Phase Diagram of $RAgSb_2$ (R=Y,La,Gd) and (Magneto)Thermoelectric effects in Fe_3GeTe_2

AARON BREIDENBACH

JIUN-HAW CHU, JOSH MUTCH, SHUA SANCHEZ, ANNA ROCHE

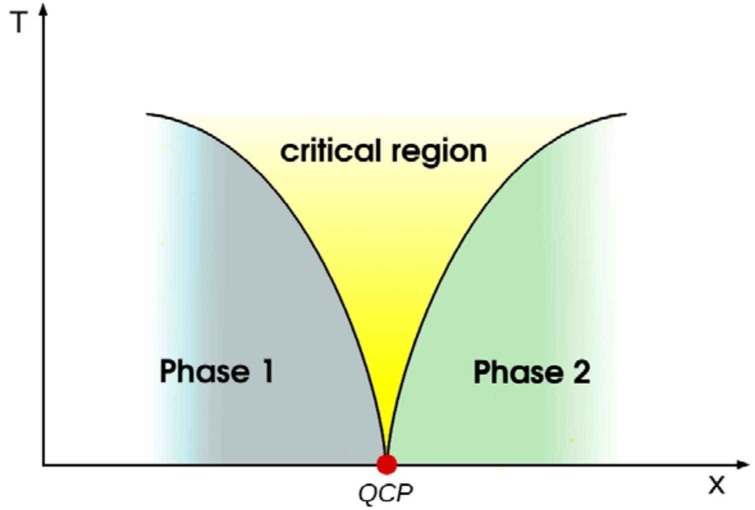
2018 UNIVERSITY OF WASHINGTON REU

Outline

- Phase diagram and superconductivity in $RAgSb_2$
  - Motivation
  - Growth/Processing
  - Analysis/Results
- (Magneto)Thermoelectric effects in Fe_3GeTe_2
  - Motivation
  - Measurement Technique
  - Device Construction

