Physical Properties of Cu/Nb Nanolamellar Composites

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Introduction

Establishing tension test capabilities in the UNM Hot Cell for testing radioactive specimens. This project is being assisted on by NSSC undergraduate student L. Sanchez

Department and University: Nuclear Engineering, University of New Mexico
Academic Advisor: Dr. Osman Anderoglu
NSSC Research Focus Area(s): Nuclear Materials Science
Academic Standing: Ph.D. Student

Lab Mentor and Partner National Laboratory:
Dr. Filip Ronning, LANL
Dr. Andrew Hoff, LLNL

Mission Relevance of Research:
Accumulative roll bonded (ARB) nanolamellar composites have increased strength and radiation damage resistance compared to conventional alloys used in nuclear systems. This makes them attractive for enrichment facilities, including centrifuge drums. Investigating the physical properties of the ARB created composites deepens the understanding of the role of interfaces in these materials, which in turn can be used to evaluate their risk as a proliferation technology.

Introduction

Goal: Understand the role of interfaces on the physical properties of nanolamellar composites produced via accumulative roll bonding

Tasks:

- Produce ARB specimens of varied layer heights & roll directions
- Measure the Electrical Resistivity from ~2-300 K
- Analyze the electrical resistivity against models
- Measure the Thermal Conductivity at room temperature
- Analyze and relate the thermal conductivity and the electrical resistivity

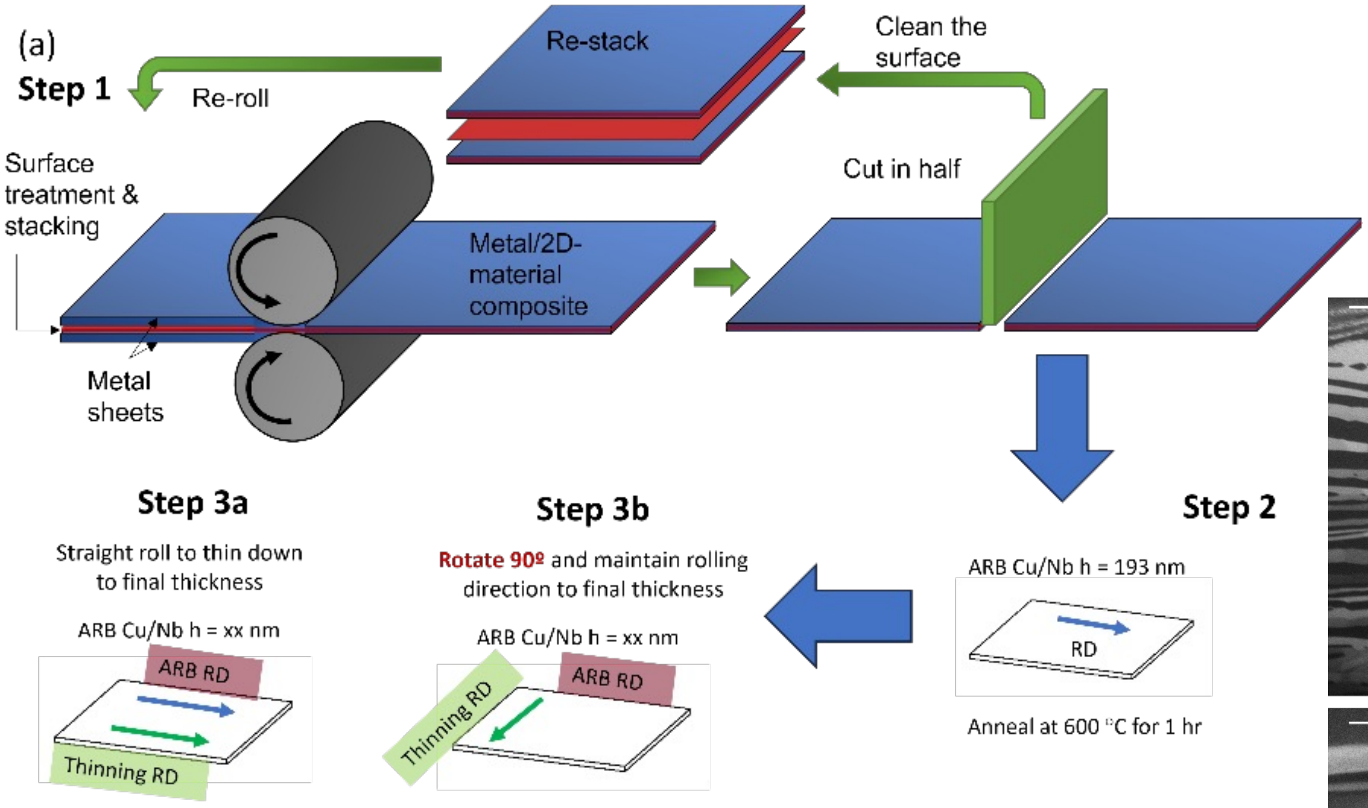
Electrical Resistivity Models and Metrics:

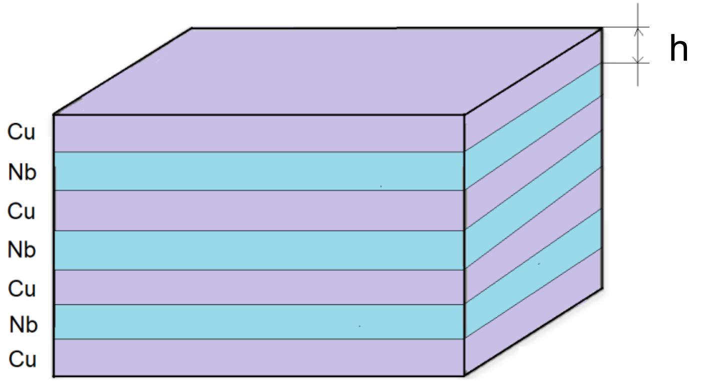
- Metrics for temperature response
- Models for interface response

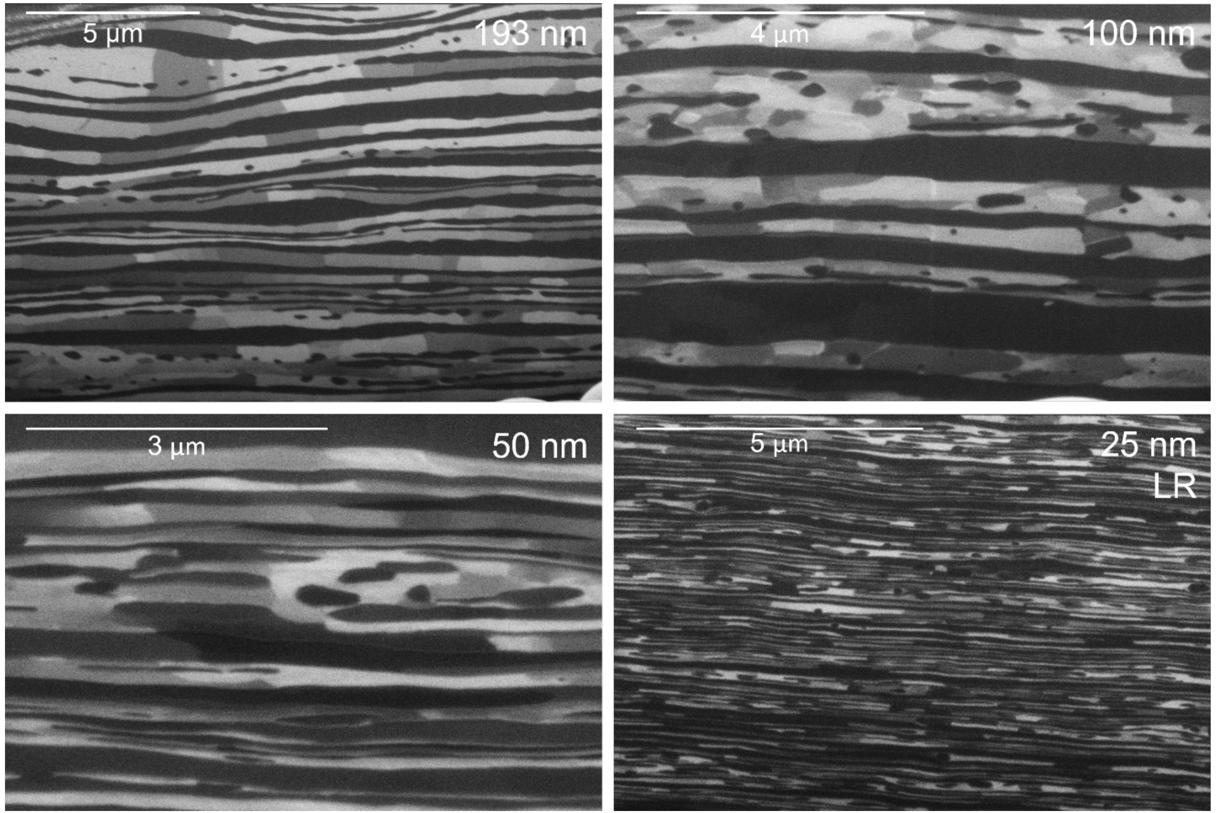
Thermal Conductivity Relations:

- Drude Conductivity and the Wiedemann-Franz law

Accumulative Roll Bonding creates materials with high interface density







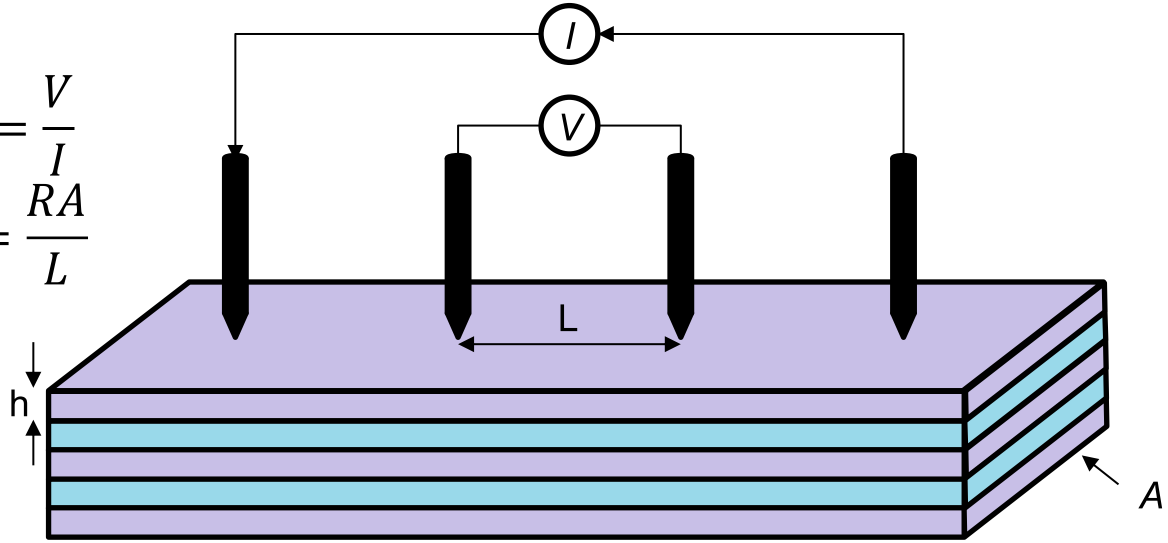
ARB produces specimens using severe plastic deformation.

