

8

2.Lab Report

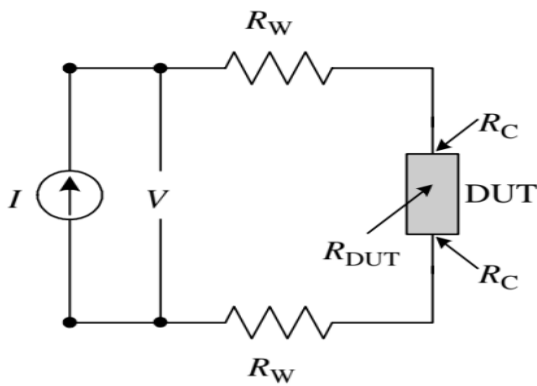
Resistivity Measurements, Mobility Measurements

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Resistivity measurements:

Theory:

1. Two terminal measurements



R_W : voltmeter internal resistance

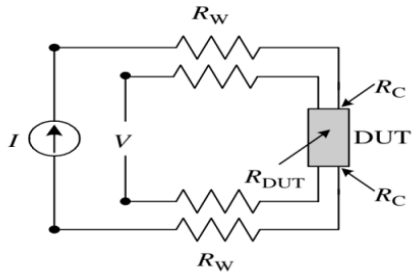
R_C : contact resistance

R_{DUT} : resistance of device under test

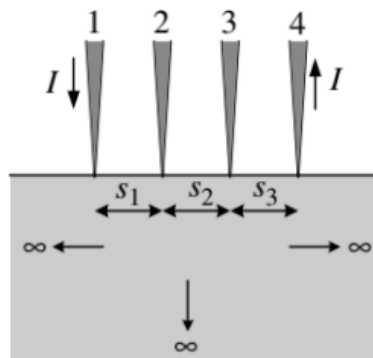
$$R_T = V/I = 2R_W + 2R_C + R_{DUT}$$

2. four terminal measurements

Objective

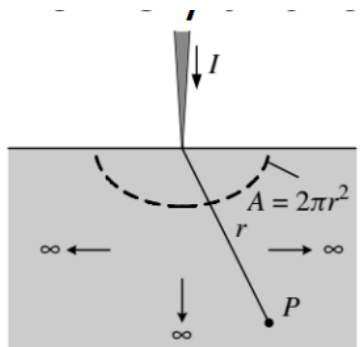


➔ Pass the current from 1 and 4 probes and measure the voltage across the 2 and 3 terminals



s_1, s_2, s_3 spacing between probes, for simplicity let us take spacing between them is equal

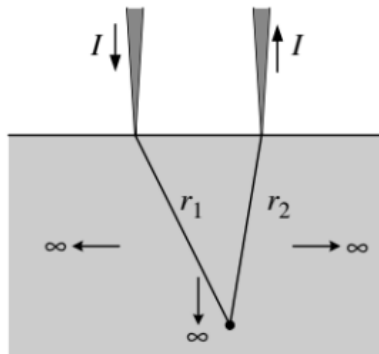
➔ Let us take a simple case



Here r is the radius until p point

$$\mathcal{E} = J\rho = -\frac{dV}{dr}; \quad J = \frac{I}{2\pi r^2}$$

$$\int_0^V dV = -\frac{I\rho}{2\pi} \int_0^r \frac{dr}{r^2} \Rightarrow V = \frac{I\rho}{2\pi r}$$



Apply superposition

$$V = \frac{I\rho}{2\pi r_1} - \frac{I\rho}{2\pi r_2} = \frac{I\rho}{2\pi} \left(\frac{1}{r_1} - \frac{1}{r_2} \right)$$

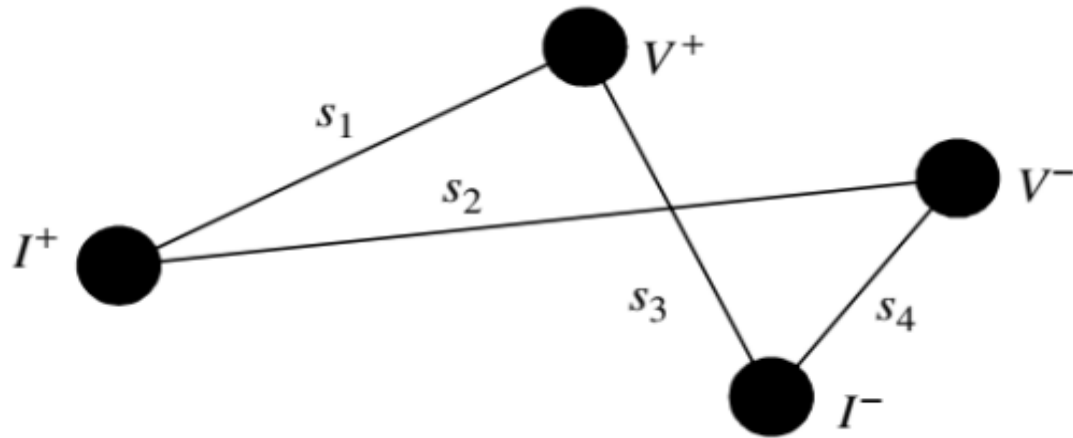
$$V_2 = \frac{I\rho}{2\pi} \left(\frac{1}{s_1} - \frac{1}{s_2 + s_3} \right)$$

$$V_3 = \frac{I\rho}{2\pi} \left(\frac{1}{s_1 + s_2} - \frac{1}{s_3} \right)$$

$V = V_2 - V_3$

$$\rho = \frac{2\pi}{(1/s_1 - 1/(s_1 + s_2) - 1/(s_1 + s_2) + 1/s_3)} \frac{V}{I} = 2\pi s \frac{V}{I}$$