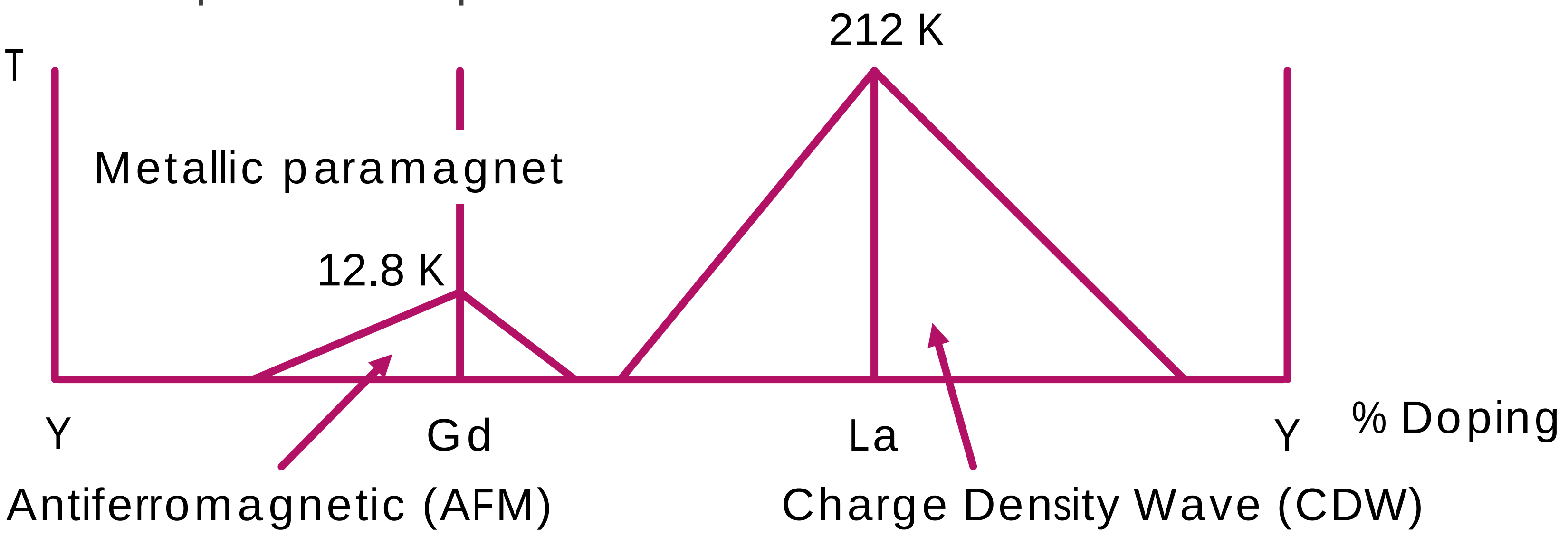
Motivation

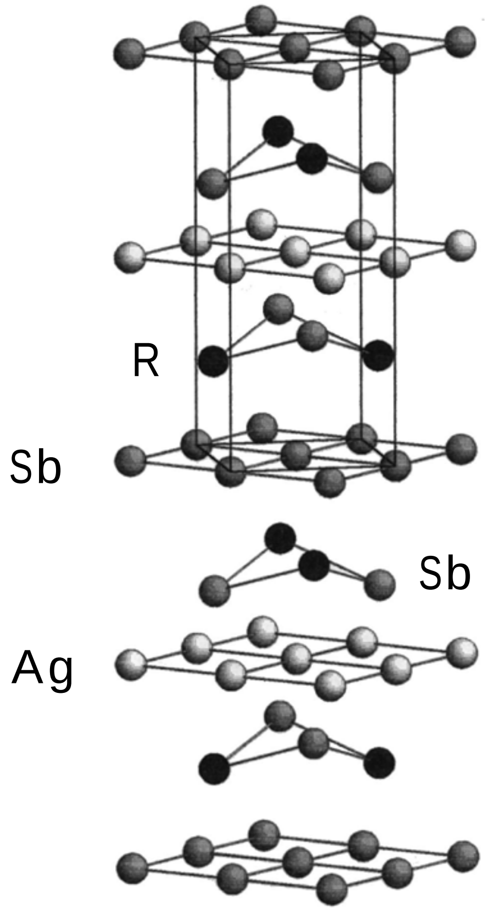
- Many applications for high-T_C superconductivity (MRI, Maglev train etc.)
- How do we go about finding new high-T_C superconductors (SC)?
- High-T_C superconductivity can arise from materials with Quantum Critical Points.
- These are continuous phase transitions that happen at absolute zero.



$RAgSb_2$

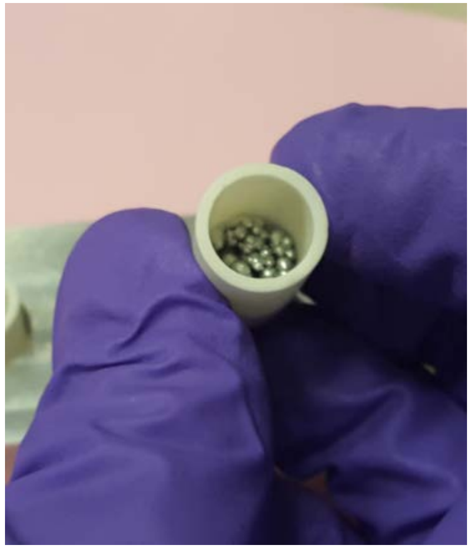
- Parent compounds $LaAgSb_2$ and $GdAgSb_2$ have known phase transitions, while $YAgSb_2$ has no low temperature phase transition[1].
- Doping from Gd-La ($La_xGd_{1-x}AgSb_2$) could have a quantum critical point, and a possible SC phase.

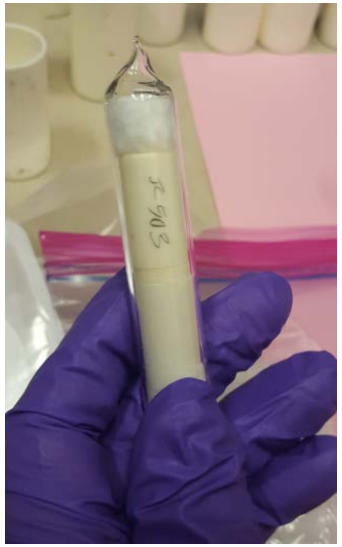


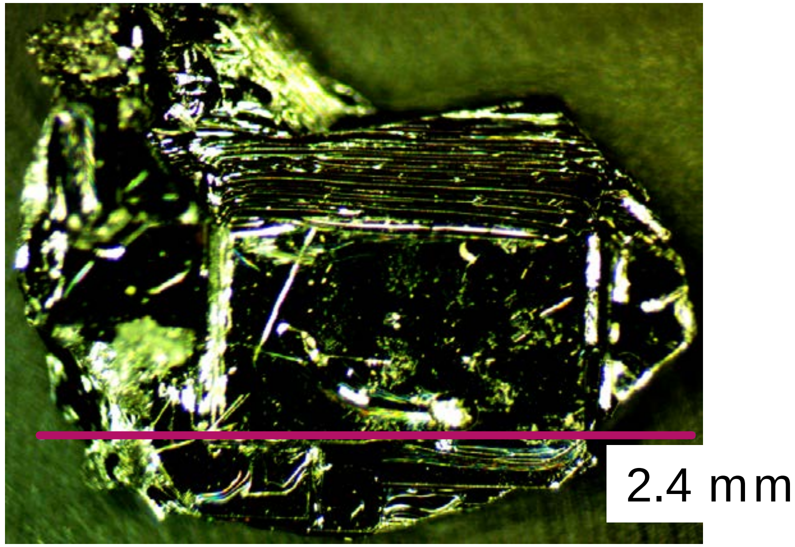


Crystal Growth

- Put elemental components in a crucible and vacuum seal in a glass tube
- Heat up very hot (~1000C) to let elements mix and cool over about a week's time
- Take out of furnace, quickly flip and centrifuge to remove flux

