Study of Isotropic and Anisotropic Electrical Conductivity

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ABSTRACT

The goal of the project is to determine the resistivity values of an isotropically conductive sample (copper) and an anisotropically conductive sample (crystalline graphite) to explore the difference in resistivity between isotropic and anisotropic materials. One would expect that an isotropic sample would have a resistivity matrix comprised of very similar values, indicating that there is little to no difference in the resistivity of the substance along different spatial axes. Conversely, one would expect that an anisotropic sample would have a resistivity matrix of markedly different values which would indicate differences in resistivity along different spatial axes. Exploring the anisotropic effect at different temperature ranges is a potential extension of the project. We predict that the anisotropic ratio will increase as temperature increases. The out of plane (c) lattice constant will increase more dramatically with an increased temperature than the in plane *(a)* lattice constant. Van der Waals forces are weaker than the sigma bonding forces, so with an increase in thermal motion this distance will be more mobile and less fixed than the *a* constant. The conductivity out-of-plane will decrease at higher temperature in comparison to the conductivity in-plane.

BACKGROUND

Anisotropicity is defined as having different properties when measured in different directions. An example of anisotropic material is graphite, an allotrope of carbon. Graphite's bulk crystalline structure is anisotropic: a pure crystal is comprised of stacked sheets of crystalline graphene held together by Van der Waals bonds, making the in plane and out of plane structure different. Anisotropic measurements have been done on both thermal conductivity and electrical conductivity. A pure crystal of graphite has sheets of graphene stacked parallel to each other, with the layers forming hexagonal structures (Krishnan).

The method for theoretically calculating resistivity and the resistivity matrix has a mathematical definition and the methods for calculating the values experimentally can be done with the use of four point probe. In an article written in 1939 published by *Nature*, scientists found that electrical conductivity along the basal plane of an axis was at least ten thousand times larger than conductivity along the normal to the plane (Krishnan). The anisotropy ratio, defined as out-of-plane resistivity over the in-plane resistivity, was 10^2 to 10^5 for graphite conductivity (Howe). However, while the researchers implied that the anisotropic conductivity was temperature dependent, it was not explicitly discussed.