For a sample with finite thickness t



$$\mathcal{E} = J\rho = \frac{I\rho}{2\pi r t} = -\frac{dV}{dr}$$

$$\int_{V_{s1}}^{V_{s2}} dV = -\frac{I\rho}{2\pi t} \int_{s1}^{s2} \frac{dr}{r} \Rightarrow V_{s1} - V_{s2} = V_{12} = \frac{I\rho}{2\pi t} \ln\left(\frac{s_2}{s_1}\right)$$

$$V_{34} = -\frac{I\rho}{2\pi t} \ln\left(\frac{s_3}{s_4}\right) \quad V = V_{12} - V_{34} = \frac{I\rho}{2\pi t} \ln\left(\frac{s_2 s_3}{s_1 s_4}\right)$$

- For colinear arrangement $s_1 = s_4 = s$ and $s_2 = s_3 = 2s$

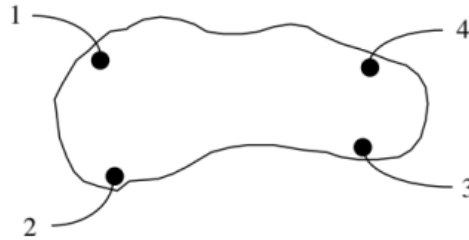
$$\rho = \frac{\pi t}{\ln(2)} \frac{V}{I} = 4.532t \frac{V}{I}$$

Van der Pauw method:

→ If the samples are in arbitrary shaped

Pass current from 1,2, and measure voltage between 3,4

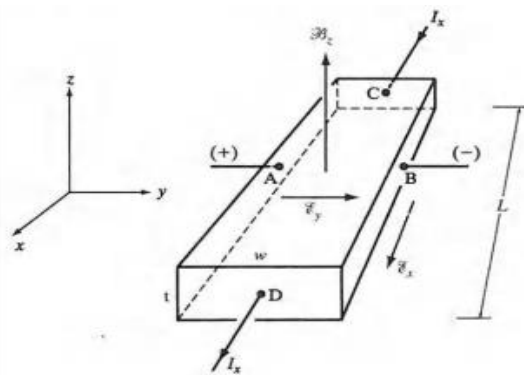
Pass current from 2,3 and measure voltage between 1,4



$$R_{12,34} = \frac{V_{34}}{I_{12}} \quad \rho = \frac{\pi}{\ln(2)} t \frac{(R_{12,34} + R_{23,41})}{2} F$$

$$e^{-\frac{\pi t R_{12,34}}{\rho}} + e^{-\frac{\pi t R_{23,41}}{\rho}} = 1$$

Hall effect

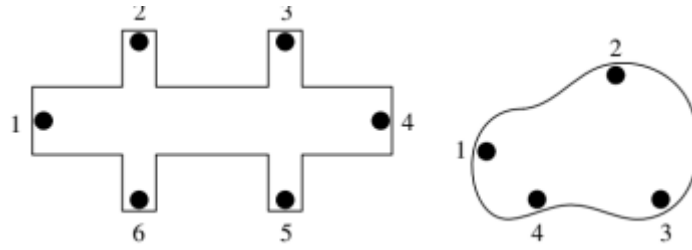


$$\mathbf{F} = q(\mathcal{E} + \mathbf{v} \times \mathcal{B}) \quad F_y = q(\mathcal{E}_y - v_x \mathcal{B}_z)$$

$$\mathcal{E}_y = v_x \mathcal{B}_z = \frac{J_x}{q p_0} \mathcal{B}_z = R_H J_x \mathcal{B}_z, \quad R_H \equiv \frac{1}{q p_0}$$

$$p_0 = \frac{1}{q R_H} = \frac{J_x \mathcal{B}_z}{q \mathcal{E}_y} = \frac{(I_x / w t) \mathcal{B}_z}{q (V_{AB} / w)} = \frac{I_x \mathcal{B}_z}{q t V_{AB}}$$

$$\mu_p = \frac{\sigma}{q p_0} = \frac{1/\rho}{q(1/q R_H)} = \frac{R_H}{\rho}$$



Pass current from 1 and 4 terminals and measure the voltage between 2,6 or 3,5.

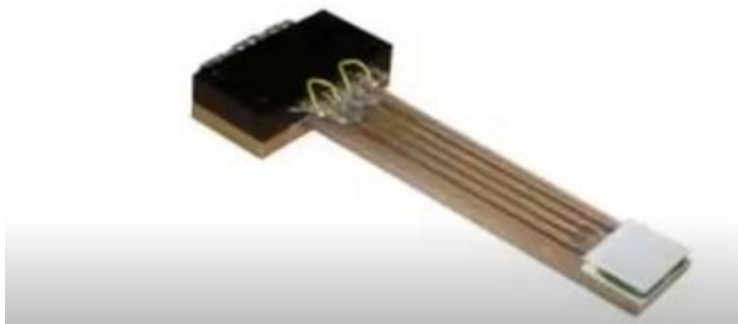
$$R_H = \frac{tV_{AB}}{I_x \mathfrak{B}_z} = \frac{tR}{\mathfrak{B}_z} \quad \mu_p = \frac{tR}{\rho \mathfrak{B}_z} = \frac{t\Delta R_{2413}}{\rho \mathfrak{B}_z} \quad \left| \right.$$

Experiment

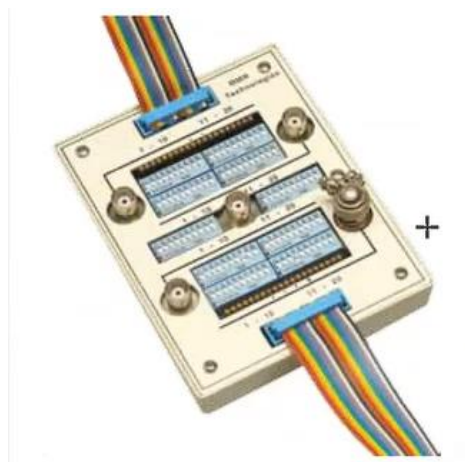
Hall measurements system: used to measuring the carrier mobility, carrier concentration and resistivity.