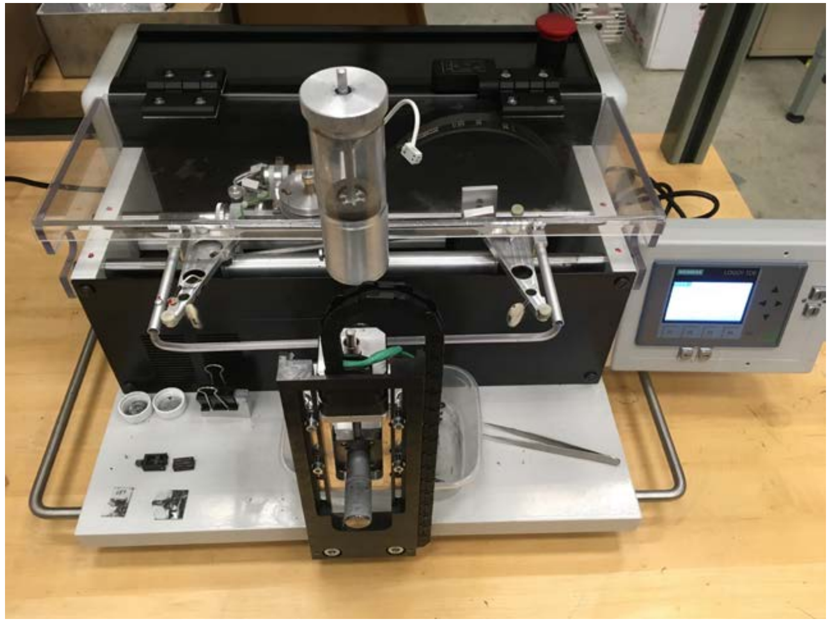


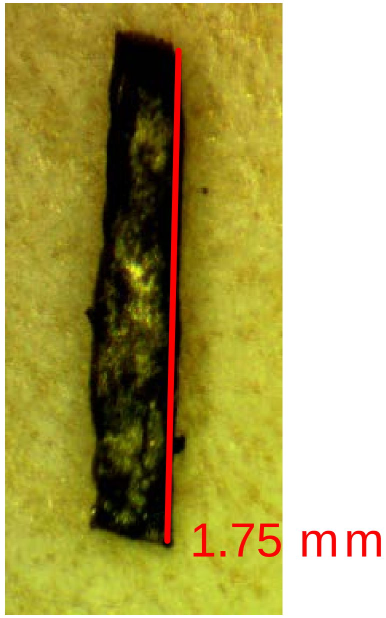


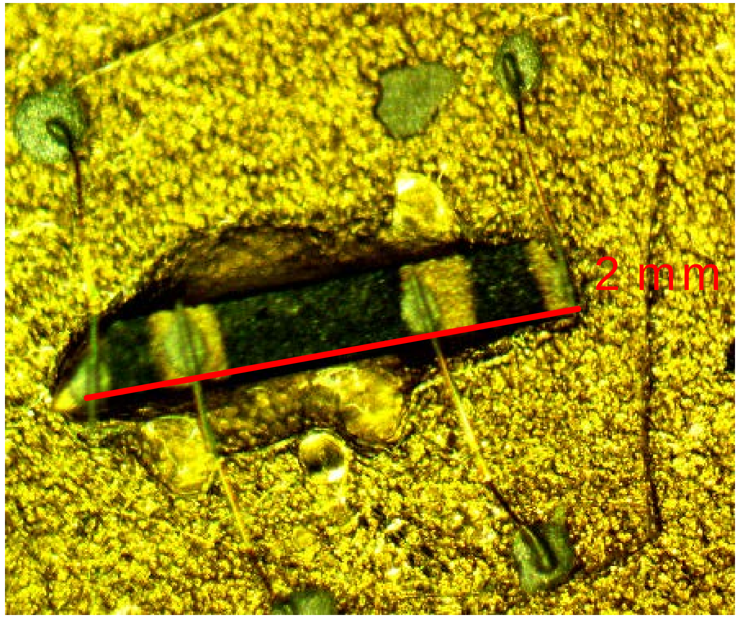


Device Processing

- Cut into thin rectangular shape
- Sputter gold contacts on
- Attach wires to gold contacts with sliver paste

