Finding the Resistivity of thin Films using the van der Pauw Method

Hugh Graham, University of the South

Abstract

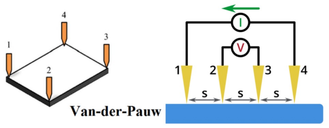
Thin resistivities of conducting and semiconducting materials were measured. The samples are thin films between 12μm and 50m thick, including aluminum, copper, silicon, and graphene. These included rectangles and squares of uniform thickness, as well as other symmetrical shapes that satisfy Van der Paw's method. This measurement technique allows a straight-forward method for determining the resistance of a square with a set of specific measurements of the resistance of the thin film. Four contacts were made on the edges of each material and the resistance between any two sets of contacts were used to determine the resistance of the square. From this the resistivity of the material is calculated. Samples included squares, rectangles, and squares with holes. The holes, which violate one important criterium for the Van der Pauw method, have been carefully studied by Chenfei Miao, who modeled them using infinite matrices.

Motivation

- Graphene is a material with incredible applications and is finally able to be produced.
- Studying the resistivity of this material will give insight to the quality of material we are dealing with.
- Measuring thin films will give insight on how different materials conduct and how to deal with small resistances

Process

1. Choosing a Method and Technique



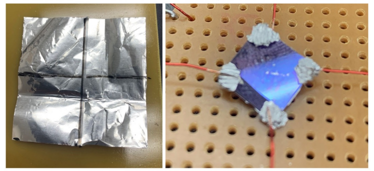
Just Using Ohm's law

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

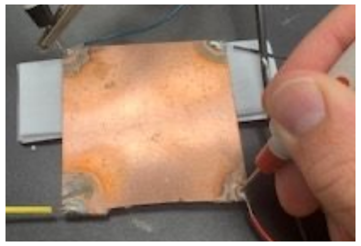
Findings:

Material:	Resistance:
Copper	0.056Ω
Aluminum(no hole)	0.055Ω
Aluminum(any hole size)	0.056Ω
Silicon	0.082Ω
Any Material	≈0.06Ω?

2. Sample Creation and Testing



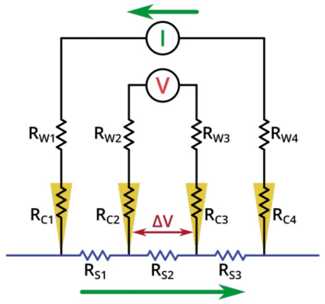
Aluminum foil and Silicon samples



Measuring resistance conventionally with a voltmeter and low-ohm contacts

Have we found some kind of engineering coincidence? No. Though we can measure up to 6.5 significant digits, we fail to eliminate contact resistances which remain larger than sheet resistances. We need a way to measure smaller Resistances without worrying about our contacts.

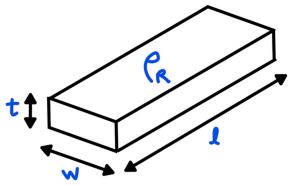
Eliminating Contact Resistance



Electrical diagram of four-point circuit

Four Points Theory

Assumptions:



$$E = \rho * J$$

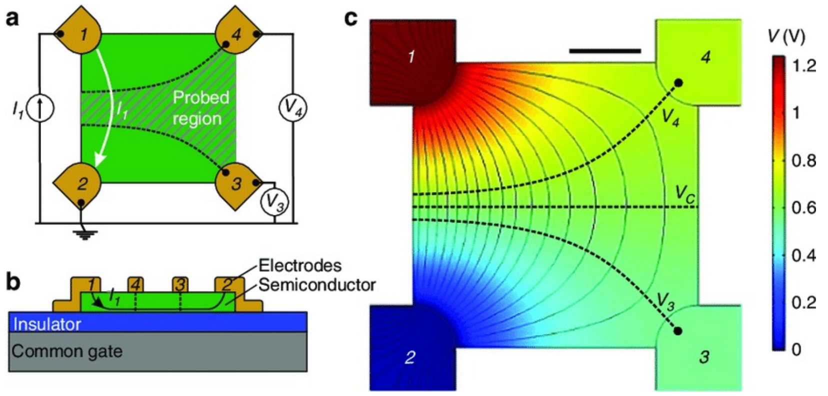
$$J = \frac{I}{w \cdot t}$$

$$\rho = R_{\square} \cdot t$$

$$\boxed{R_s = \frac{\pi}{ln(2)}\frac{\Delta V}{I} = 4.52336\frac{\Delta V}{I}}$$

This method eliminates contact resistances since only negligible current runs through the Voltmeter. The method, however, must be refined in order to study unique sheets.

van der Pauw Method



Method only requires that contacts are placed at the circumference of the sample, and that they are sufficiently small.

$$e^{-(\pi R_{AB,CD} d/\rho)} + e^{-(\pi R_{AD,BC} d/\rho)} = 1$$

Measuring 7cm x 10cm copper:

I (A)	ΔV (mV)
1.002	0.88
1.003	0.881
1.007	0.882
1.002	0.88
1.005	0.056
1.006	0.059
1.005	0.057
1.001	0.058

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

R (mOhm)
0.8782435
0.8783649
0.8758689
0.8782435
0.0557214
0.0586481
0.0567164
0.0579421

R2(avg): 8.777e-4Ω

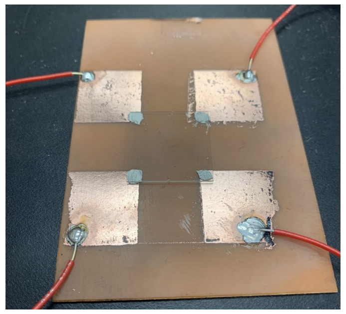
R1(avg): 5.723e-5Ω

	Copper:
sample size:	ρ(nΩ*m): (+/- 0.5)
15cm*10cm	18.12
10cm*7cm	18.53
7cm*7cm	18.43
avg:	18.36
(Brittanica)	17.7

Our method has averaged a 3.72% difference from the accepted value of Resistivity for copper, even taking different shapes of material into account. While the value lays slightly outside our error range, this can likely be attributed to uneven thickness of our copper layer, which was found to be under 1/3 its advertised thickness. Now, we can move on toward studying more difficult materials.

Using Graphene:

Printing toner, ironed onto a sheet of copper



Graphene placed on top of the copper contacts

PCB toner transfer paper was used to create a pattern to hold our graphene sample. Once the pattern was ironed onto a copper board, the board was immersed in Ferric Chloride to dissolve the bare copper. The protecting toner was then scraped off with steel wool. Finally, a 1in^2 sheet of graphene was placed atop the copper contacts with a conducting layer of silver epoxy making electrical connection.

$$\rho_{graphene} = 3.24 \text{ +/-} 0.2 \text{ n}\Omega\text{*m}$$

Analysis/Conclusions:

	ρ (nΩ*m)	univ. values:
copper	18.36	17.7
aluminum	30.019	26.5
silicon	34100	N/A
graphene:	3.24	20

Resistivity values for copper, aluminum foil, doped silicon, and graphene were measured. The method proved to work well for our copper and aluminum samples, though there was a large deviation for our graphene compared to what others have found. The largest source of error for the graphene was the thickness, which lacked uniformity due to its poor quality. The thicknesses of the copper and aluminum were difficult to measure due to their thin nature, with the most accurate value being measured by dissolving off the copper layer and using the mass difference. With the success with the other materials, it can be concluded that our method would produce reliable results for better quality graphene.

References and Thanks:

I'd like to thank Dr. Peterson for his invaluable help on this project, as well as the Physics department for their support.

- L.J van der Pauw, Feb. (1958) A method of measuring specific Resistivity and Hall effect of Discs of arbitrary Shape. Research Laboratory of N.V Philips Gloeilampenfabrieken, Eindhoven, Netherlands
- Rolin, Cedric & Kang, Enpu & Lee, Jeong-Hwan & Borghs, Gustaaf & Heremans, Paul & Genoe, Jan. (2017). Charge carrier mobility in thin films of organic semiconductors by the gated van der Pauw method. Nature Communications. 8. 14975. 10.1038/ncomms14975.
- https://www.energy.gov/eere/ssl/articles/doe-publishes-2022-solid-state-lighting-rd-opportunities
- Metalgrass LTD. Graphene-Catalog. What is Graphene? https://www.graphene-info.com/graphene-introduction
- Oscilla. Calculate Sheet Resistance Using the Four-Probe Method