Here mobility, carrier concentration and resistivity are a function of temperature

Joule thomson refrigerator: this used for cooling and heating sample. Sample is placed on the heating plate operating range is from 80k to 580k.



Circuit breakout box: used to give power supply to joule thomson refrigerator, this circuit breakout interfaced with the temperature controller.



The filter/dryer setup : in order to reduce the temperature below the room temperature, Nitrogen Flows to the chamber form the metal wire.



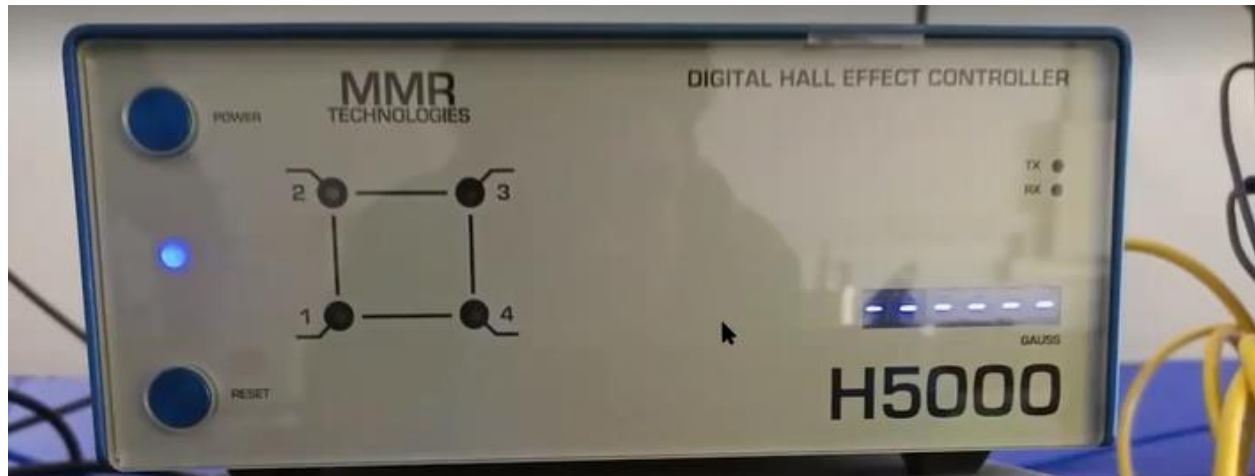
Dryer is connected to chamber. The complete chamber show below



Permanent magnet : in our lab we have 7500 gauss magnet.



Digital hall effect multiplier: this Digital hall effect multiplier is controlled with the help of software.

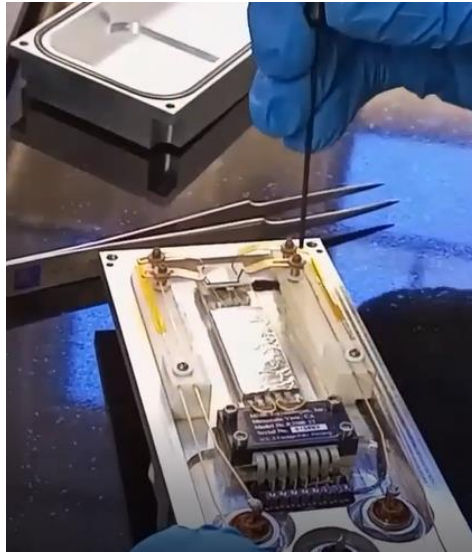


Here 4 point configuration given, we can supply current to any two probes and we have to measure the voltage between remaining two nodes.

Digital temperature controller(k2000):



- ➔ Take si sample, thickness is 380 micrometer. 1 cm X 1 cm .this sample have to place in the cheark in the chamber.
- ➔ After placing the sample, we have to see the electrical connections to four probes. Fix the sample with help of screw



- ➔ close the chamber, joule thomson refrigerator ground connection have to connect with any one of four screw which was used to close the chamber.



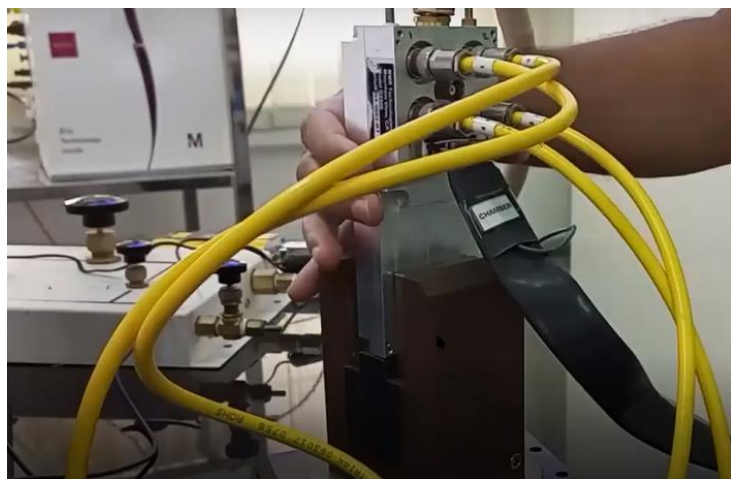
- ➔ From the Digital temperature controller(k2000) take 4 cables and connect as shown below. This cables number must be matched.



- ➔ Switch on the Digital temperature controller, Digital hall effect controller.
- ➔ Turn on the vacume pump, which creates the vacume in chamber to remove the gases and dust particles in chamber. We reduce the vacume below 40 m tor.



