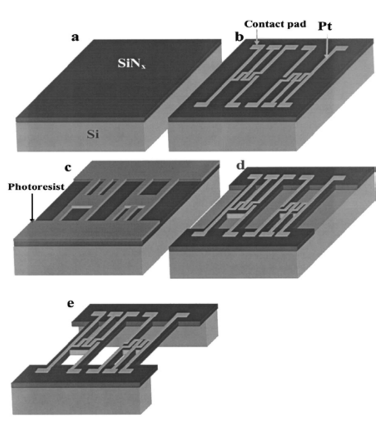
In-plane Thermal and Electrical Conduction Measured by Suspended Structure and Device Structure

- To study in-plane thermal conduction of device and to eliminate out-of-plane thermal conduction effect, the device is built on thin SiNx pads suspended in space and anchored on Si substrate on both ends.
- To eliminate heat loss by convection the device will be placed in vacuum 1E-6 torr
- To minimize heat transfer by radiation, the environment in the chamber will be controlled to a temp equal the sample temperature using lakeshore Model 331 temperature controller with radiation shield.



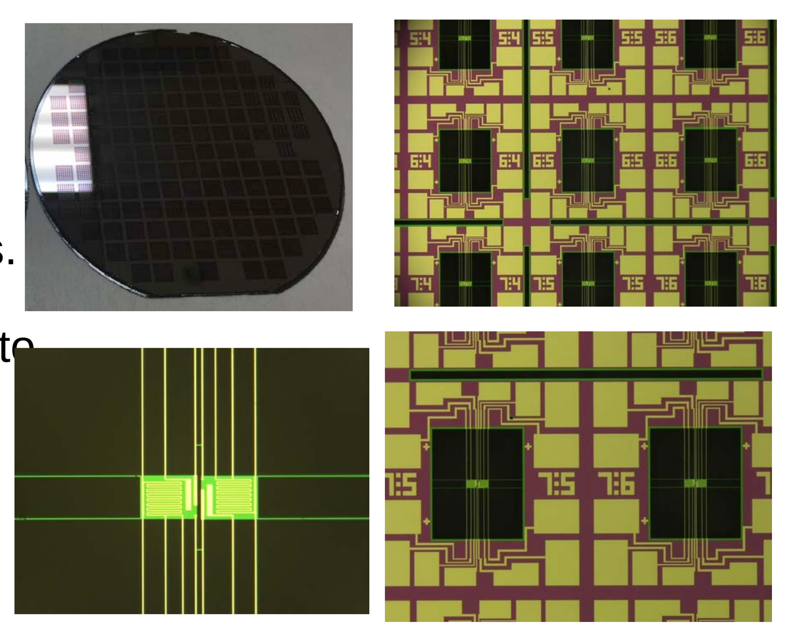
Sample Bi_2Te_3 or Bi_2Se_3 is connected to suspended pads of SiNx with Pt heater element on one side and Pt sensing Element on the other.
The whole structure is suspended in space and anchored to substrate (environment) via bars of SiNx and Pt conductors

Fabrication of Suspended Device Heater and Sensor Pads



- 500nm SiNx (silicon Nitride) deposited over Si substrate using LPCVD (low pressure chemical vapor deposition)
- 30nm Pt deposited and patterned using PMMA EBL resist. Later developed with MBIK/IPA solutions. Pt is etched using in milling
- Photoresist applied and patterned to protect the pads prior to Si etching
- SiNix film etched by reactive ion etching (RIE)
- Si substrate etched using (TMAH) tetramethylamonium hydroxide leaving structure suspended on SiNx/Pt beams