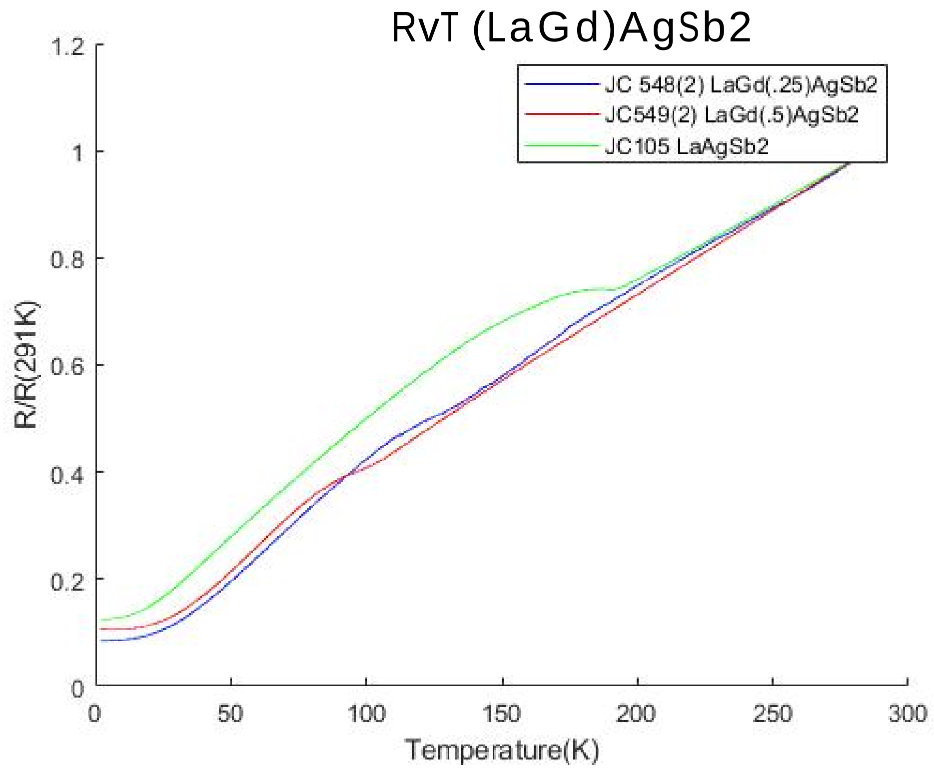


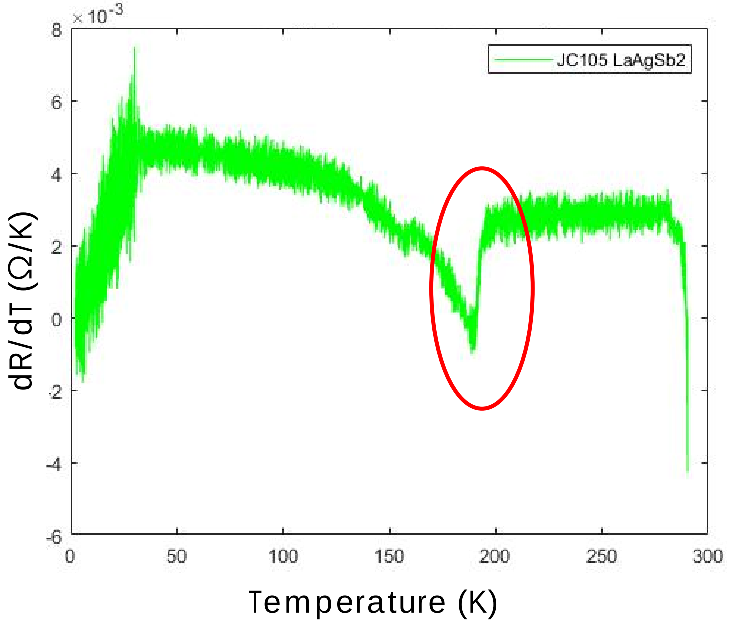




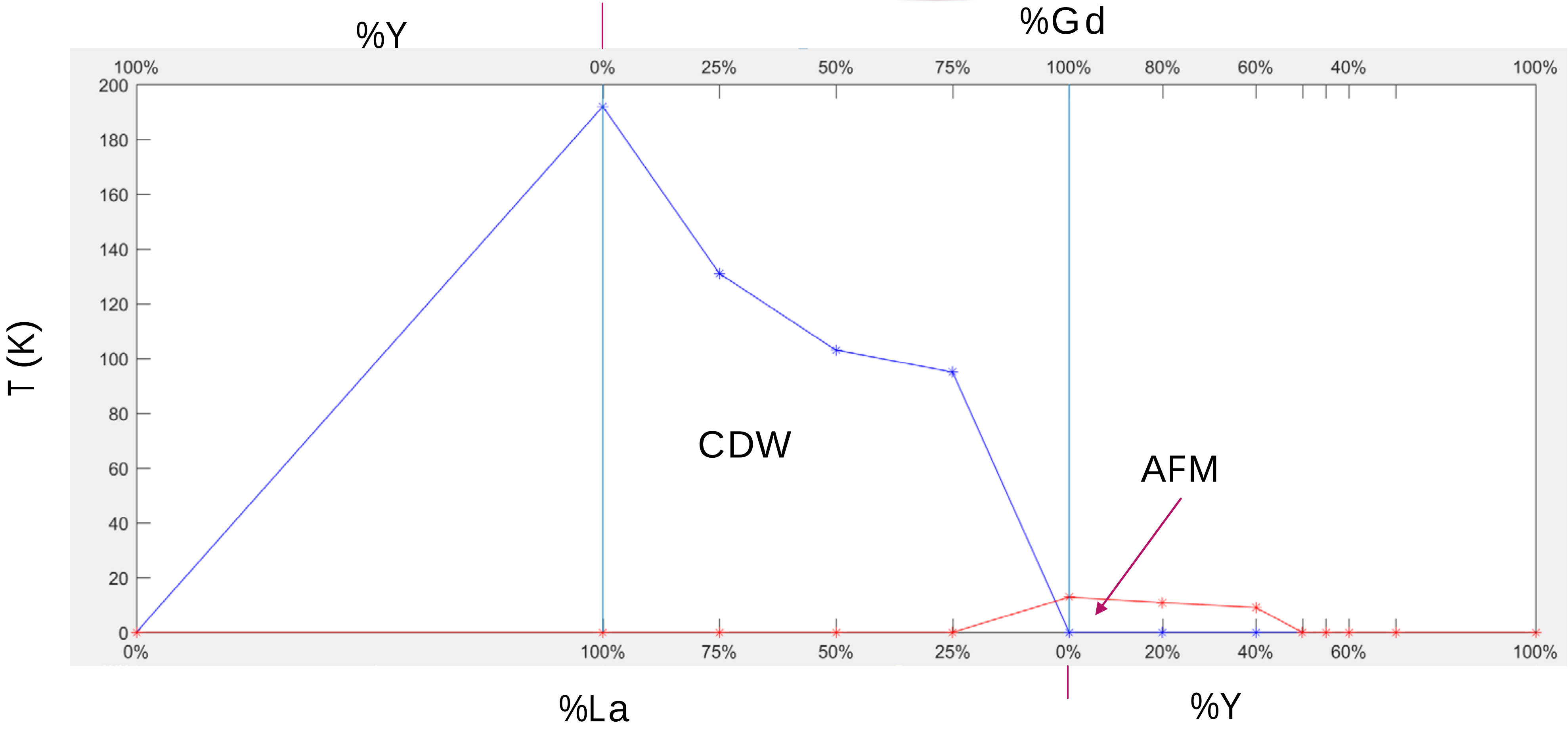
Measuring Phase Transitions

- Phase transitions appear as a kink in the resistance vs temperature (discontinuous derivative)
- Further data is needed to determine type of phase transition
- X-ray diffraction can directly image CDWs
- Magnetic susceptibility measurements can determine AFM states





Results So Far



Further Work

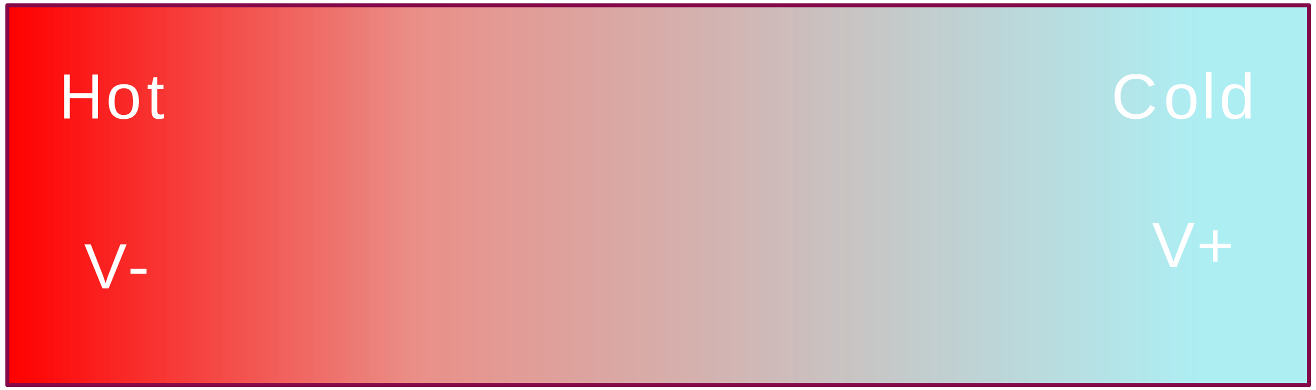
- Zoom in doping where AFM state disappears in La doped $GdAgSb_2$
- Measure Y doped $LaAgSb_2$
- Further Doping: Ag→Ni or Pd, Sb→Bi.
- Changing Ag to Ni and Pd is known to create SC phase
- Changing Sb for Bi will affect the lattice spacing and could change CDW spacing

Part 2: Magnetothermoelectrics

(Magneto)Thermoelectric Effects (MTE)

- Charged particles are also particles!
- Affected by chemical potential as well as ∇V (μdN from thermo)
- Voltages and currents can be created by temperature gradient
- Called Seebeck effect:

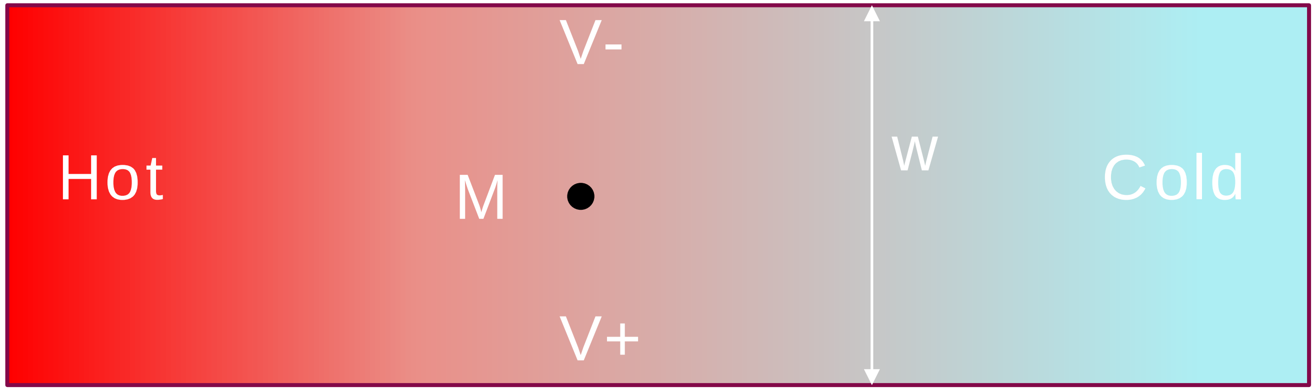
$$J = \sigma(\partial_x V - S\partial_x T) \rightarrow S = -\frac{\Delta V}{\Delta T} \quad (1)$$



MTE Effects Continued

- Like in traditional E&M, magnetic fields can create transverse voltages
- The thermoelectric analogs are termed “Nernst effects”
- Anomalous Nernst Effect is transverse voltage measured when running a thermocurrent through a magnetized sample

$$S_{xy}^{A} = \frac{-\Delta V}{w \partial_x T} * \frac{M_s}{M} \quad (2)$$

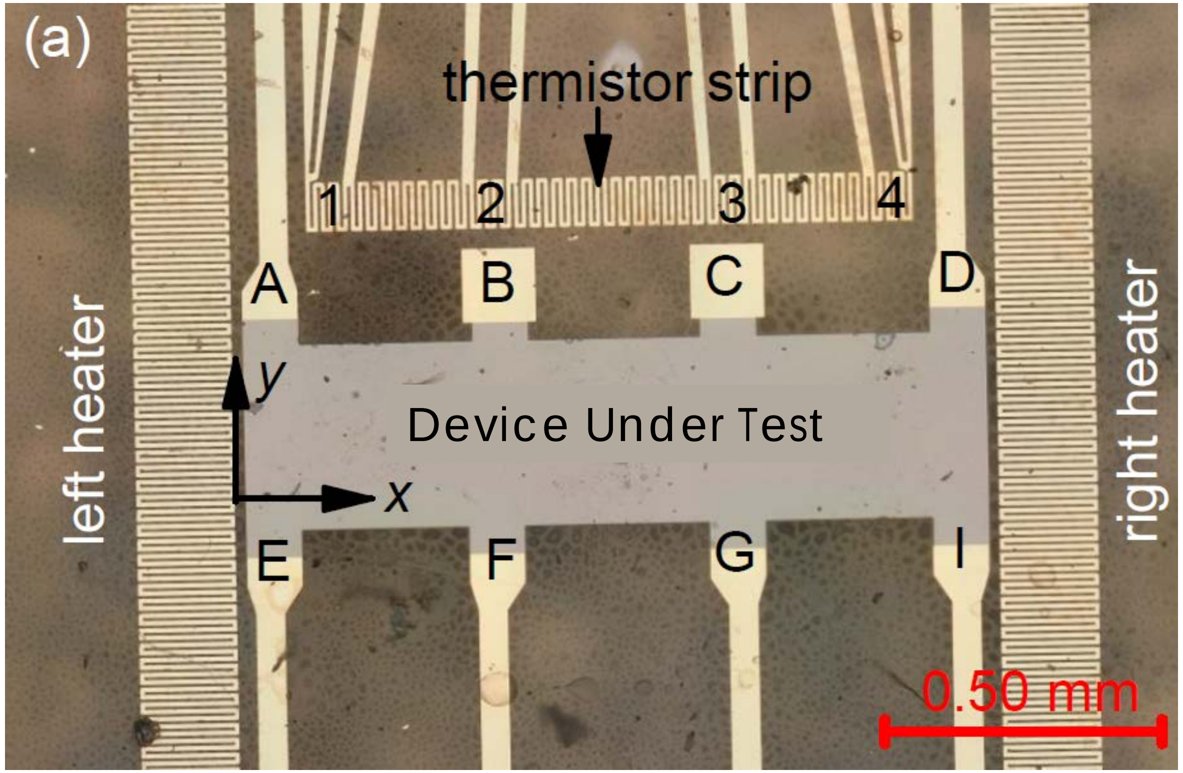


Motivation

- MTE provides a probe to the energy derivative of the band structure of a material at the Fermi Energy
- A recent paper has measured large Anomalous Hall Effect (AHE) and Hall angle in Fe_3GeTe_2[2]
- Author shows that large AHE is due to large Berry Curvature
- The interesting band structure of this material deserves further attention, and could also lead to large MTE effects.

Measurement

- Thermoelectric voltages are small, need lock-in amplifier to measure.
- Run current ∝ sin(ωt) through heater by device.
- Thermoelectric voltages ∝ heat ∝ I^2R
- $sin^2(\omega t) = \frac{1}{2}(1 - \cos(2\omega t)) \rightarrow$ $2\omega\ detection$



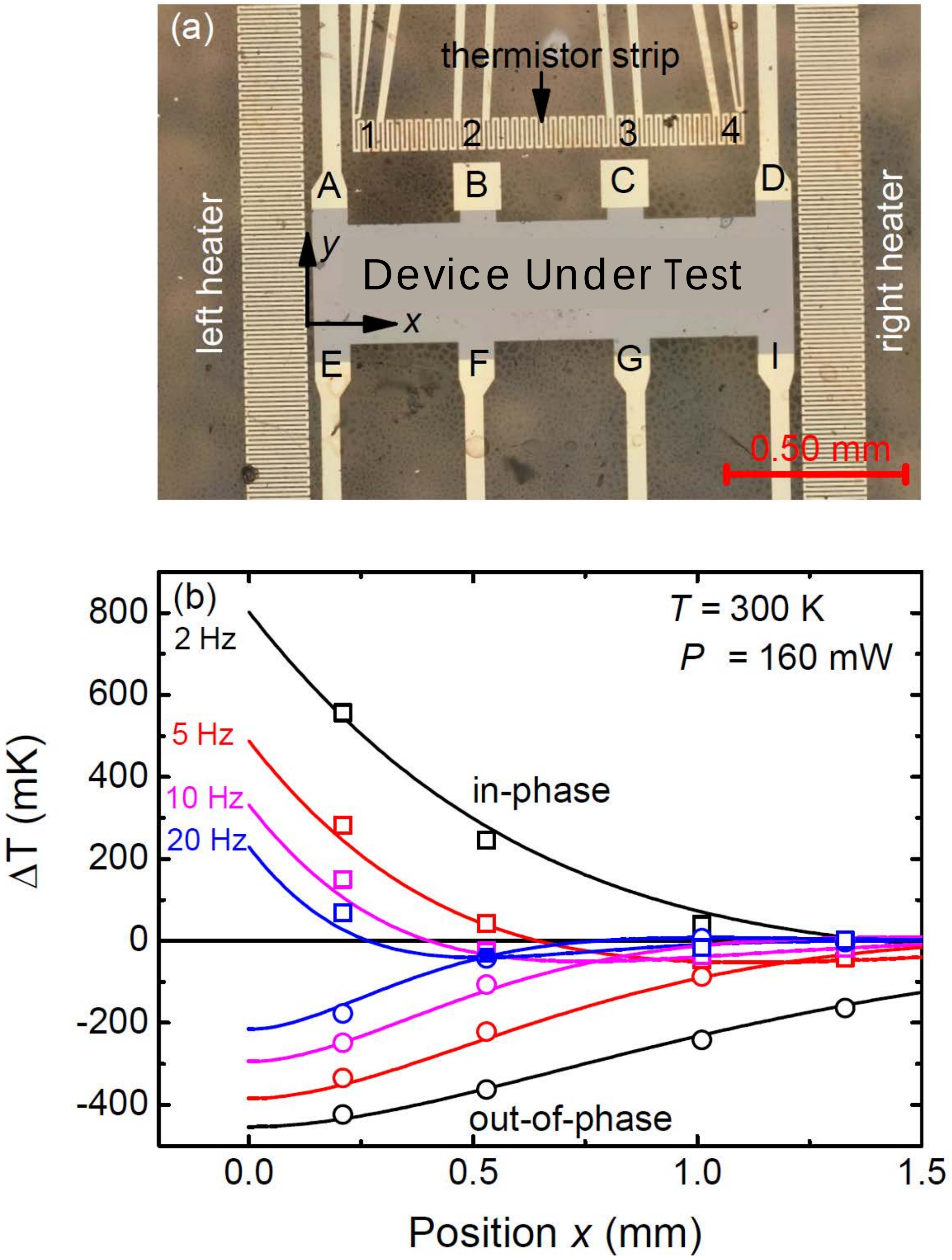
Thermal Modeling

- Need multiple thermometers to measure temperature profile.
- Need to model temperature profile to obtain the temperature gradient
- Solve modified heat equations with some assumptions (1D Helmholtz equation)[3]

$$\frac{dT}{dt} = D\partial_x^2 T - rT \quad (3)$$

- Harmonic solution is

$$\tilde{T}^{2\omega}(x,t) = A\frac{\exp\left(-\sqrt{\frac{r+i(2\omega)}{D}}|x|\right)}{2\sqrt{\frac{r+i(2\omega)}{D}}}e^{i(2\omega)t} \quad (4)$$

