# 4-POINT PROBE MEASUREMENTS OF EVAPORATED ALUMINUM

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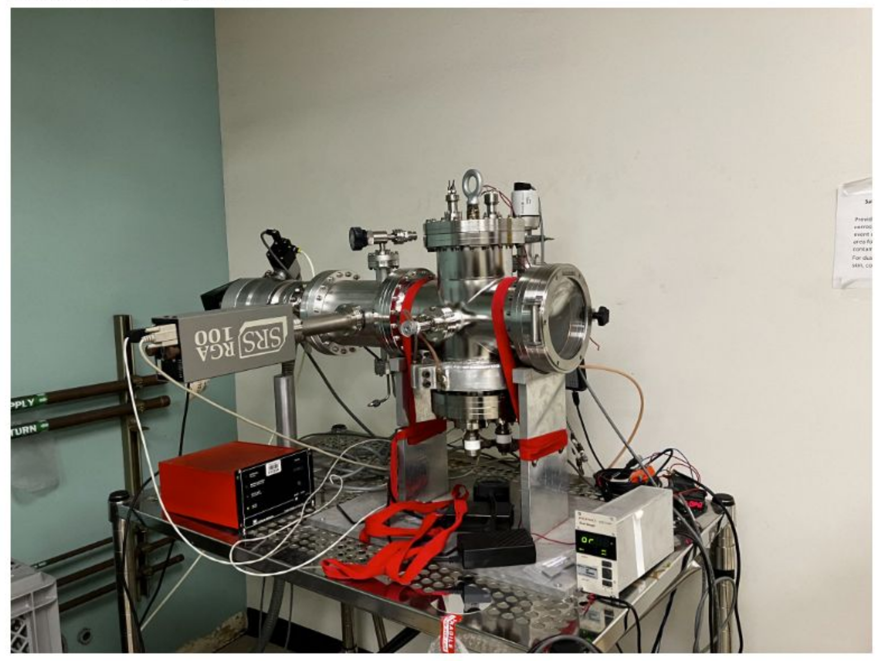
## Introduction

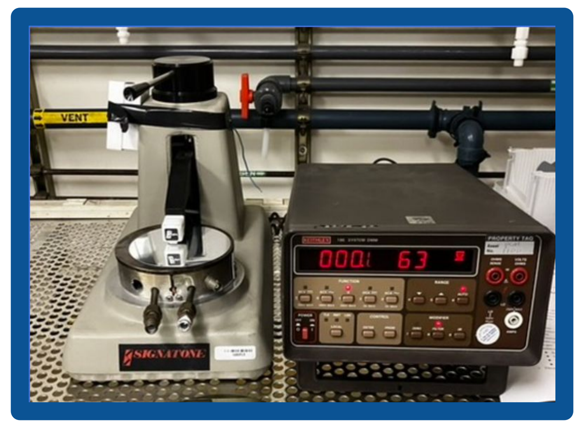
The experiment sought to answer two major questions. Firstly, it wanted to know if there was a noticeable change in resistance by the machine over time. Secondly, it wished to figure out if there was a warm-up time for the machine, and if so, how long the warm-up time was and how that affected the results.

ASIC Picture From Tiny Tape:

Picture of our evaporator:



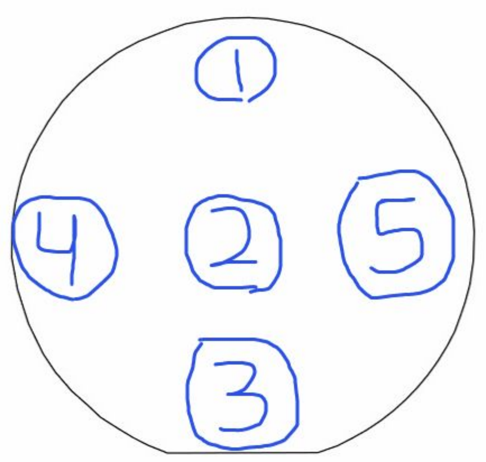
## Methods



A four-point probe is a device commonly used to determine the electrical resistance of different thin films of various types. Thin films are usually located on the surface of a semiconductor. Thin films are materials deposited on the surface of substrate (semiconductor) that have a thickness measured in angstroms (10^ -10 meters). The electrical resistivity of a material can be defined by the equation $r = (rho/t) * (W/L)$, where $rho$ represents the electrical resistivity, in Ω * m (Ohm-meters), and $t$ represents the thickness of a particular wafer (in mm). The four-point probe measures equal width and length, so the $(W/L)$ part of the equation cancels out. Therefore, the electrical resistivity is also called resistance per unit squared, as all the other values and units cancel out. To measure the electrical resistance, a four-point probe is used by channeling current through two outer probes and then reading the voltage across two inner probes. Then, Ohm's law ($V = IR$) can be used to measure the resistance by dividing the measured voltage by the produced current ($R = V/I$).

For the experiment, the following steps were performed:

1. For each set of measurements, the resistance at each of the 5 areas shown was measured. However, the exact same spot was not measured for each area, so that some natural variation would be present.
2. 100 sets of such measurements were performed, with each set taking about 1.5 minutes. There was also a 30-second break between each set of measurements.




## Results

Trials 1-10

| 2 | Time (min) | Position 1 | Position 2 | Position 3 | Position 4 | Position 5 |
|---|---|---|---|---|---|---|
| 3 | 0 | 0.0232 | 0.0186 | 0.0227 | 0.0273 | 0.0145 |
| 4 | 1.5 | 0.0208 | 0.0158 | 0.02 | 0.0245 | 0.0129 |
| 5 | 3 | 0.0178 | 0.0147 | 0.0205 | 0.0244 | 0.0123 |
| 6 | 4.5 | 0.0183 | 0.0143 | 0.0188 | 0.0234 | 0.0123 |
| 7 | 6 | 0.0188 | 0.0151 | 0.0191 | 0.0245 | 0.012 |
| 8 | 7.5 | 0.0185 | 0.0147 | 0.0185 | 0.0247 | 0.0121 |
| 9 | 9 | 0.0183 | 0.0151 | 0.0191 | 0.0247 | 0.0122 |
| 10 | 10.5 | 0.0183 | 0.0143 | 0.02 | 0.0232 | 0.0124 |
| 11 | 12 | 0.0168 | 0.0145 | 0.0178 | 0.0232 | 0.0124 |
| 12 | 13.5 | 0.0183 | 0.015 | 0.0176 | 0.025 | 0.0122 |
| 13 | 15 | 0.0187 | 0.0159 | 0.0201 | 0.0242 | 0.0123 |

Mean and Median values for Positions 1-5 (from left to right):

| | | | | | |
|---|---|---|---|---|---|
| **Mean** | 0.01762277228 | 0.01407524752 | 0.01892178218 | 0.0239019802 | 0.01130891089 |
| **Median** | 0.0176 | 0.014 | 0.0186 | 0.024 | 0.011 |

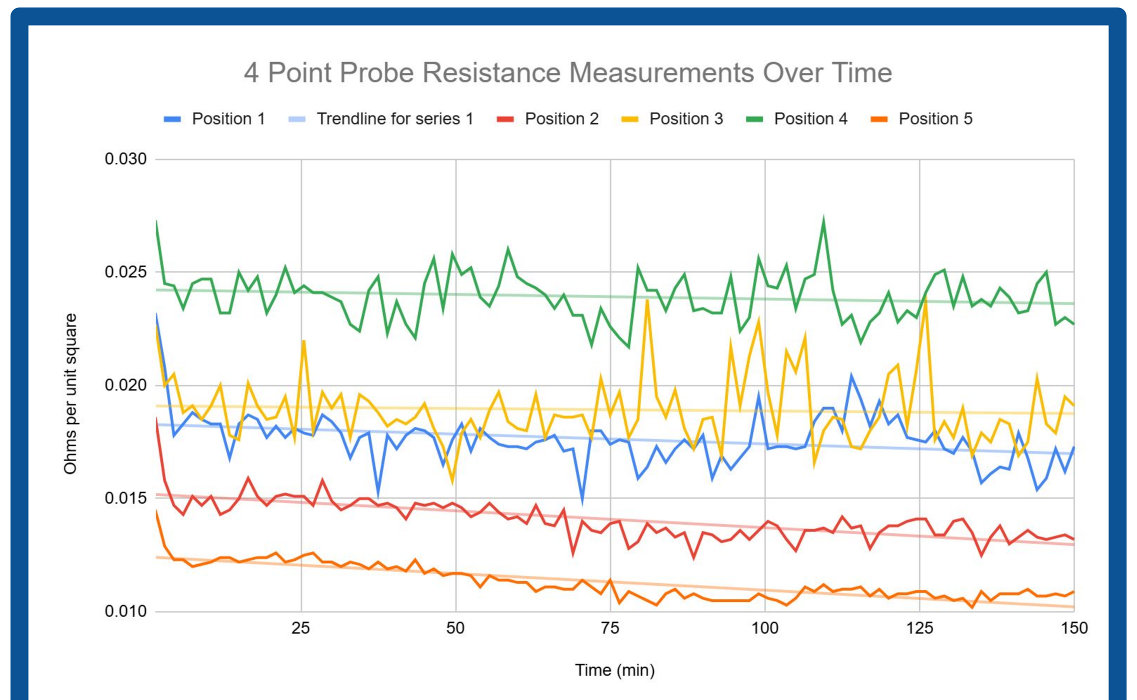
Standard deviation values for Positions 1-5 (from left to right) and the linear regression results for Positions 1-5:

| | | | | | |
|---|---|---|---|---|---|
| **Std. Deviation** | 1.11E-03 | 8.74E-04 | 1.47E-03 | 1.06E-03 | 7.61E-04 |
| | | | | | |
| | **Linear Regression** | | | | |
| | **Reg. Coeff.** | **Y-Intercept** | | | |
| **P1** | -8.65E-06 | 1.83E-02 | | | |
| **P2** | -1.46E-05 | 1.52E-02 | | | |
| **P3** | -2.38E-06 | 1.91E-02 | | | |
| **P4** | -4.50E-06 | 2.42E-02 | | | |
| **P5** | -1.45E-05 | 1.24E-02 | | | |

In general, a decrease in resistance was observed when trendlines were fitted to the resistance values for each of the five positions. It was also observed that for positions 2 and 5 on the four-point probe, the resistance values were much more consistent than the other positions, and seemed to flatten over time. Another trend was that there was more variation in the resistance values when the alumnimum (thin-film) layer was thinner. This suggests that film thickness plays an important role in the stability and uniformity of resistance across the surface, with thinner films contributing to increased variability in measurements.

Trials 90-100:

| | | | | | | |
|---|---|---|---|---|---|---|
| 93 | 135 | 0.0161 | 0.0133 | 0.0175 | 0.0235 | 0.0105 |
| 94 | 136.5 | 0.0164 | 0.0138 | 0.0185 | 0.0243 | 0.0108 |
| 95 | 138 | 0.0163 | 0.013 | 0.0183 | 0.0239 | 0.0108 |
| 96 | 139.5 | 0.0179 | 0.0133 | 0.0169 | 0.0232 | 0.0108 |
| 97 | 141 | 0.0168 | 0.0136 | 0.0175 | 0.0233 | 0.011 |
| 98 | 142.5 | 0.0154 | 0.0133 | 0.0203 | 0.0245 | 0.0107 |
| 99 | 144 | 0.0159 | 0.0132 | 0.0183 | 0.025 | 0.0107 |
| 100 | 145.5 | 0.0172 | 0.0133 | 0.0179 | 0.0227 | 0.0108 |
| 101 | 147 | 0.0162 | 0.0134 | 0.0195 | 0.023 | 0.0107 |
| 102 | 148.5 | 0.0173 | 0.0132 | 0.0191 | 0.0227 | 0.0109 |
| 103 | 150 | 0.017 | 0.0137 | 0.0184 | 0.0225 | 0.0107 |




## Conclusions

From the data, the experiment found that for all 5 positions, the coefficient of linear regression (slope) was smaller than the standard deviation between the resistance values. This suggests that the observed decrease in the resistance values for each position, while present, is relatively minor compared to the inherent variability of the measurements. The experiment discovered that thinner films create more "noise" or variability in resistance than thicker films. One possible reason for these findings could have been the fact that the 4-point probe requires a 2-hour warmup period. This was indicated in the slight dip that was present in the graphs for the 5 positions at the start of the experiment. If the experiment were to be repeated, it would be performed a few hours after the probe is turned on, so that the measurements are even more accurate.

## References

https://www.sciencedirect.com/topics/materials-science/thin-films#:~:text=It%20involves%20condensation%20of%20atoms,molecule%2C%20or%20layer%20by%20layer.

https://mail.google.com/mail/u/0?ui=2&ik=168c07bb3e&attid=0.1&permmsgid=msg-f:1829603036719184363&th=19640e44ab9f79eb&view=att&disp=inline&realattid=f_m9kjw1p30&zw

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