METHODS

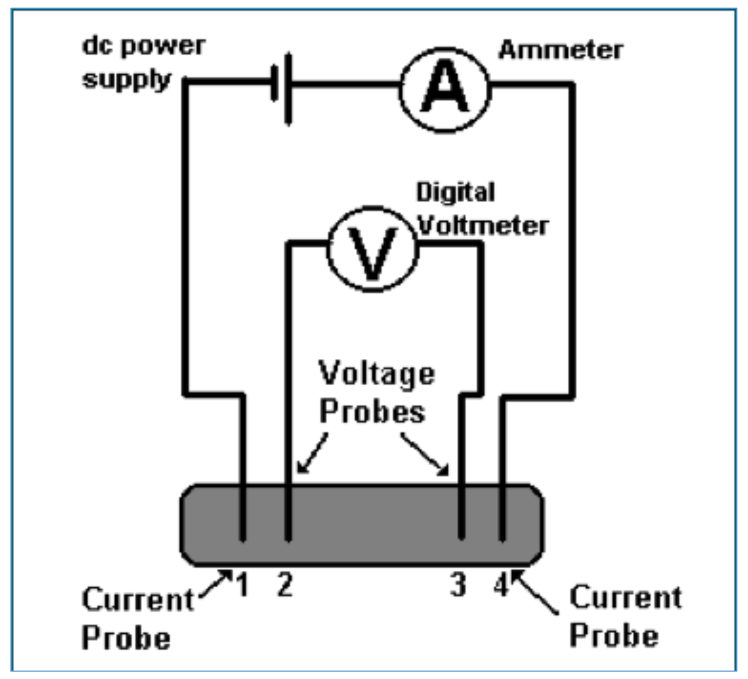

Figure 1: Four Point Probe Schematic

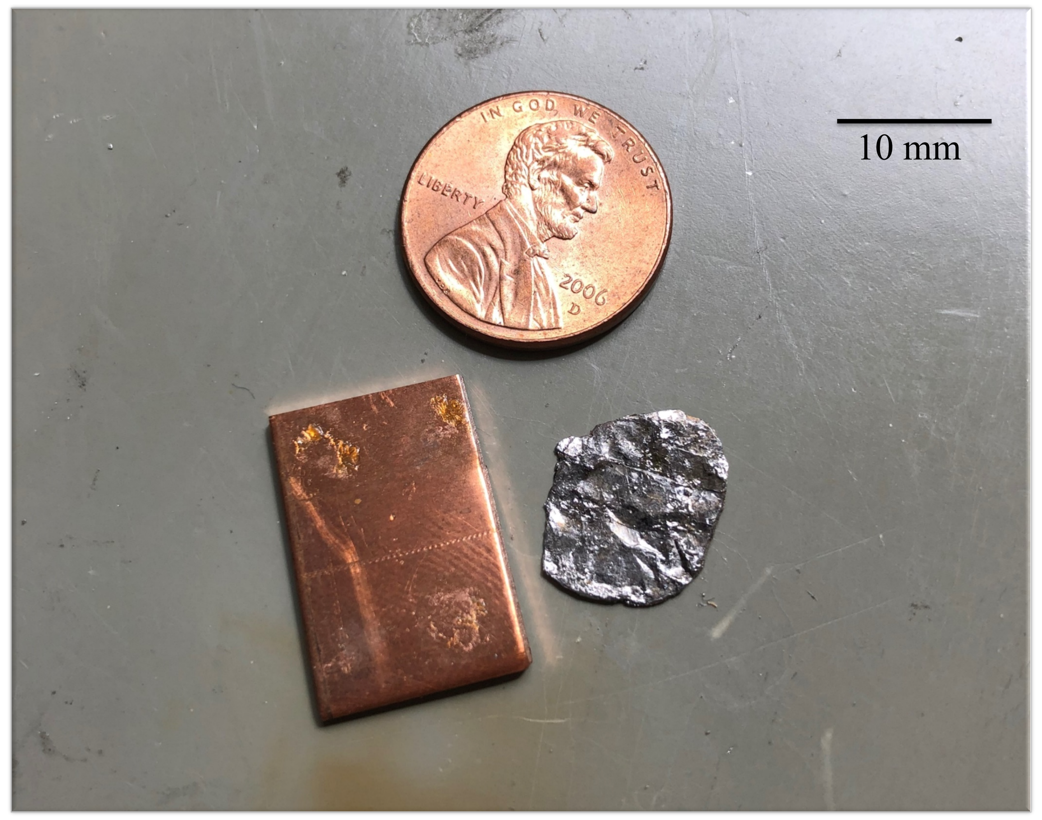

Figure 2: Samples of copper, graphite, and size comparison

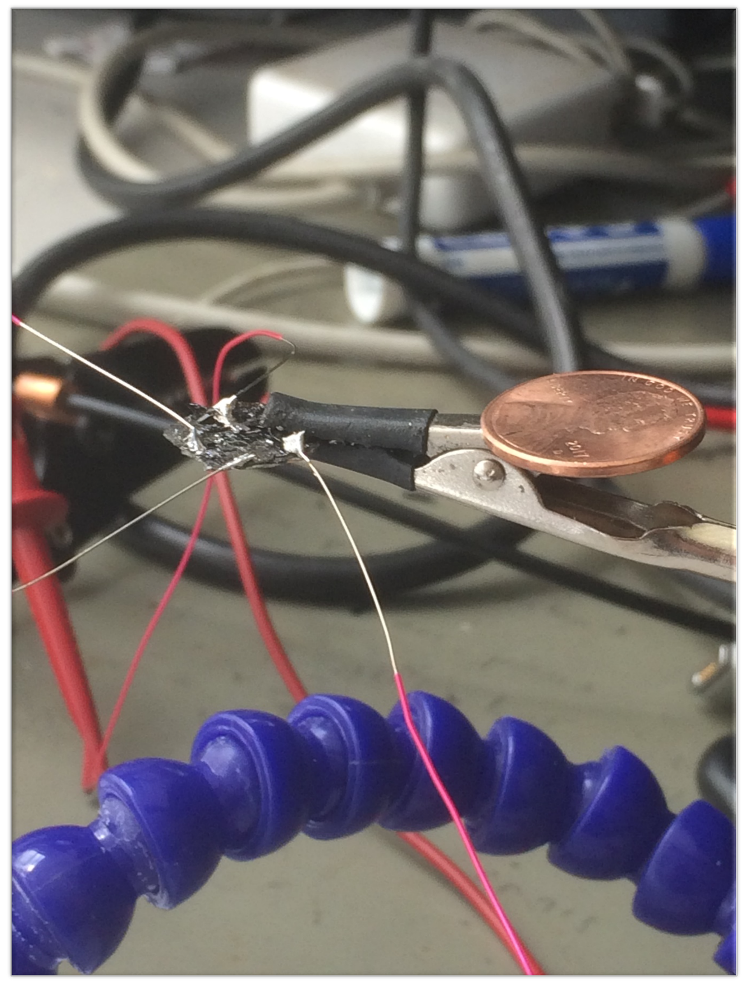

Figure 3: Graphite with wires soldered, measuring in-plane conductivity

RESULTS

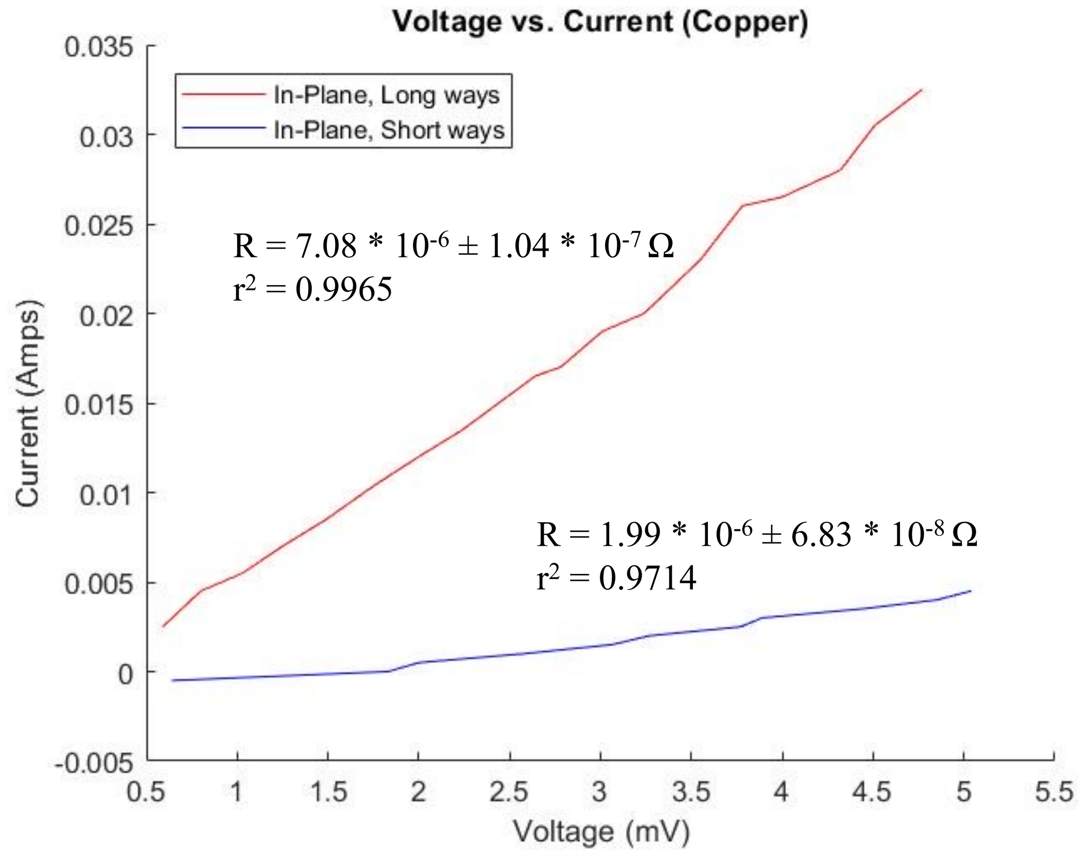

Figure 4: Voltage vs. Current Measurements for Copper

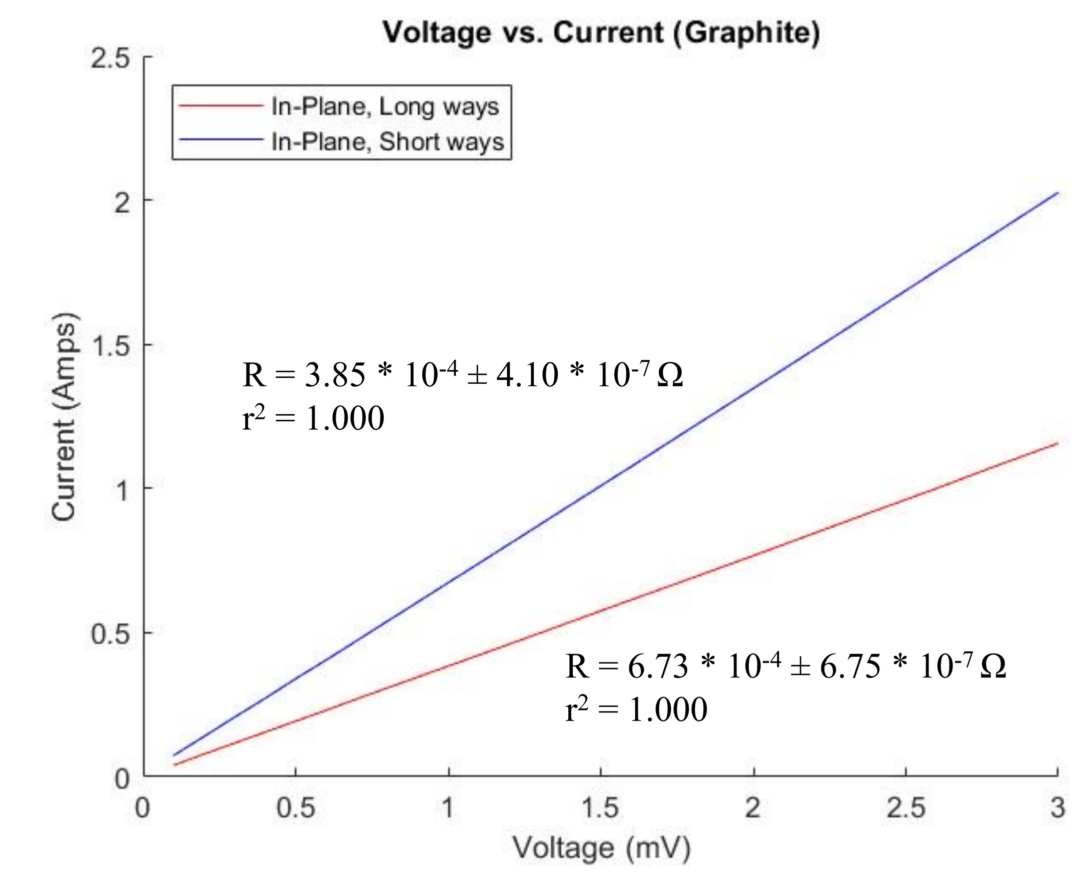

Figure 5: Voltage vs. Current Measurements for Graphite

$$V = I * R \qquad R = \frac{\rho L}{A}$$

ρ = resistivity
L = length
A = cross sectional area

Resistance is found as the slope of a linear regression plot of the V vs. I graph, and is then converted to resistivity using the measured dimensions of the samples.