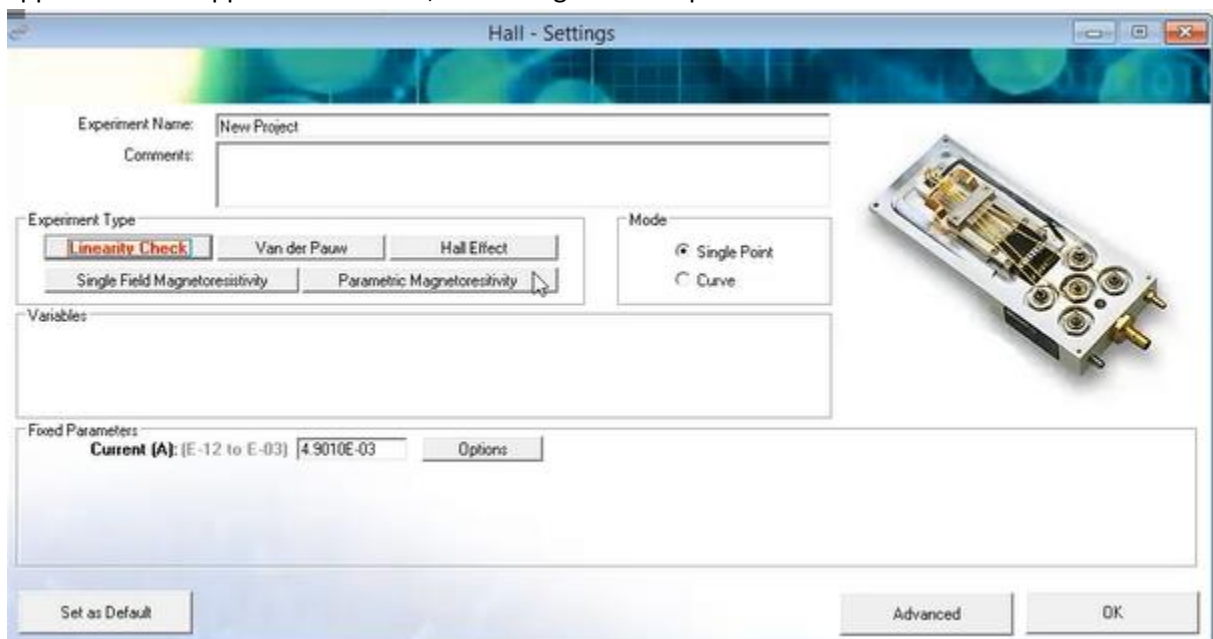
- ➔ Place the chamber in between the permanent magnet



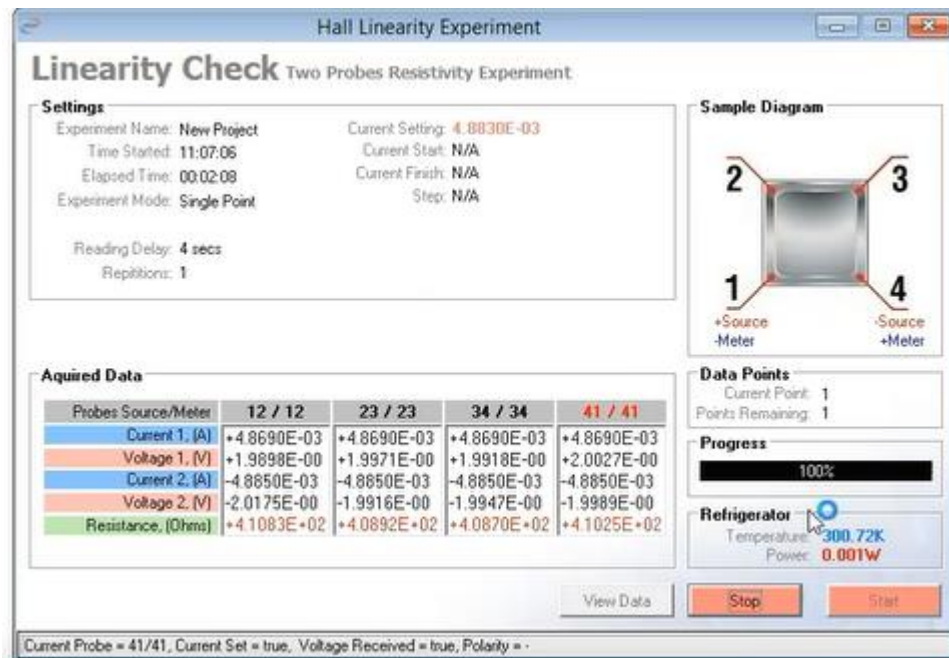
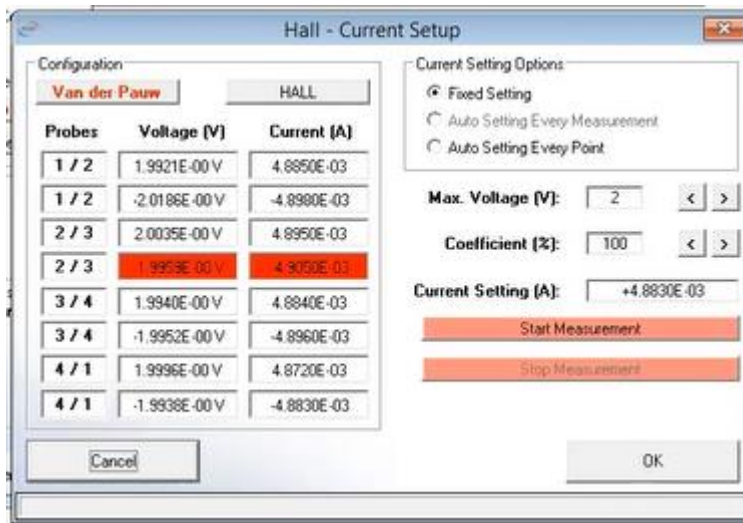
- ➔ Open the software Mmr technology
- ➔ We are using comm4 and comm5 for communications.