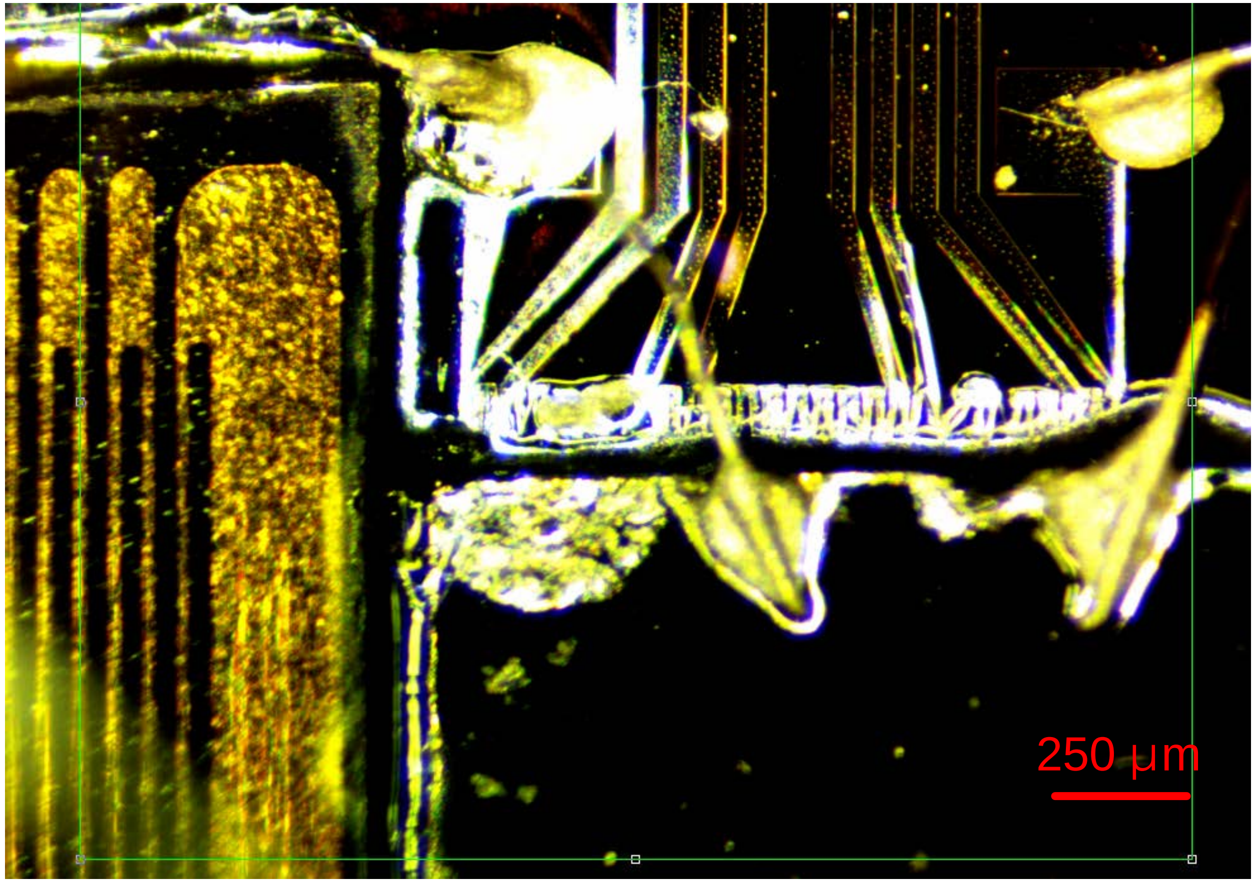


Summary of Method

- Drive heater at ω, measure thermal response at 2ω.
- Measure thermistors at different separations to get $T(x)$
- Fit model of $T(x)$ to thermistor data
- Use model to obtain ΔT and ∇T.
- Use ΔT and ∇T to derive MTE coefficients from voltages

Device Processing

- Thermistor strip is patterned with E-beam lithography
- Deposit evaporated Platinum onto pattern
- Glue crystal matchstick on Si/SiO_2 with stycast epoxy
- Glue on strain gauge for heater



Acknowledgements

- Special thanks to
- REU Program Directors Deep Gupta and Gray Rybka
- Program Administratiors Linda Vilett and Cheryl McDaniel
- Lab Members Shua Sanchez, Josh Mutch, Anna Roche and Prof. Jiun-Haw Chu
- National Science Foundation and the University of Washington Physics Department

References

1. K.D Myers et al. “Systematic study of anisotropic transport and magnetic properties of RAgSb2 (R=Y, La–Nd, Sm, Gd–Tm)”. In: Journal of Magnetism and Magnetic Materials 205.1 (1999), pp. 27–52. issn: 0304-8853
2. Kyoo Kim et al. “Large anomalous Hall current induced by topological nodal lines in a ferromagnetic van der Waals semimetal”. In: Nature Materials(2018). issn: 1476-4660.doi:10.1038/s41563-018-0132-3.
3. T. A. Peterson, Ph.D. thesis, University of Minnesota (2018).

Image Credits

- https://www.nibib.nih.gov/science-education/science-topics/magnetic-resonance-imaging-mri
- https://www.theguardian.com/technology/2018/may/29/maglev-magnetic-levitation-domestic-travel
- http://inspirehep.net/record/1276422/plots

Backup

Thermometer Calibration

- Resistance as a function of temperature is measured with zero heater power.
- Can fit to R vs T and obtain dR/dT
- With heater on, local change in temperature due to resistive heating is approximately