

DSU: Alex Farnsworth, Dr. Samuel Tobler
 UVU: Jacob Kodra, Bryce Wright, Dr. Paul Weber

Abstract

Precise understanding of the resistivity of metals is an important factor in the optimization of circuit designs and electrical systems. We studied the fabrication of, and measurement of electrical properties of thin films of copper, gold, and nickel. Resistivity measurements of these films were made using 4-point probes designed and built at Dixie State University (DSU). The making of the films at DSU used thermal deposition and sputtering deposition. The making of the films at Utah Valley University (UVU) used RF sputtering deposition. Analysis of the smoothness of the films was verified with atomic force microscopy (AFM) at UVU. Thicknesses were measured using ellipsometry at BYU and with a stylus profilometer at NIST in Boulder, Colorado. Scanning electron microscopy was also used in the analysis of the films. Resistances similar to bulk properties of the films was seen in thicker films. Thinner films showed an increase in the resistance of each film.

Motivation

The understanding of electrical properties of thin films and small dimension conductors is an area of great interest in the field of circuit design and performance. From nanowires and nanodots [1] to how thin films [2] differ from bulk material, the detailed properties of small dimension conductors are being studied in increasing detail. A direct application of these studies is seen in the continually decreasing sizes of circuits and features in electrical and microprocessor designs.

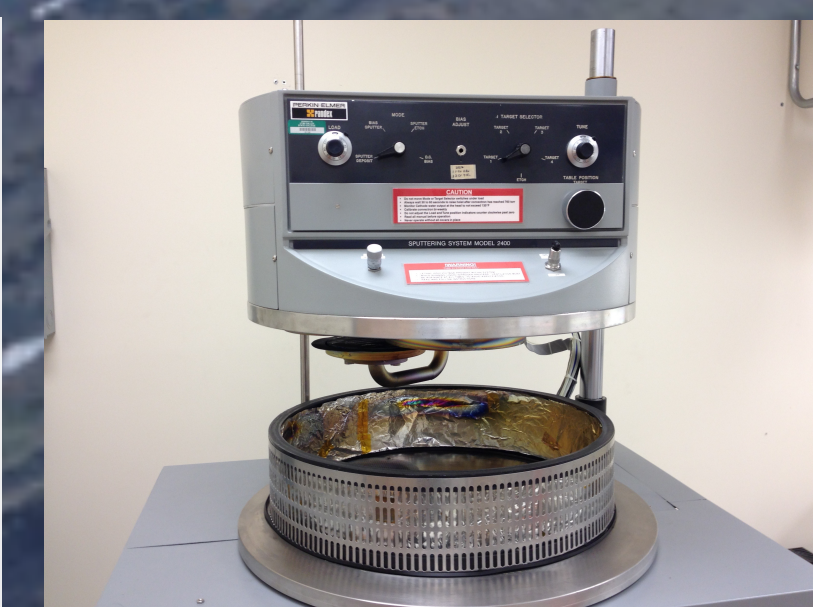
Thin films provide current to flow in a two-dimensional plane. By restricting the thickness of the conductors to small values, charge carriers are more likely to interact with the boundaries as they flow with the current. Nanowires, which limit the current into a nearly one-dimensional space, have been shown to exhibit higher resistivities when compared to their bulk counterparts [3]. It is anticipated that thin films will also exhibit higher resistivities when compared to bulk, although not as high as nanowires.

Departures of resistivity from bulk values are expected to occur when film thicknesses approach the mean free path of electron drift – which is in the nanometer range for most metals. Thus very thin films are required to see any effect.