- ➔ First linearity check
 Applied current upper limit is 10mA, and voltage can be upto 2 volts.

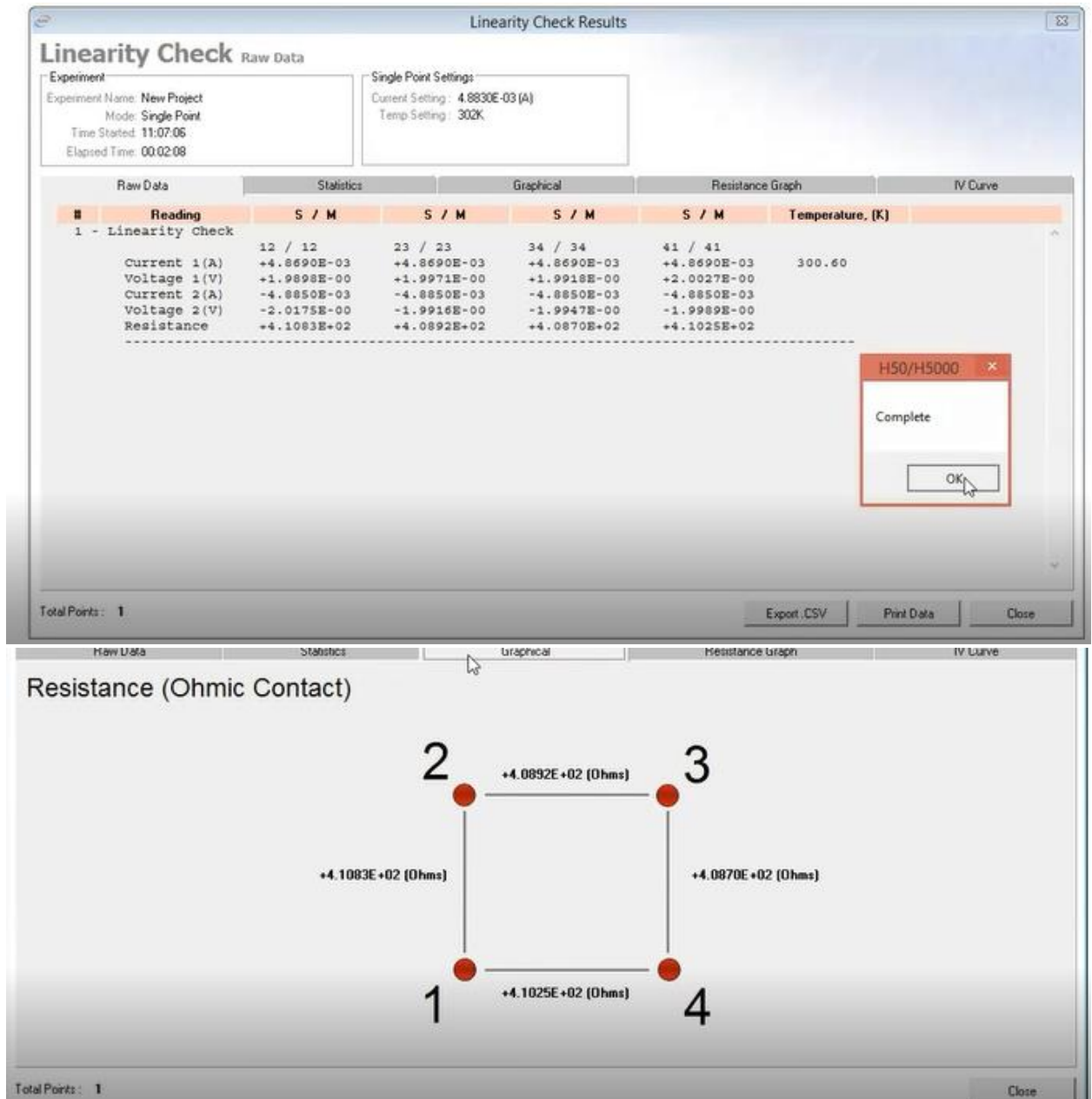


➔ For single point current



Compare values from
obtained analytically from
equations

Results:



→ Now let us go for curved point current

Experiment Name: New Project

Comments:

Experiment Type

Linearity Check Van der Pauw Hall Effect

Single Field Magnetoresistivity Parametric Magnetoresistivity

Mode

☐ Single Point ☒ Curve

Variables

Temp (K) Field (G) **Current (A)** ☒ Linear ☐ Log 1-2-3 ☐ Log 1-3-10 ☐ Log 1-10-100

Start (A) Finish (A) Step (A)