Specimens have complex microstructure with high interface and dislocation density

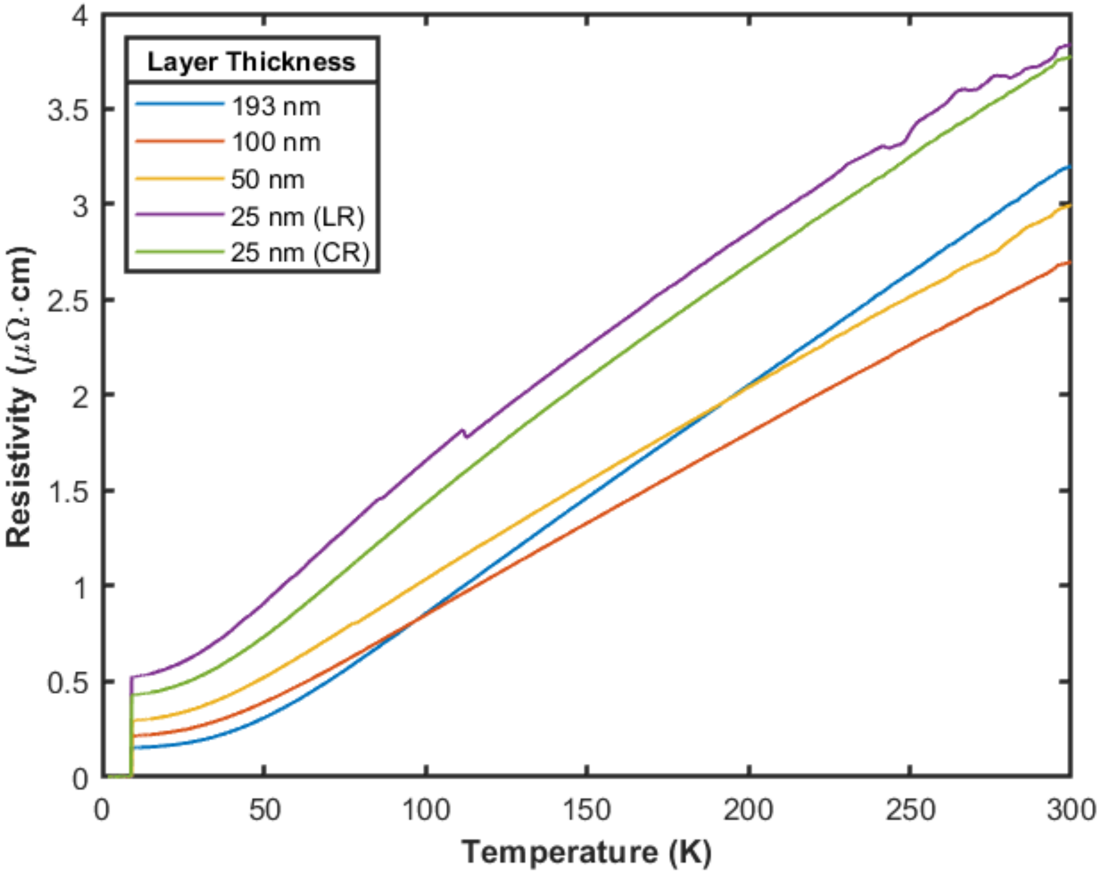
Electrical resistivity using the four probe method