Actual Device

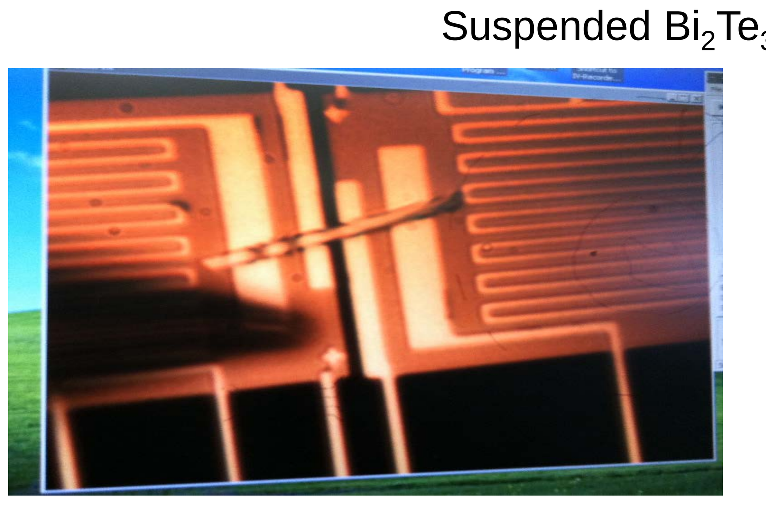


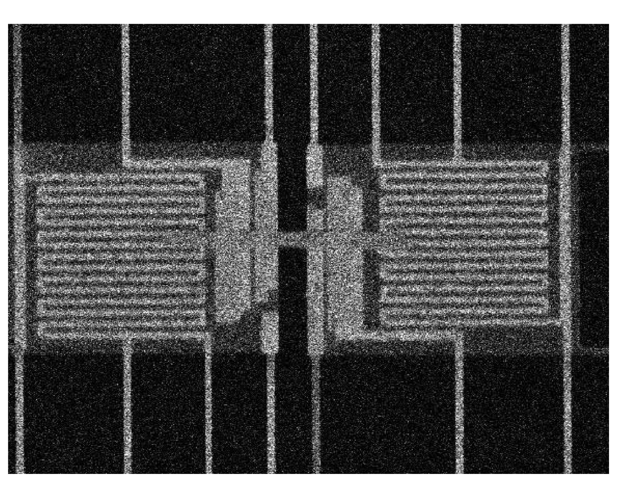
*Source: LI Shi et al, Measuring Thermal and Thermoelectric Properties of Nanostructures Using Microfabricated Device, Journal of Heat Transfer, Oct 2003, vol 125

Suspended Nano Ribbons

Bi_2Se_3 or Bi_2Te_3 Nano Structures

Suspended Bi_2Te_3 Nano Ribbon





Determination Of Thermal Conductance

Thermal Conductance Measurements

- DC voltage is applied to the heater element generating Q_h heat = v^2/R.
- Q_h causes a temperature rise in the heating element side T_h
- Some of the heat is transferred to substrate via leads Q_L
- The balance of the heat is transferred through the element Bi_2Te_3 or Bi_2Se_3 to the sensing coil via in-plane thermal conduction.
- This heat causes a temperature rise T_s on the sensing side
- Very small Ac current (500nA) is applied to both sides heater and sensor at different frequencies. 1.1kHz at the heater side and 199 Hz at sensor side
- The AC voltage associated with the AC current is measured (4 point probe technique) using Lock in Amplifiers (Stanford Research systems model SR830 and SR810) at the respective frequencies.
- The resistance of the heater side element and the sensor side Rs and Rh can easily be calculated from Vac/Iac at both sides at the respective Dc currents

Determination of Ts and Th and Thermal Conductance Gs

Once Rh and Rs are calculated, the corresponding temperatures on either side can be calculated:

•from Fourier Law:

- o Rh = Ro (1+αΔT)
- o Rs = Ro (1+αΔT)

where: Ro is reference temperature
α is temperature coefficient of resistance = 0.003927 at ref temp 20°C

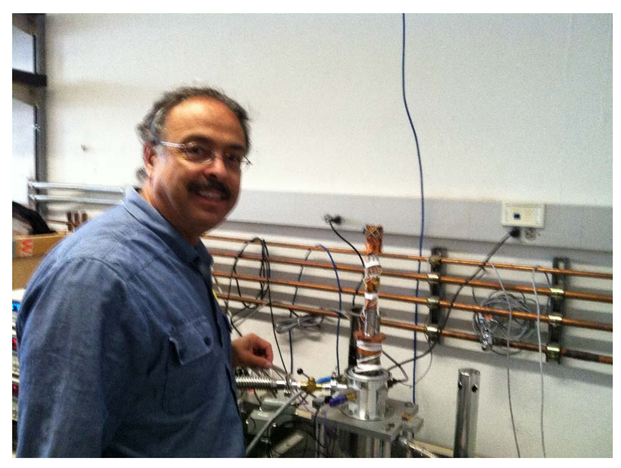
•Or measured

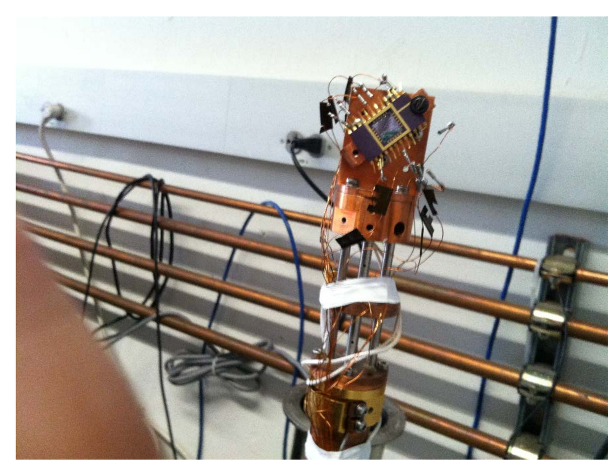
- o ΔT = T – Tref

Thermal conductance of sample is then calculated from:

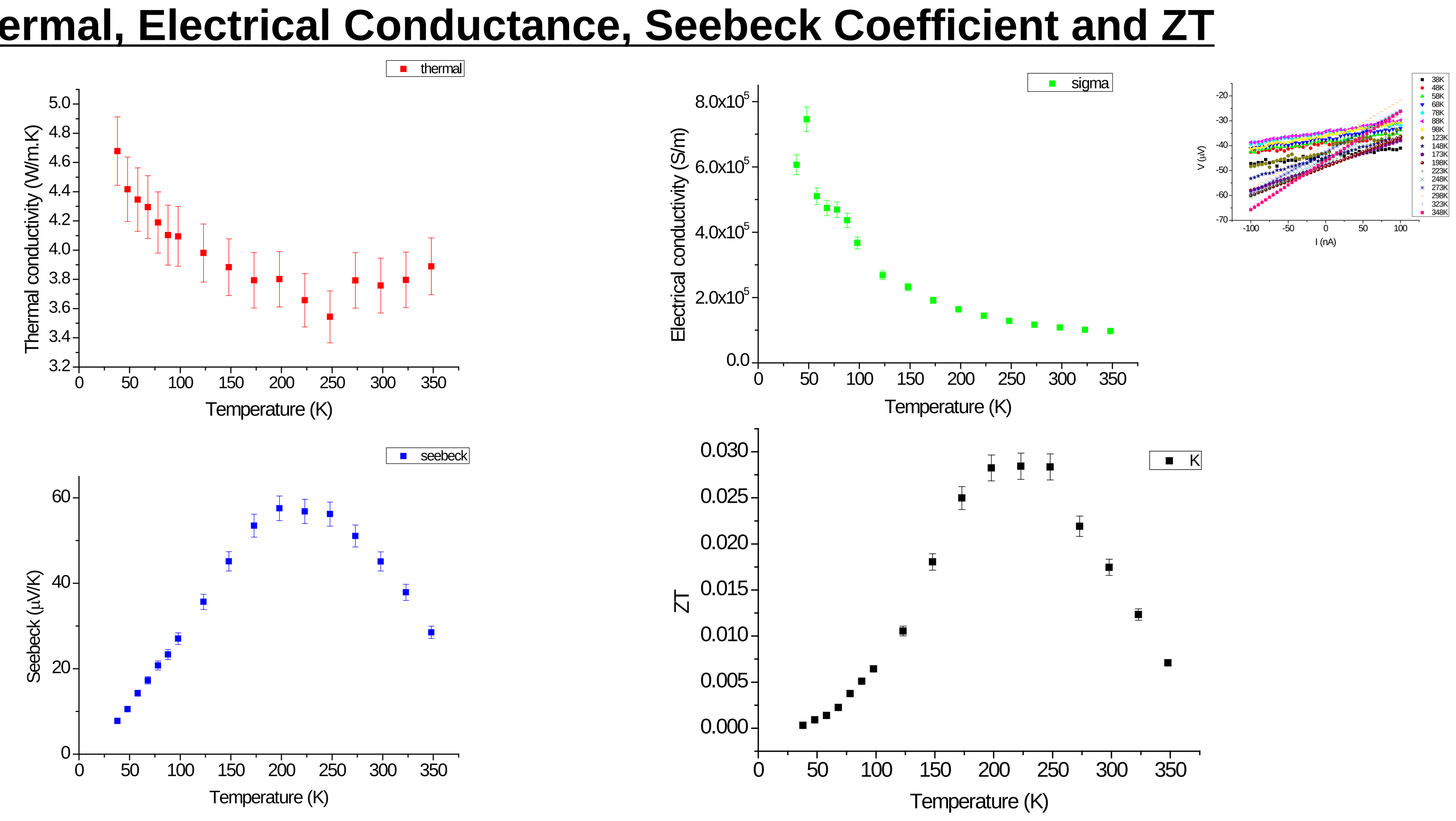
- o Q stripe = Qh – QL = Gs * ΔT

Loading Sample in Cryostat





Thermal, Electrical Conductance, Seebeck Coefficient and ZT



Conclusion: Established a method for measurement of thermoelectric properties of nanoscale devices

Future Plan:

•Introduce defects in samples by irradiation with Helium ion

•Defects are expected to decrease the thermal conductance of the device but not the electrical conductance

•This will result in higher ZT factor (more efficient thermo-electric conversion factor)

•Optimization by trying different geometries and different materials

Support Information

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