Fixed Parameters

→

Linearity Check Results

Statistics

Experiment

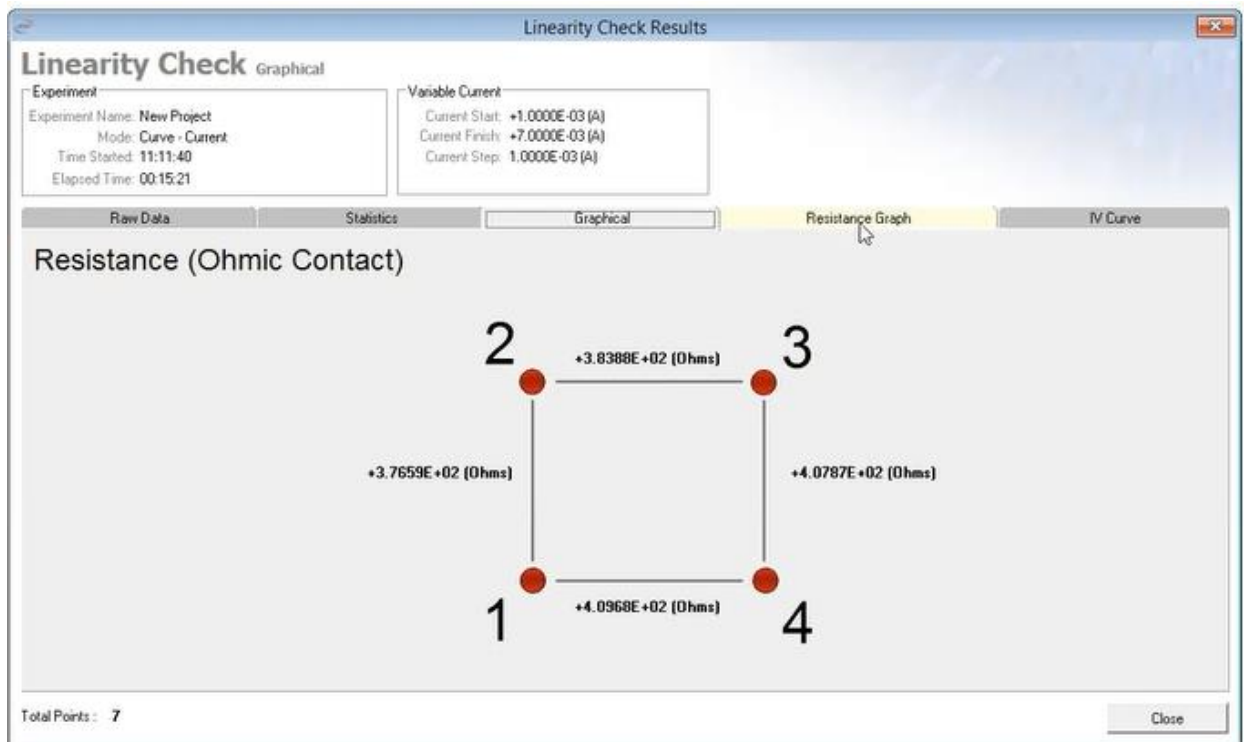
Experiment Name: New Project
Mode: Curve - Current
Time Started: 11:11:40
Elapsed Time: 00:15:21

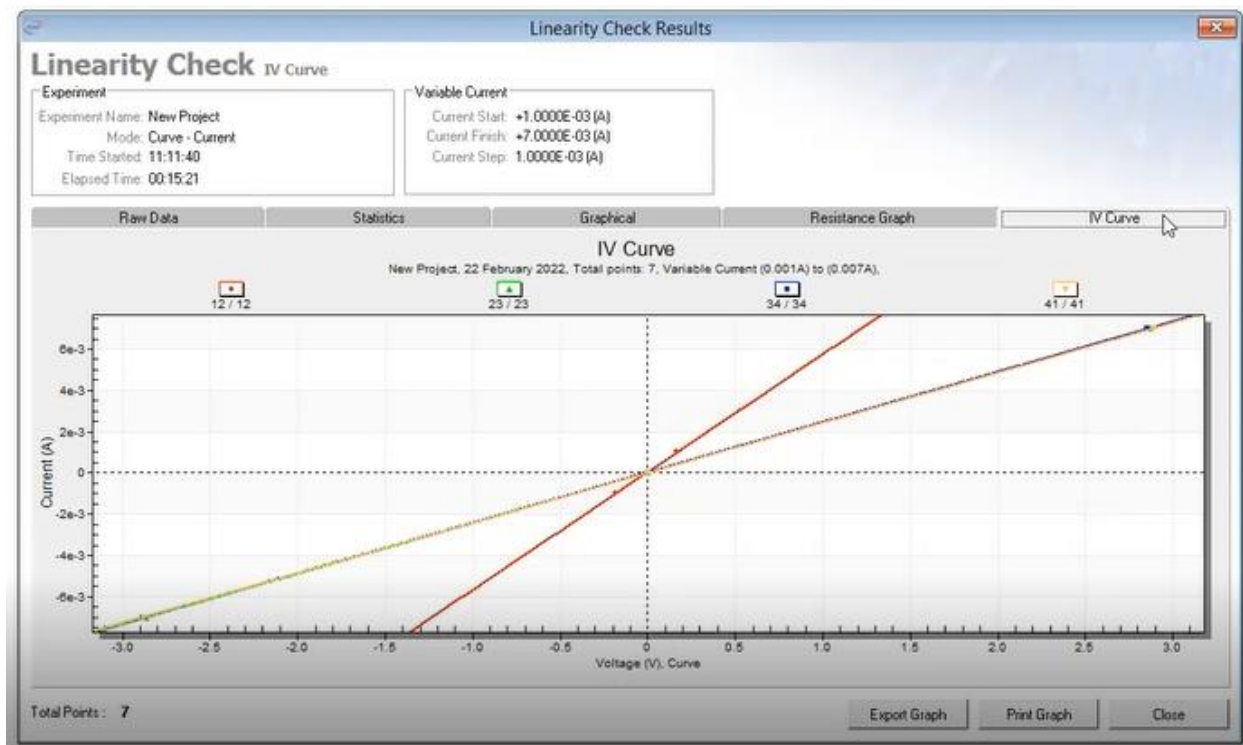
Variable Current

Current Start: +1.0000E-03 (A)
Current Finish: +7.0000E-03 (A)
Current Step: 1.0000E-03 (A)