$$R = \frac{V}{I}$$

$$\rho = \frac{RA}{L}$$

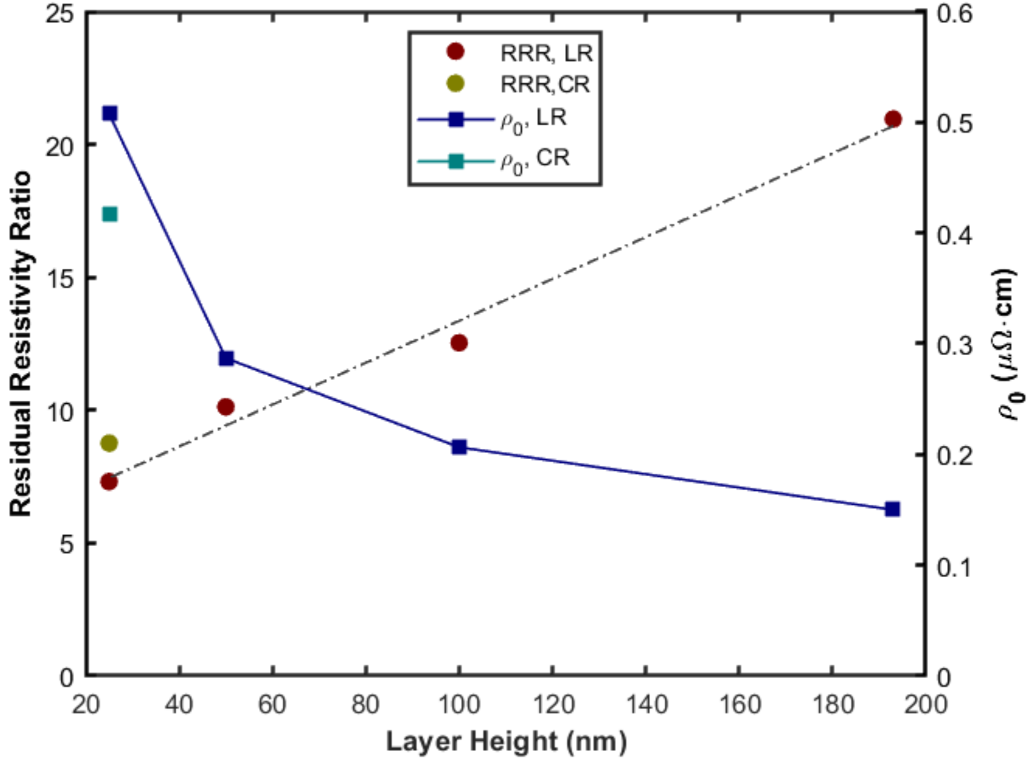


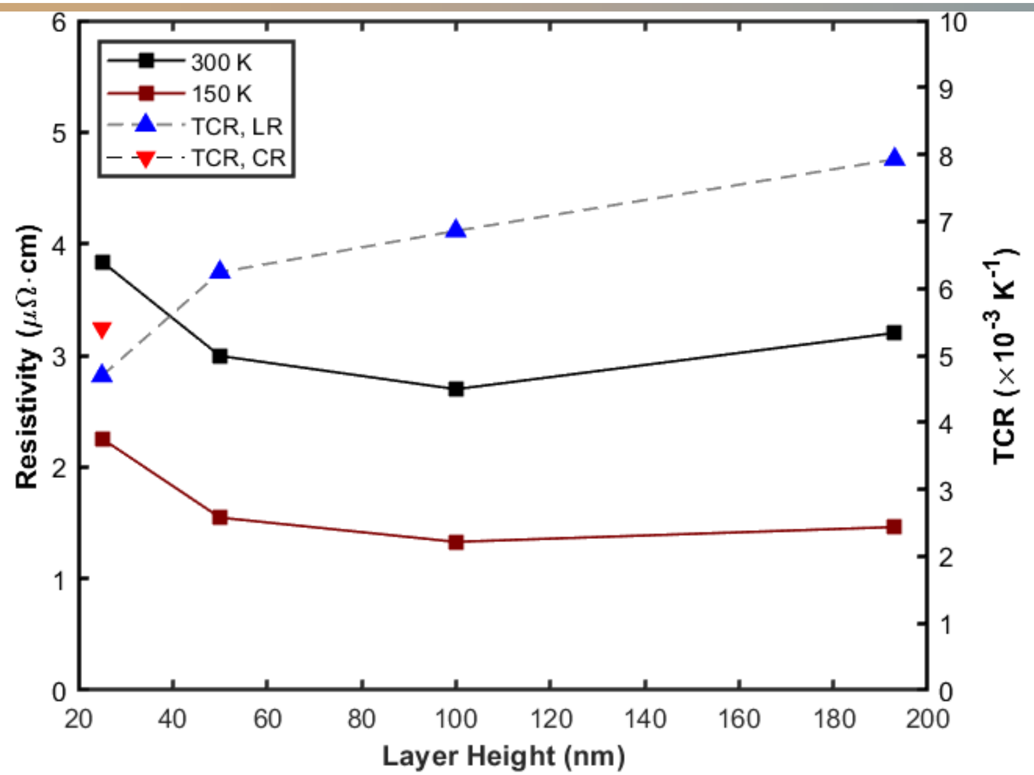
Four-Probe Resistivity Measurement



- Resistivity measured || to layers
- Slope related to the thermal sensitivity
- Superconductivity due to Niobium presence
- Residual resistivity is the resistivity before superconductivity

Temperature Dependence decreases with decreasing layer height





Dislocations, interfaces, & impurities are temperature invariant scattering sources

Residual Resistivity is found from fitting low T data to $\rho = \rho_0 + JT^k$

- Decreases because interface density decreases

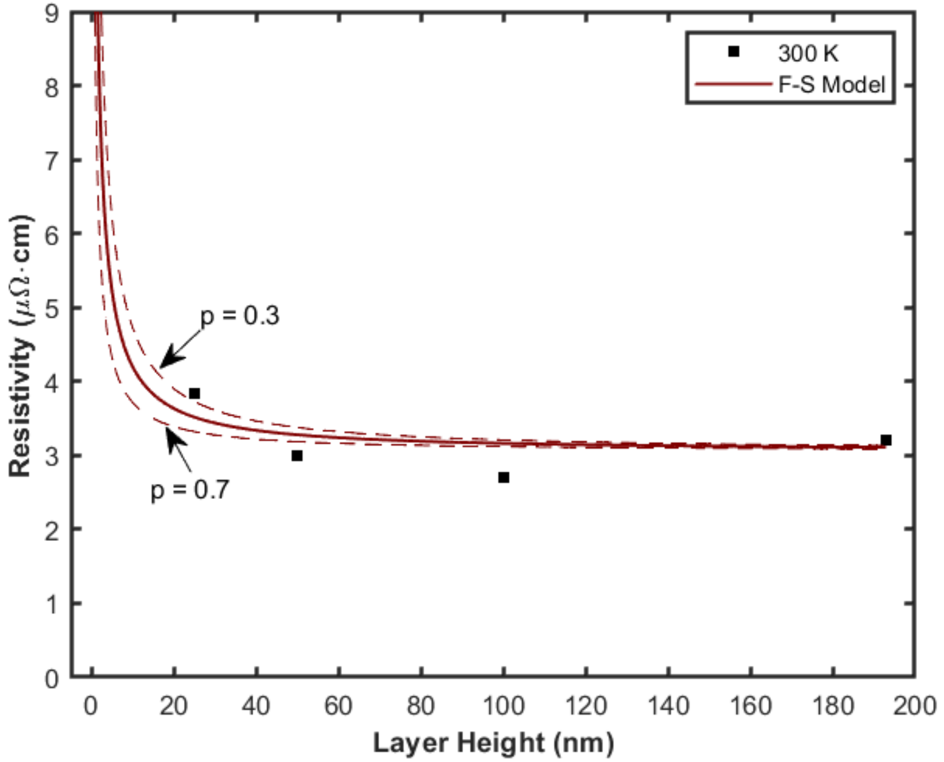
Residual Resistivity Ratio is ratio of room temp to residual resistivity

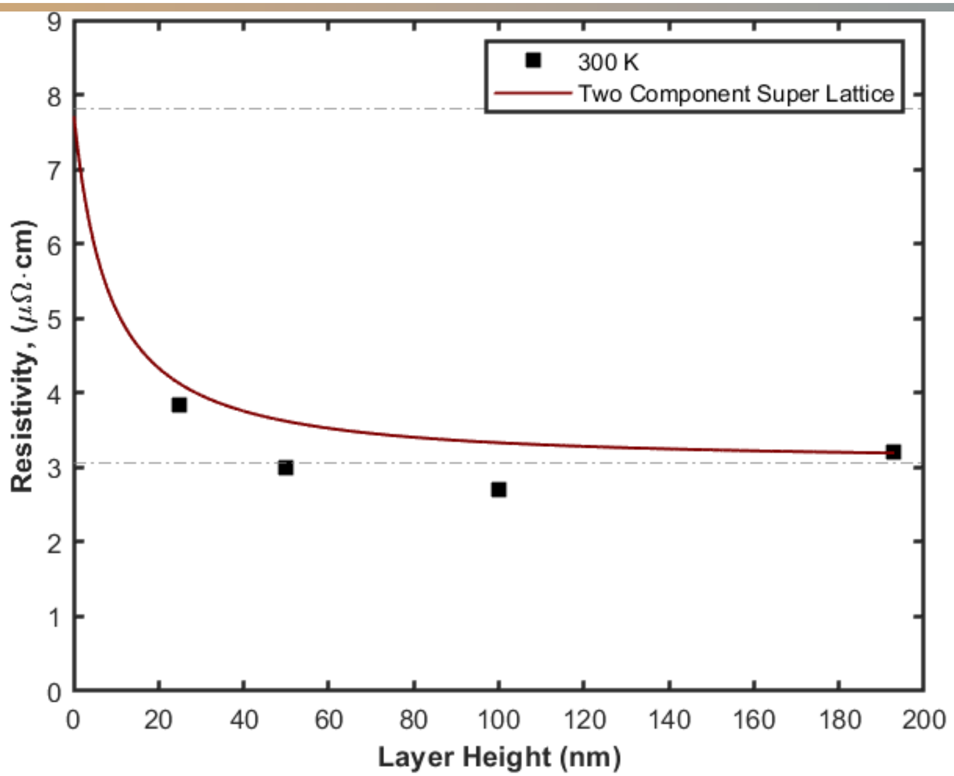
- Relationship remarkably linear with layer height

Temperature Coefficient of Resistivity gives the percent increase in resistivity per degree

- It increases with layer height, as phonons are more able to propagate and become the dominant resistivity mechanism

Models are highly sensitive to inputs





Two resistivity models were used to understand the resistivity of the nanolamellar composites

The **Fuchs-Sondheimer** model is the most widely used, but was developed for single layer thin-films

Later this was expanded to encompass bi-metallic thin-films, so-called **two component super lattices**

The resistivity was fit to both of these models and compared

Challenge: Choosing the appropriate inputs into the models to properly model physics

- Electron mean free path, bulk resistivity, reflection coefficients.

Resistivity is Directionally Dependent

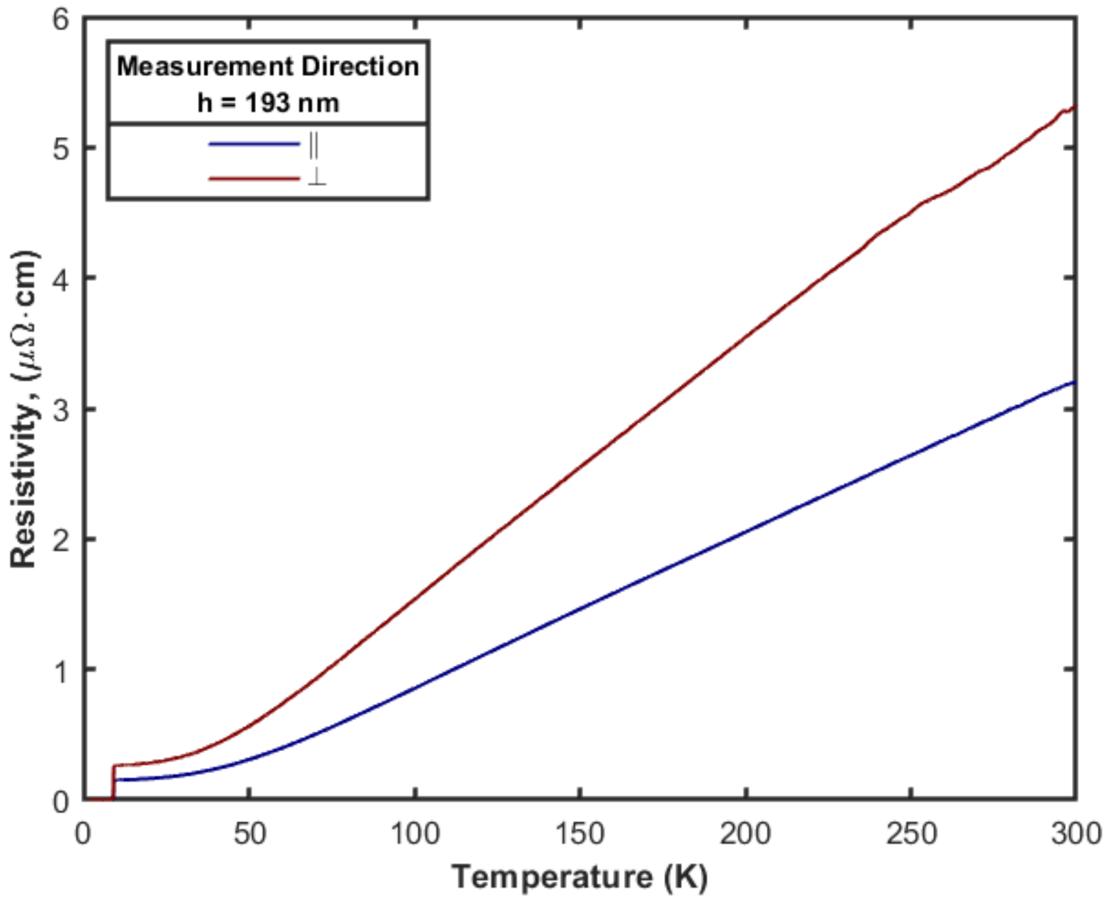
The 193 nm specimen's resistivity was measured both ∥ to layers, and ⊥ to layers

Specimens measured ∥ still see interfaces, though less directly than those measured ⊥

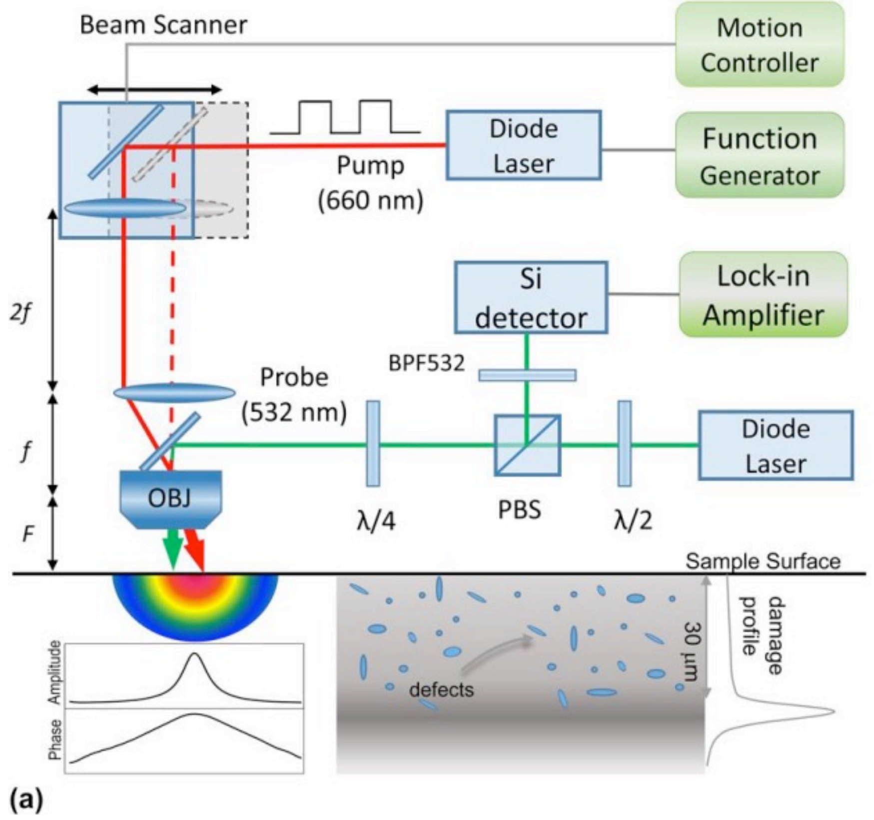
- Electrons don't travel in straight lines along a layer, they have "grazing" collisions with the boundary

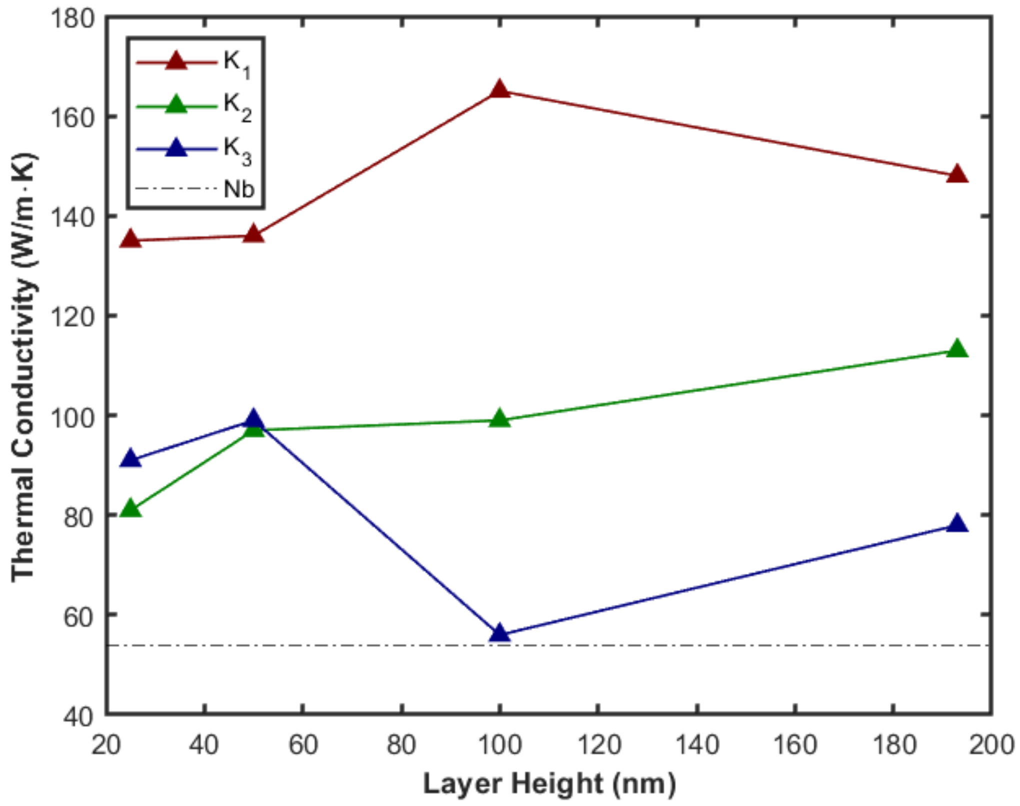
Resistivity is a function of the angle of the interfaces relative to electric field

In real materials, the electrons may encounter an interface at any angle



Thermal Conductivity is highly directional



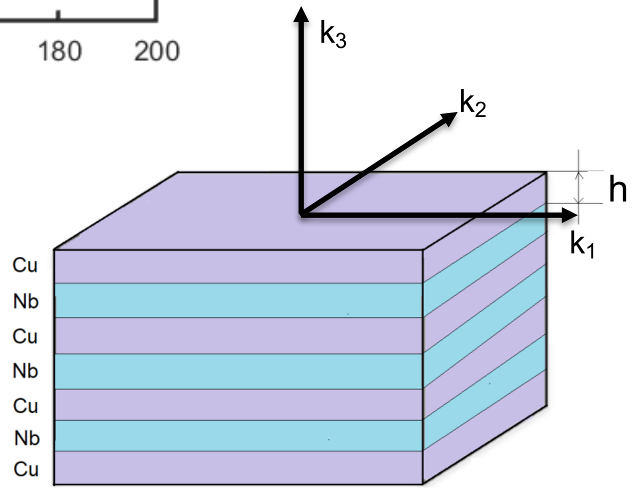


Measurement taken using Modulated Thermoreflectance (MTR)

The thermal conductivity was measured in 3 orthogonal directions

Perpendicular to interfaces, the thermal conductivity was unsurprisingly diminished

In-plane with the interfaces, the discrepancy is caused by the grain structure



Electrons and phonons have reduced impacts on physical properties

The electrical and thermal conductivity are related by the Wiedemann-Franz Law

$$L = \frac{\kappa}{\sigma T}$$

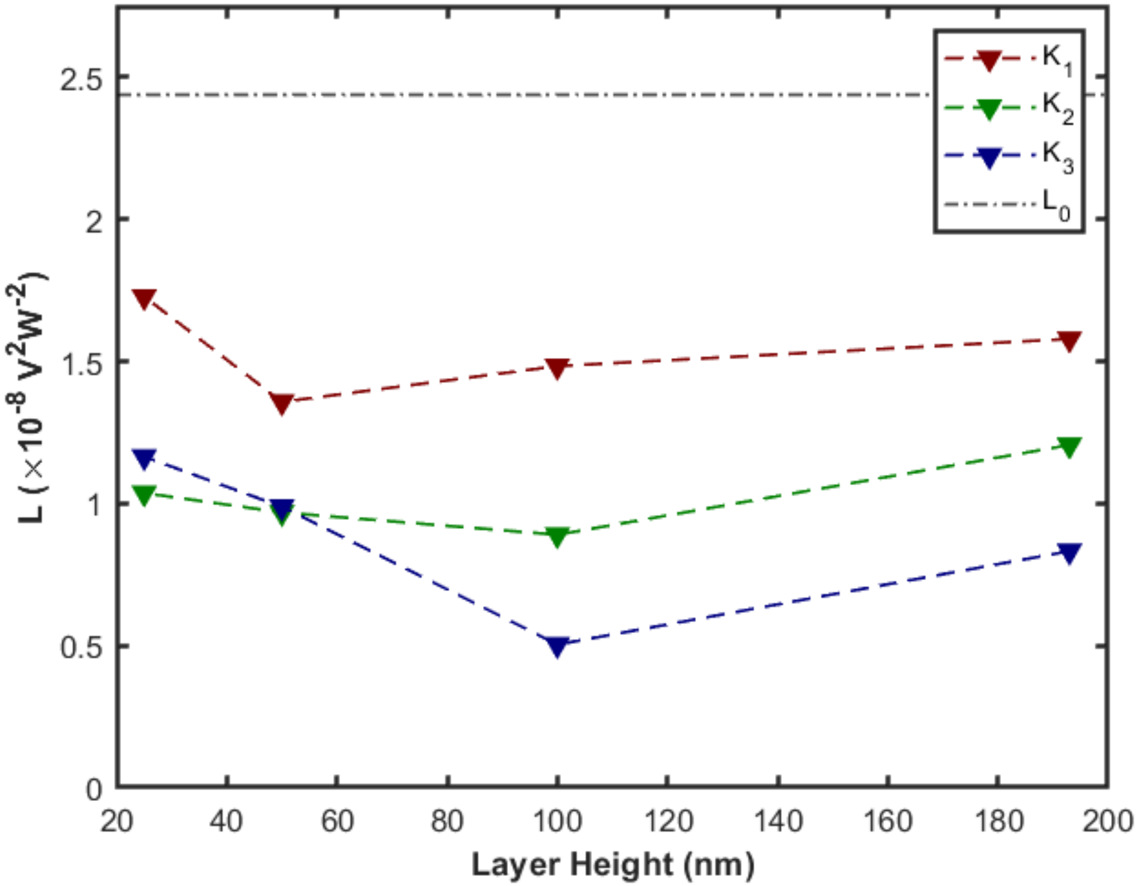
The Lorenz number, L, has a theoretical value of $2.44\times10^{-8}\ \mathrm{V^2K^{-2}}$

Deviation from this value is due to 2 factors

1. Phonons promoting head conduction but diminishing electrical conduction
2. Free-electron movement being restricted

Phonons propagation is diminished as seen in the TCR

So free electron movement must therefore also be significantly diminished



The NSSC Experience

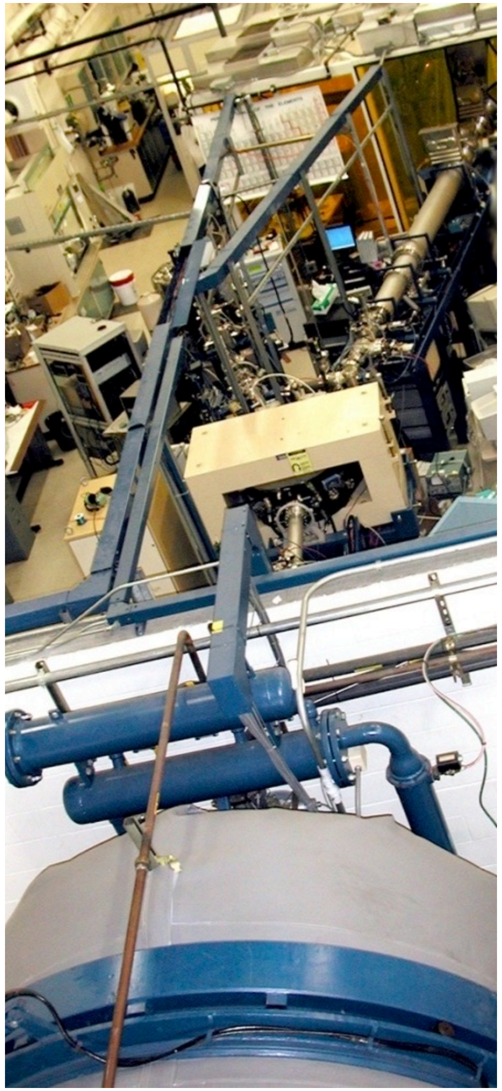
Presented posters at UPR ‘22, & ‘23

Connected to LLNL and completed two Summers there working with my mentor

- Connected to unique facilities for future projects
    - 4 Million Volt Accelerator for radiation damage studies
    - Advanced Manufacturing lab for specimen creation
- Attend lectures from the Center for Global Security Research
- Will return to continue LLNL collaboration

Will give oral presentations at two upcoming conferences w/ NSSC support

- Rio Grande Symposium on Advanced Materials
- TMS 2024



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Acknowledgements

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