$$\rho_{copper, long} = (6.07 \pm 0.0896) * 10^{-9}\ \Omega\ m$$
$$\rho_{copper, short} = (6.33 \pm 0.217) * 10^{-9}\ \Omega\ m$$

$$\rho_{graphite, long} = (2.80 \pm 0.00299) * 10^{-7}\ \Omega\ m$$
$$\rho_{graphite, short} = (3.33 \pm 0.00334) * 10^{-7}\ \Omega\ m$$

$$\frac{\rho_{copper, long}}{\rho_{copper, short}} = 0.958, \frac{\rho_{graphite, long}}{\rho_{graphite, short}} = 0.841$$

CONCLUSIONS

Copper showed isotropic behavior in-plane, as expected, with an anisotropy ratio near 1. Graphite surprisingly showed slightly anisotropic behavior in the planar measurements, which may be due to its crystal structure. Further testing would need to be done before conclusions can be made about the anisotropy of graphite.

FUTURE WORK

Given more time and different equipment, we would endeavor to first explore the out-of-plane resistivities of copper and graphite, possibly using a different method for making electrical contacts. To calculate an anisotropy ratio for the in-plane resistivity compared to the out-of-plane resistivity would have require extra measurements that we were not able to make due to time constraints, soldering issues, and limitations of the accuracy of the equipment used. Second, we would endeavor to explore the effect of temperature on resistivity and the anisotropy ratio of both copper and graphite.

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