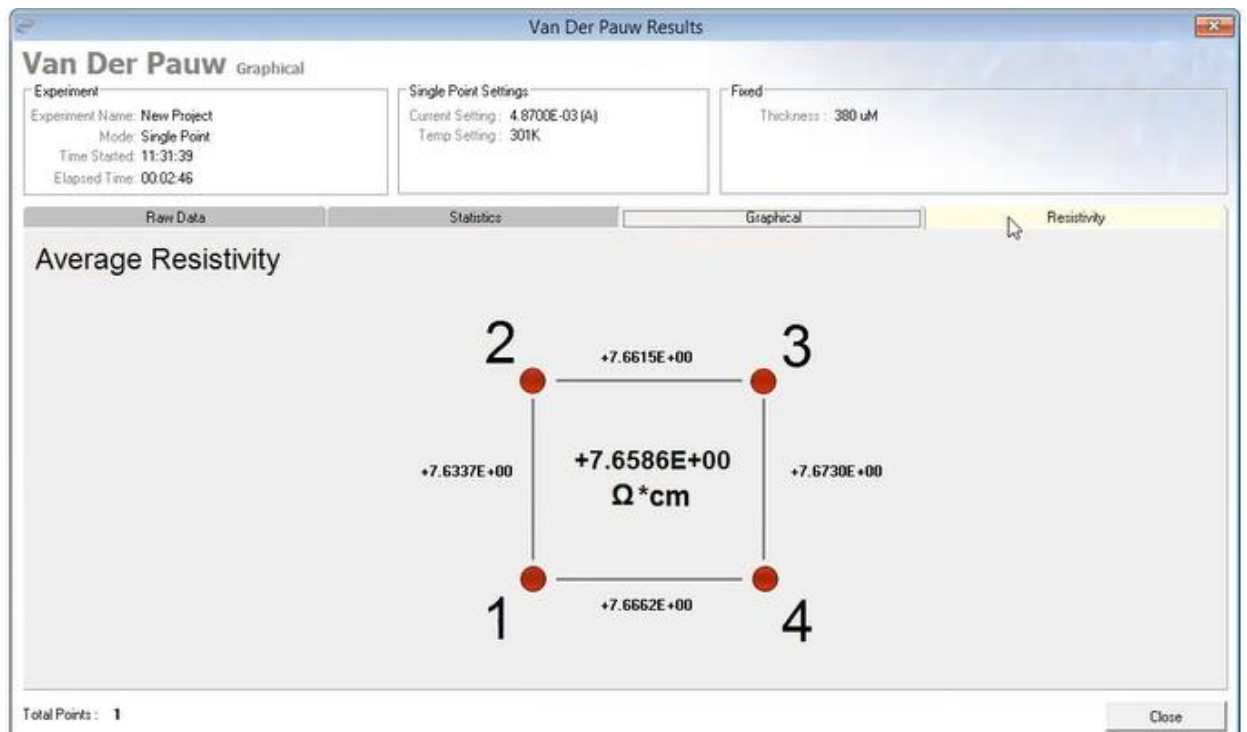
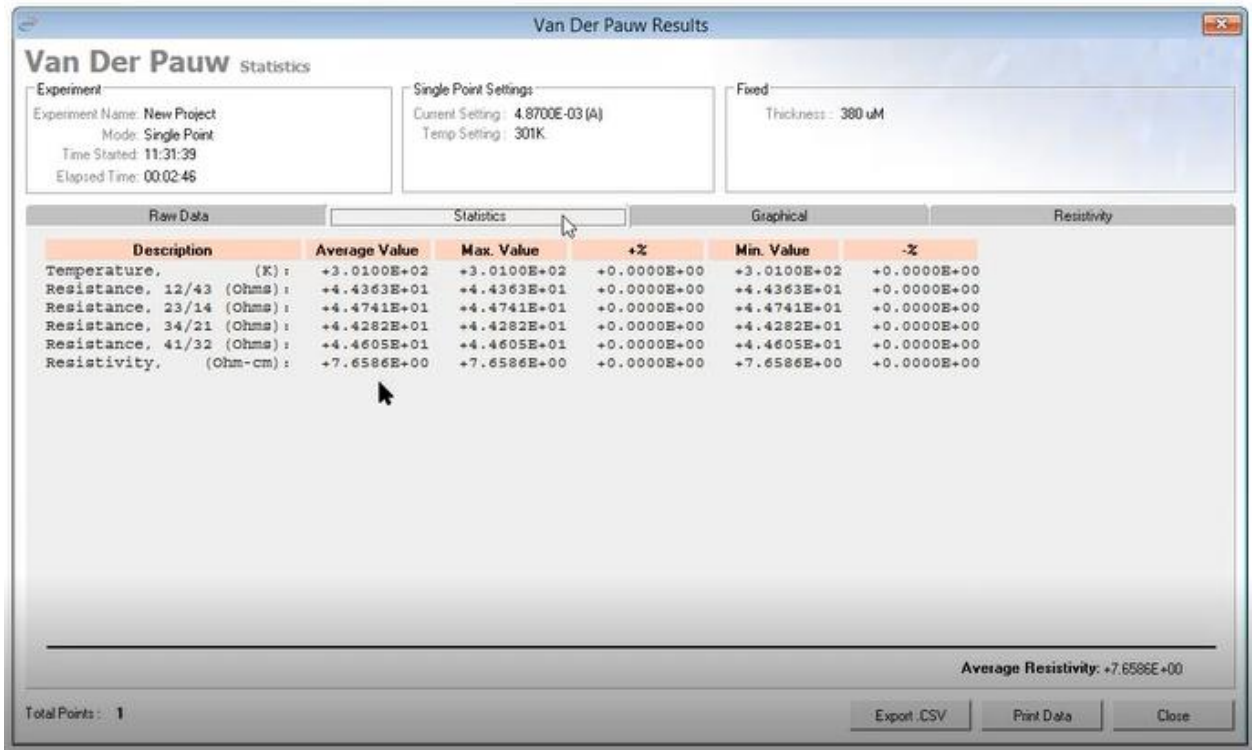
Description	Average Value	Max. Value	+%	Min. Value	-%
Temperature (K)	+3.0028E+02	+3.0075E+02	+1.5509E-01	+3.0008E+02	+6.8030E-02
Resistance, 12/12 (Ohms)	+3.7660E+02	+4.1278E+02	+9.6070E+00	+1.7486E+02	+5.3568E+01
Resistance, 23/23 (Ohms)	+3.8388E+02	+4.0949E+02	+6.6701E+00	+2.4112E+02	+3.7189E+01
Resistance, 34/34 (Ohms)	+4.0787E+02	+4.1042E+02	+6.2414E-01	+4.0636E+02	+3.7126E-01
Resistance, 41/41 (Ohms)	+4.0968E+02	+4.1249E+02	+6.8449E-01	+4.0846E+02	+2.9918E-01