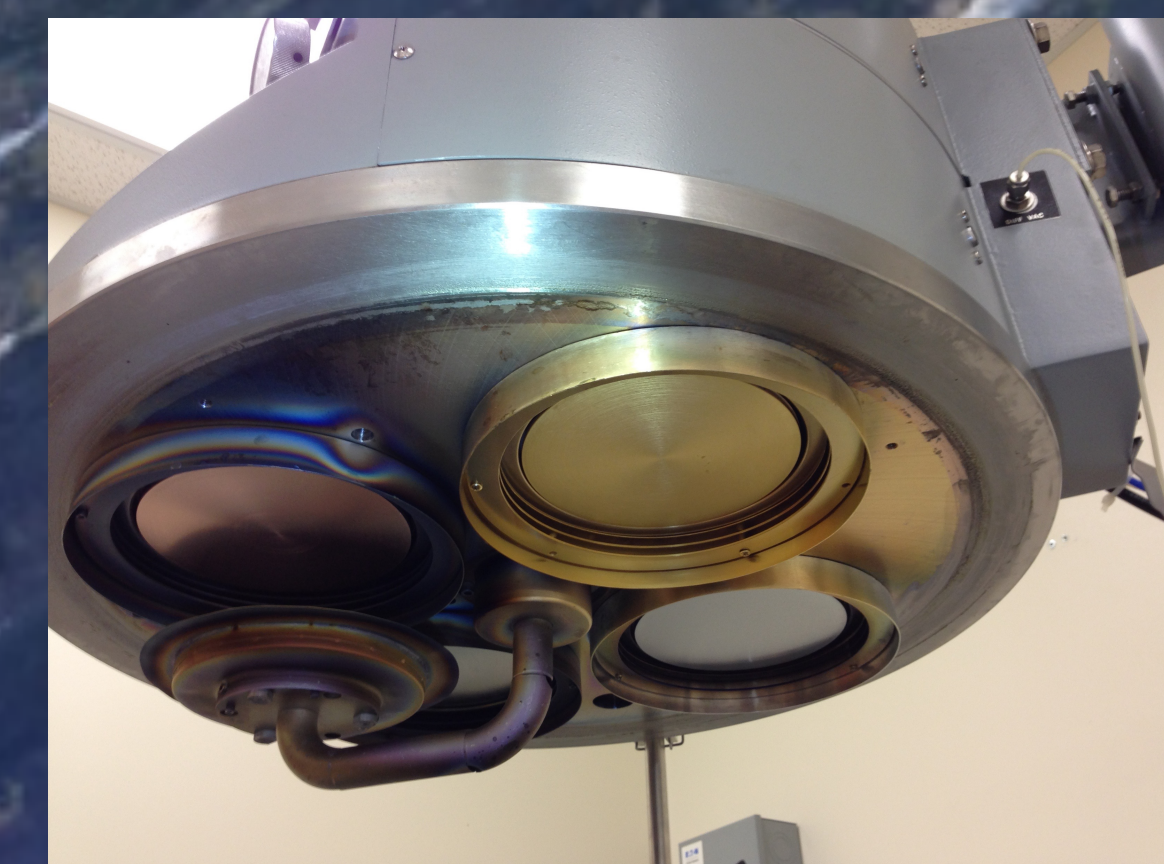
Experiment

Both groups started by creating gold films with their small Cressington sputter coater units. Then thin films of all three of Au, Ni and Cu were made at UVU with RF sputtering, changing the thicknesses by varying the exposure time. Samples were created on glass slides, with a short pre-coating of chromium (30 seconds) being necessary for the Au and Cu films in order to adhere to the glass. This was not needed for the Ni films. These samples were then analyzed for resistance and resistivity using a four point probe. The probe worked by having four probes pressed into the sample then running a measured current through the outside probes and measuring the voltage drop across the inside two probes. By doing this we were able to calculate and plot the resistance levels.

RF sputtering unit, with 6" targets

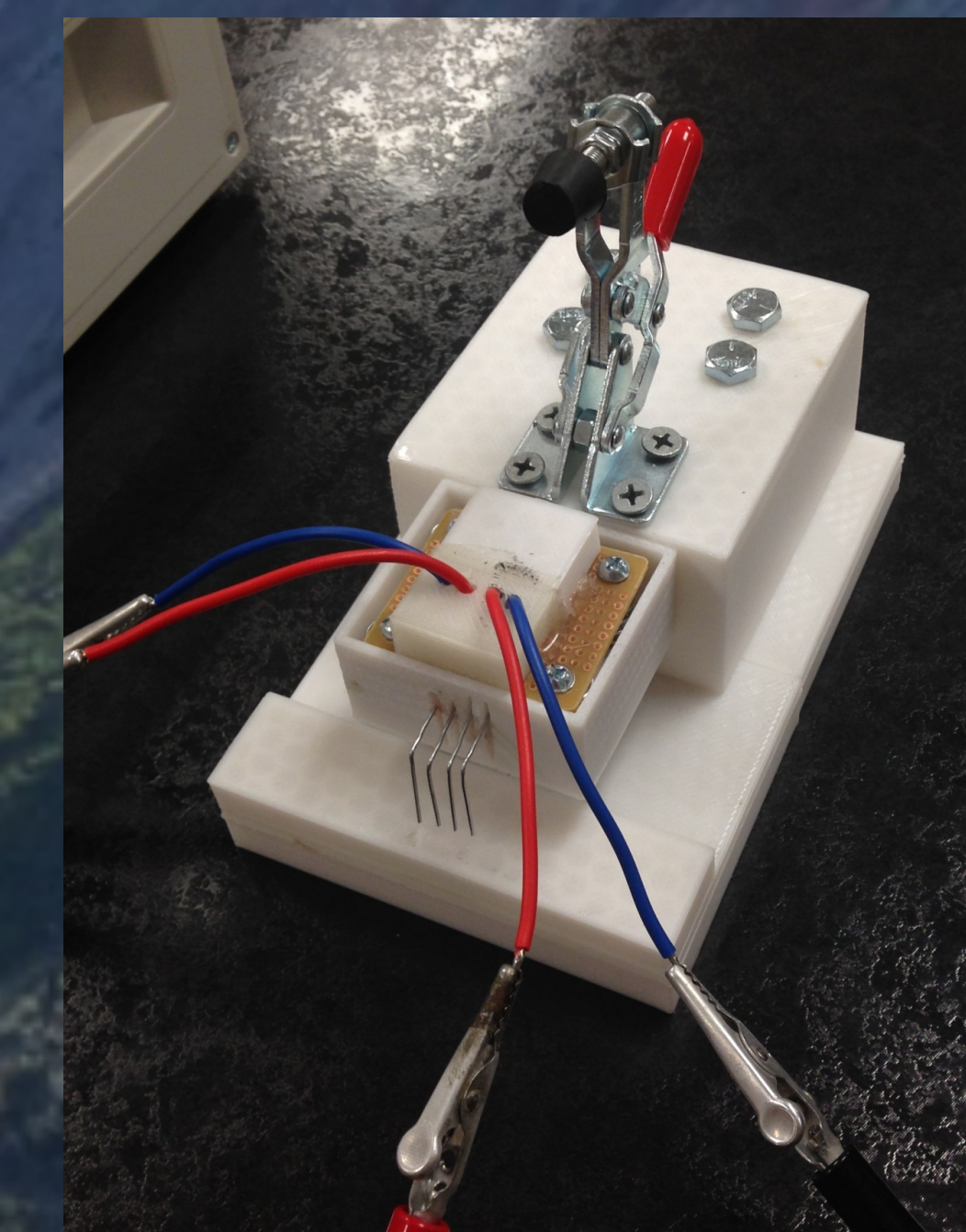


Samples of Au, Cu and Ni, produced on glass in panels, that aid in resistivity and profilometry measurements



Resistivity

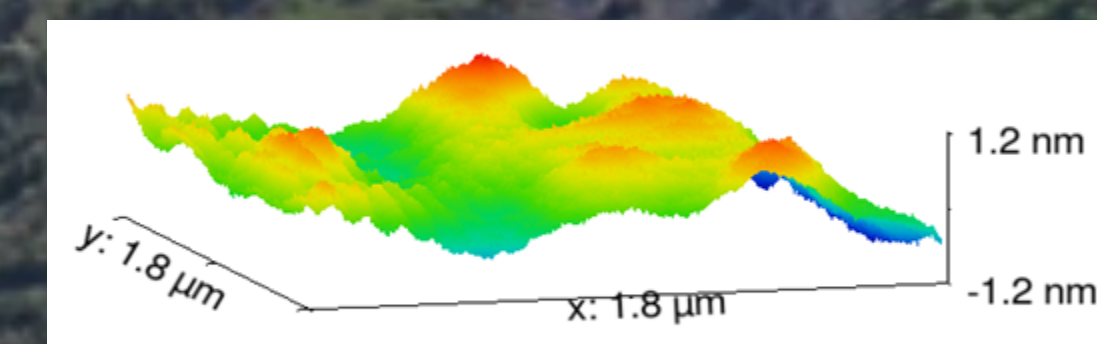
Four point probe resistance measurements were adjusted for sample plane dimensions and assessed thickness^[4].



4-Point Probe. Designed and 3D printed by Alex Farnsworth at DSU. Used to measure resistances in films

Measuring Thickness

Three reference samples were measured with a stylus profilometer (courtesy D. P. Pappas, NIST, Boulder, CO). All others were measured in reference to these, using the intensity of light transmission.



AFM IMAGE

Conclusion

Thin films of high quality have been produced, of varying thicknesses of nickel, gold and copper. A basic four-point probe was fabricated, and used to measure resistivity values that are somewhat higher than the bulk values, possibly indicating the effect of the boundaries. Fundamental differences in the electrical and sputter deposition properties of the Ni, Au and Cu were observed.

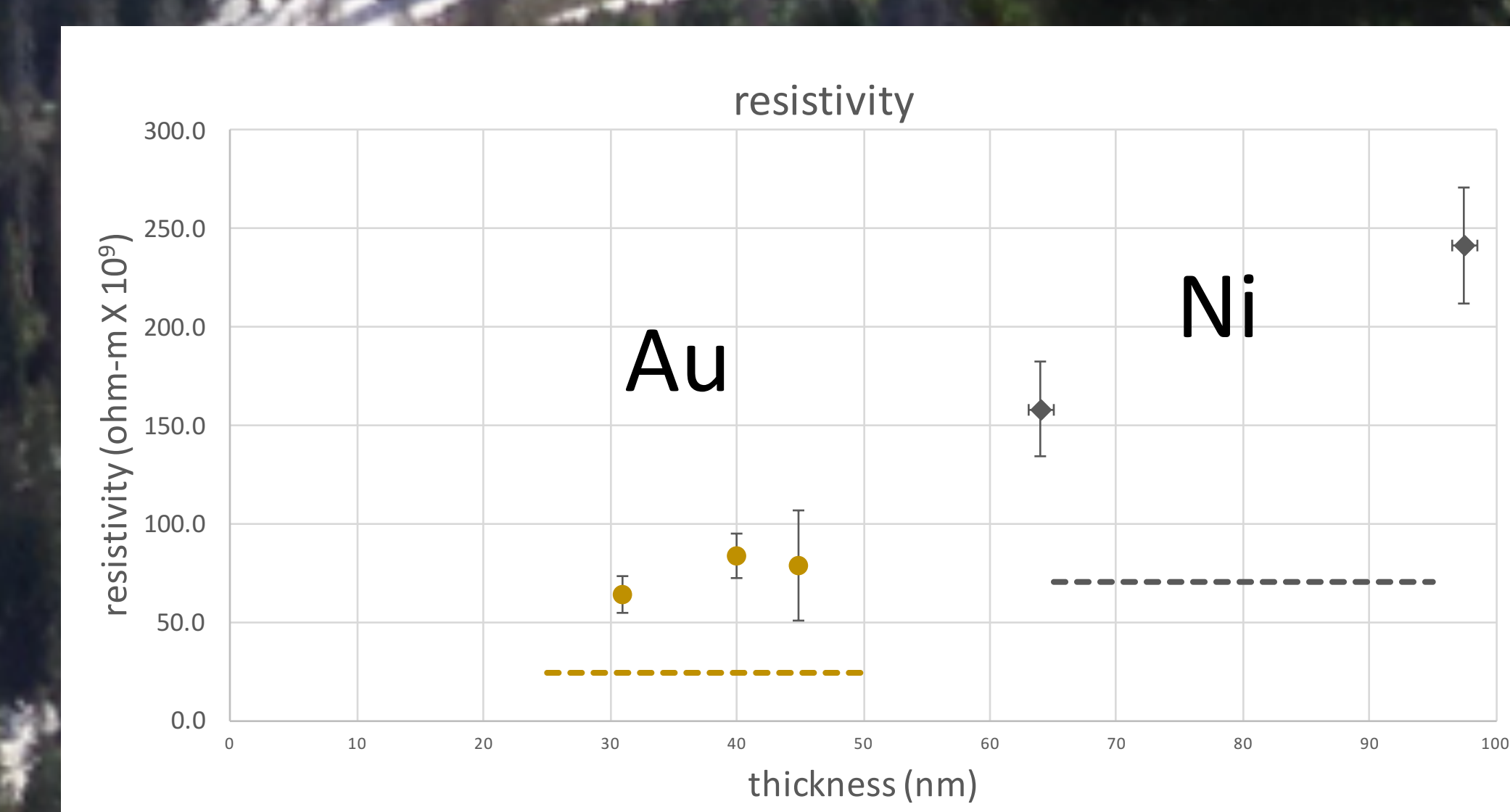
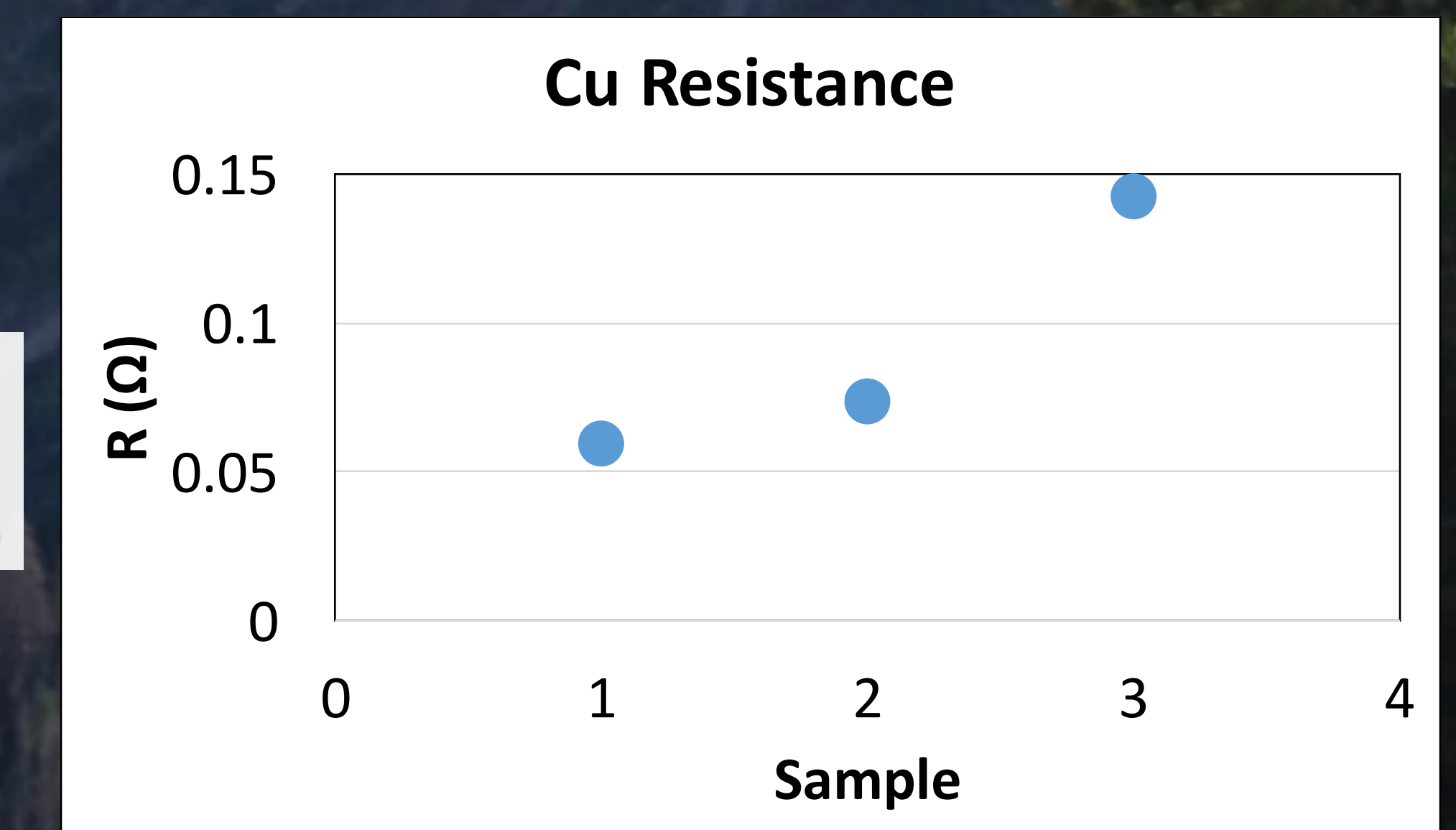
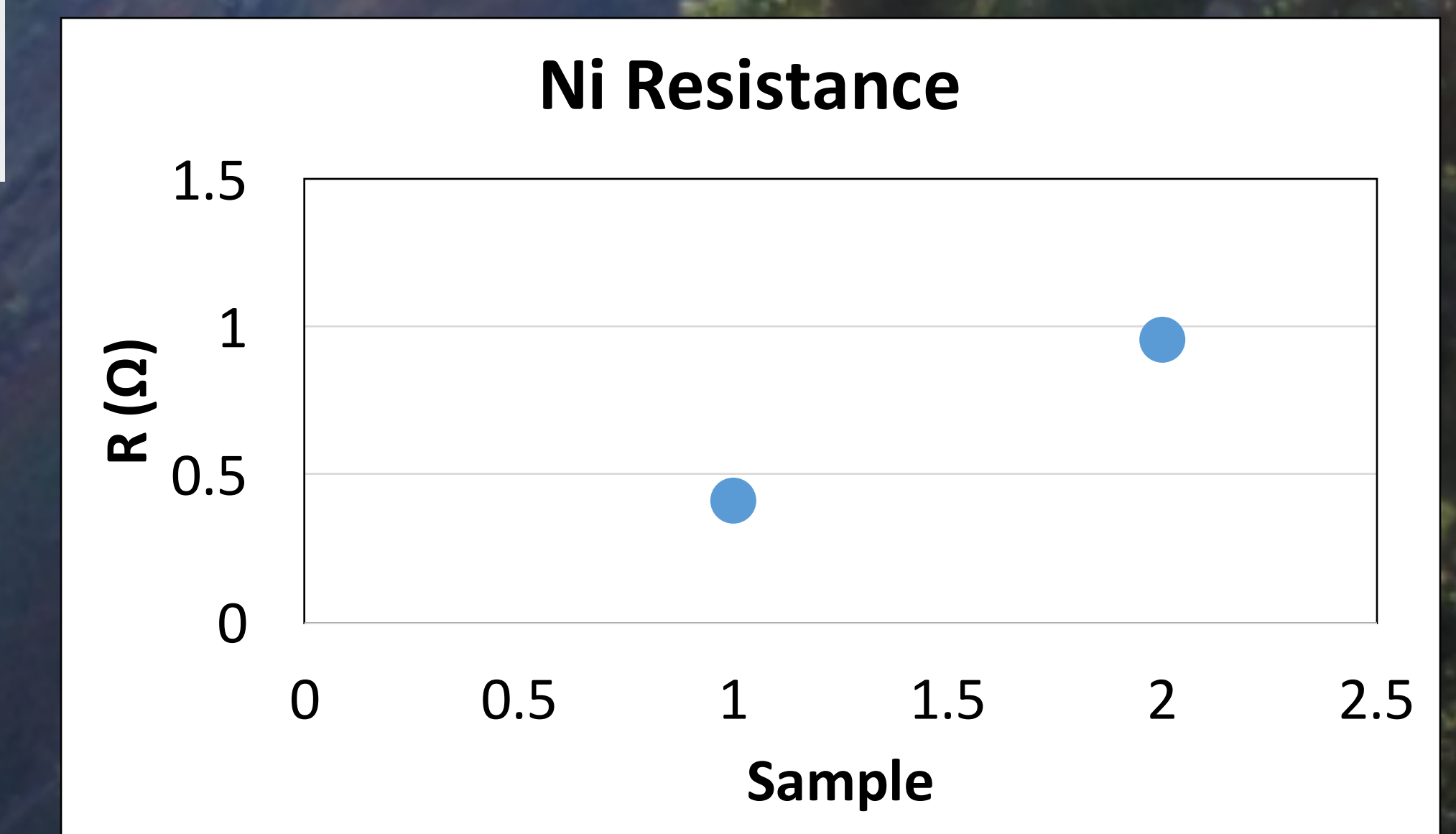
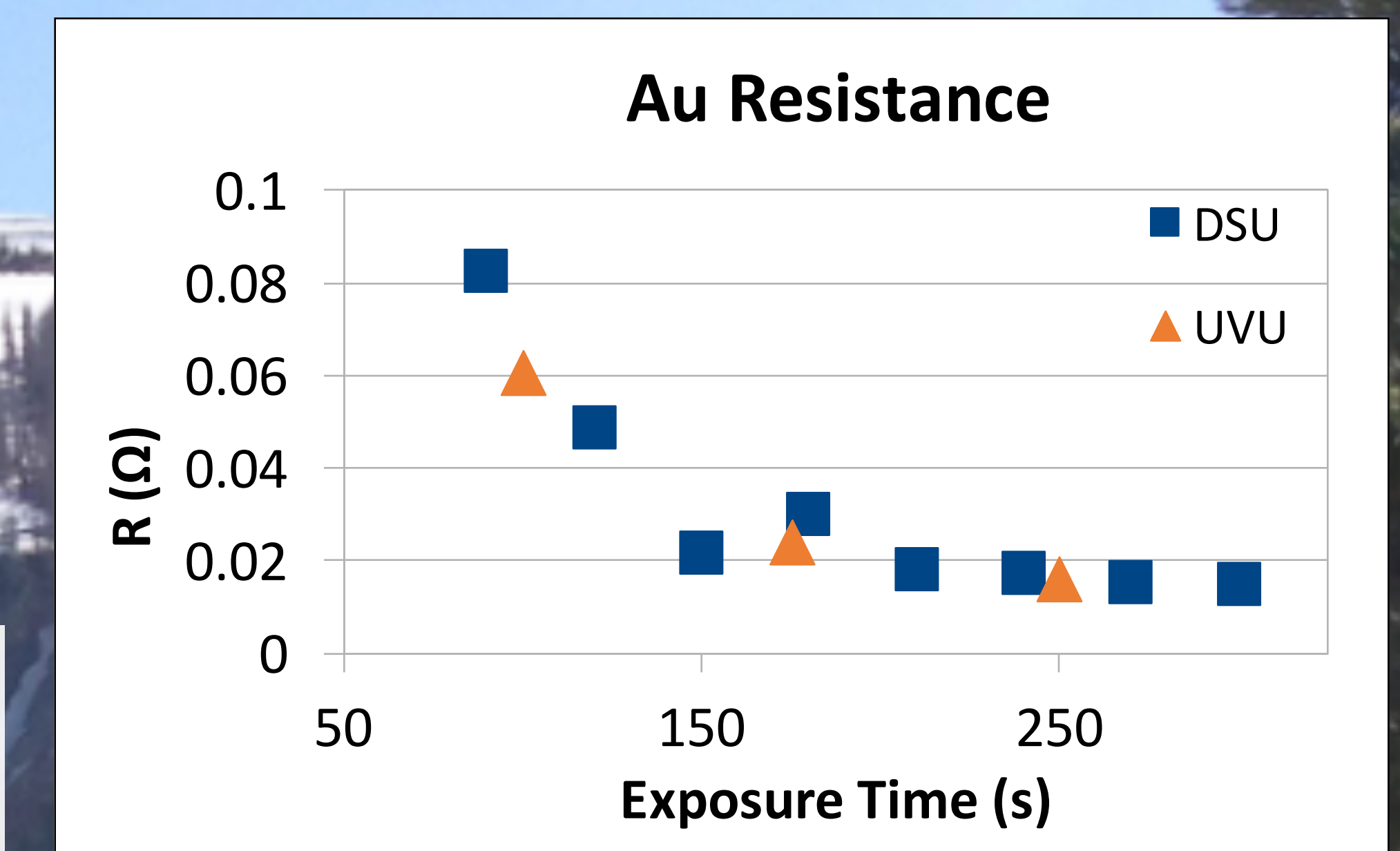
Future Research

There is great deal yet to be studied here. The sputtering process is being learned in great detail. Techniques for assessing thickness of the films at this minute level were developed, and can be used to aid in producing even thinner films where the boundary effects clearly show deviation from the bulk resistivity values.

References:

- [1] P. A. Bennett *et al.*, *Endotaxial Silicide Nanowires: A Review*, *This Solid Films*, 2011, p 8434-8440
- [2] L. Alvarez-Fraga *et al.*, *Indium-tin oxide thin films deposited at room temperature on glass and PET substrates: Optical and electrical properties variation with the H-2-Ar sputtering gas mixture*, *Applied Surface Science*, 2015, V. 344, p 217-222
- [3] Tobler, S. K., *Resistivity of Endotaxial Silicide Nanowires Measured with a Scanning Tunneling Microscope*, PhD Dissertation, ASU, 2011
- [4] F. M. Smits, *Measurement of Sheet Resistivities with the Four-Point Probe*, *Bell System Technical Journal* 37:3 (1958).

Data



Resistivities in Au and Ni films, compared to their bulk values, showing evidence of increased resistivity compared to bulk values (dashed lines).