Total Points: 7





Now temperature changed from 300 k to 301 k



Hall effect

Hall - Settings

Experiment Name:

Comments:

Experiment Type

Linearity Check:

Mode

☒ Single Point ☐ Curve

Variables

Fixed Parameters

Current (A): [E-12 to E-03]

Temperature (K): [70K to 730K]

Temp Ramp (K/min): [1K to 15K]


Field Control Mode: ☒ H50/H5000 ☐ Manual

Thickness (μm): [0.001 to 2000]

Field (G): [1 to 8000] #1

Field Ramp Const: [1 to 100]

Sensitivity V/kG: [0.001 to .02]



When the above message pops up, need to apply magnetic field.

Hall Effect - Experiment

Hall Effect Four Probes Resistivity Measurement

Settings

Experiment Name: Field Current:

Time Start:

Elapsed Time:

Experiment Mode:

Soak Time:

Reading Delay:

Repetition:

Manual Field Set

Please set new field.

Target Field (G):

Field Reading (G):

Acquired Data

Probes Source	Field Reading (G)	Reading...	Please Wait	OK
Current 1 (A)	+1.9714E-01	+1.9574E-01	+1.9670E-01	+1.9573E-01
Current 2 (A)	-4.4260E-03	-4.4260E-03	-4.4260E-03	-4.4260E-03
Voltage 1 (V)	-1.9511E-01	-1.9960E-01	-1.9448E-01	-1.9838E-01
Voltage 2 (V)	+4.4397E+01	+4.4747E+01	+4.4276E+01	+4.4605E+01
Ratio	+9.9200E-01	+9.8900E-01	+9.9700E-01	+9.9500E-01
Form Factor	0.999	1	1	1
Resistivity (Ωho/cm)	+7.6764E+00	+7.6662E+00	+7.6361E+00	+7.6644E+00

Acquired Data - Hall

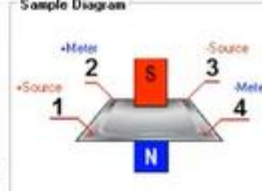
Probes Source/Meter	13 / 24	24 / 31	13 / 24	24 / 31
Current 1 (A)				
Voltage 1 (V)				
Current 2 (A)				
Voltage 2 (V)				
Resistance (Ωho/cm)				
Field (G)				

View Data

Stop

Waiting for manual field.

Sample Diagram



Data Points

Current Point: 1

Points Remaining: 0

Progress

50%

Refrigerator

Temperature:

Power:

Hall Results

Temperature: 301.04K

Resistivity (ohm/cm): +7.6608E+00

Mobility (cm²/Vs)

Density (cm⁻³)

Hall Coeff. (cm³/Coul)

Sheet Number (cm⁻²)

Sheet Res. (ohm/cm²)

Type of Carrier

When the above message pops up , we need to reverse the magnetic field direction

Hall Effect - Experiment

Hall Effect Four Probes Resistivity Measurement

Settings

Experiment Name: **New Project** Fixed Current: **4.4250E-03/[0.004425] A**

Time Stop
Elapsed T
Experiment M
Soak T
Reading De
Replite

Manual Field Set

Please set new field.

Target Field (G): **-7500 ±500**

Acquired Data

Field Reading (G): **-49** Reading..... Please Wait OK / 32

Probes Source	Field Reading (G)	13 / 24	24 / 31	13 / 24	24 / 31
Voltage 1. (V)	+1.9714E-01	+1.9574E-01	+1.9670E-01	+1.9573E-01	
Current 1. (A)	-4.4260E-03	-4.4260E-03	-4.4260E-03	-4.4260E-03	
Voltage 2. (V)	-1.9511E-01	-1.9960E-01	-1.9448E-01	-1.9836E-01	
Resistance. (Ohms)	+4.4397E+01	+4.4747E+01	+4.4276E+01	+4.4605E+01	
Ratio	+9.9200E-01	+9.8900E-01	+9.9700E-01	+9.9500E-01	
Form Factor	0.999	1	1	1	
Resistivity. (Ohm*cm)	+7.6764E+00	+7.6662E+00	+7.6361E+00	+7.6644E+00	

Sample Diagram

Data Points

Current Point: **1**
Points Remaining: **0**

Progress

75%

Refrigerator

Temperature: **301.09K**
Power: **0.005W**

Acquired Data - Hall

Probes Source/Meter	13 / 24	24 / 31	13 / 24	24 / 31
Current 1. (A)	+4.4090E-03	+4.4090E-03		
Voltage 1. (V)	+2.0542E-02	+1.9971E-02		
Current 2. (A)	-4.4270E-03	-4.4270E-03		
Voltage 2. (V)	-2.0883E-02	-1.9034E-02		
Resistance. (Ohms)	+4.6882E+00	+4.4143E+00		
Field. (G)	7106 GAUSS			

Hall Results

Temperature: **301.04K**
Resistivity (ohm*cm): **+7.6608E+00**
Mobility (cm²/Vs):
Density (cm⁻³):
Hall Coeff. (cm³/Coul):
Sheet Number (cm⁻²):
Sheet Res. (ohm/cm²):
Type of Connect:

View Data Stop II Start

Waiting for manual field...

Hall effect results:

