Hall Effect Measurement System

Hall and van der Pauw Measurements

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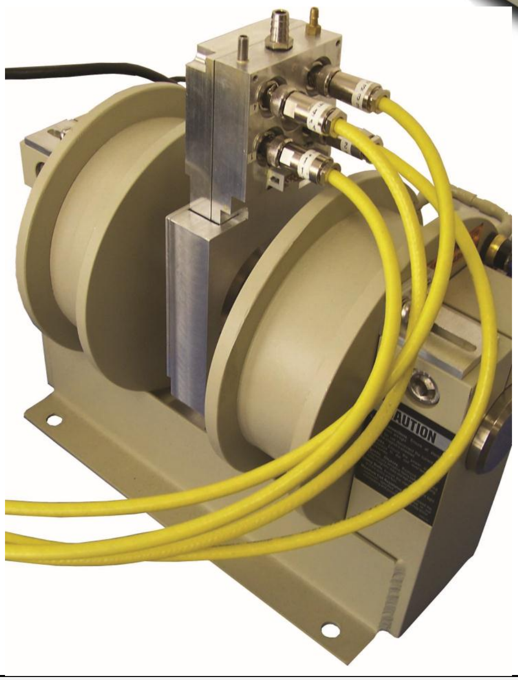
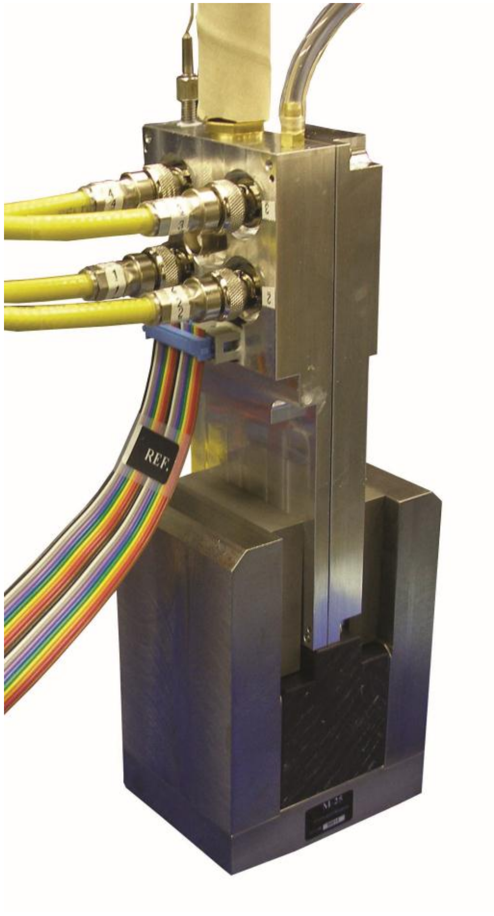
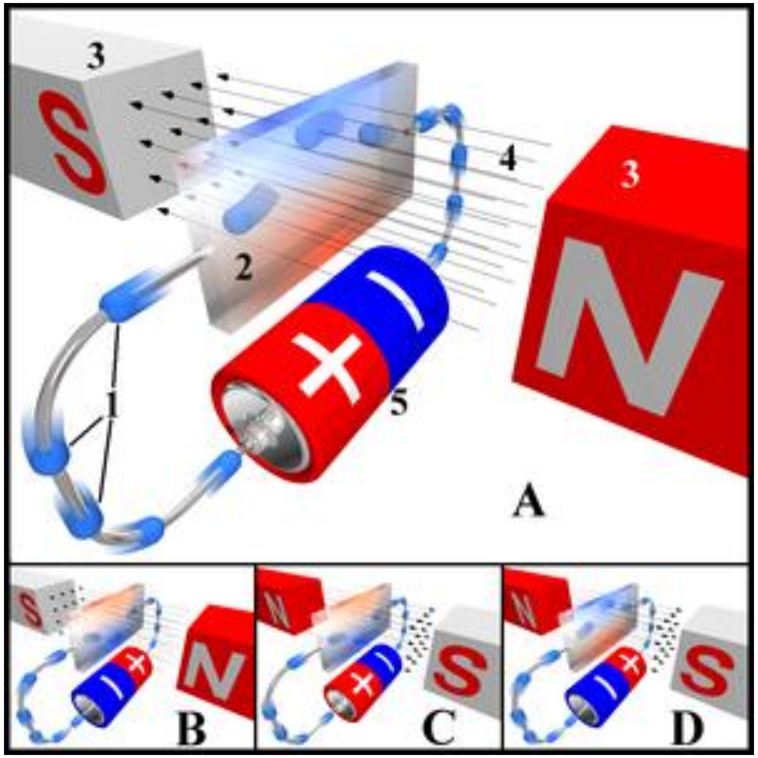
The Hall Effect Measurement System





The Hall Effect

- Hall effect refers to potential difference (Hall voltage) on opposite sides of a thin sheet of conducting or semi-conducting material through which an electric current is flowing, created by a magnetic field applied perpendicular to the Hall element
- Presence of measurable transverse voltage is called the **Hall effect** after E. H. Hall who discovered it in 1879.



The Hall Effect

- Ratio of voltage created to product of the amount of current and the magnetic field divided by the element thickness is known as the Hall coefficient
  - Characteristic of the material
- Conduction phenomenon
  - Different for different charge carriers
- Hall voltage has a different polarity for positive and negative charge carriers
  - Used to study the details of conduction in semiconductors and other materials which show a combination of negative and positive charge carriers.

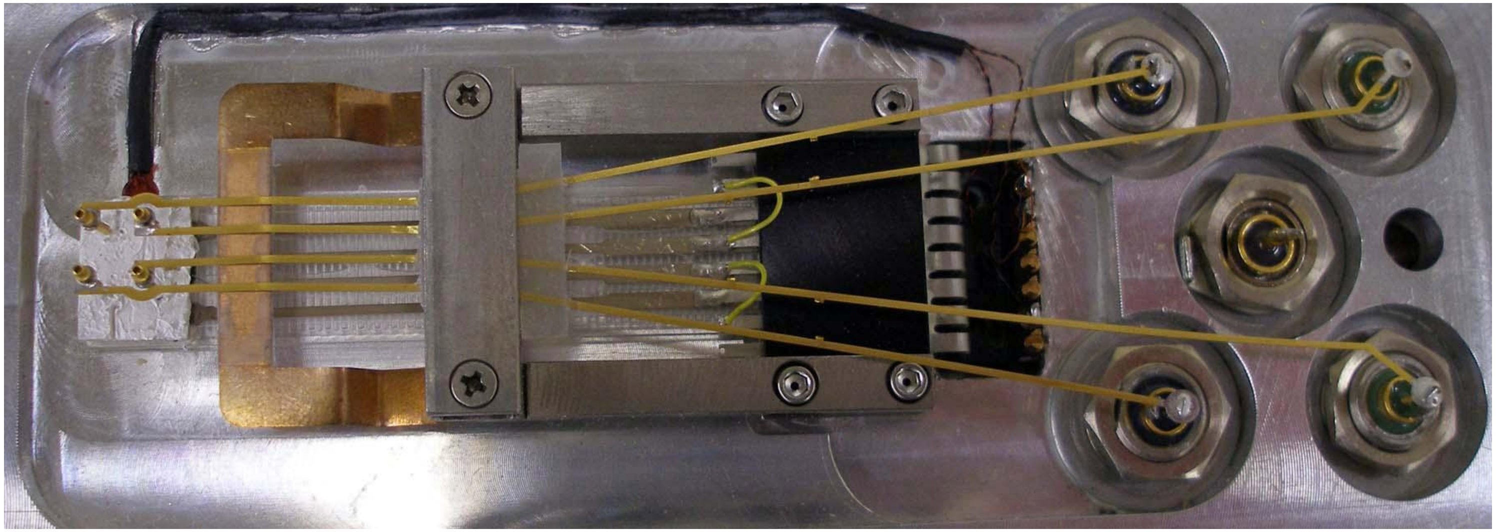
The van der Pauw Method

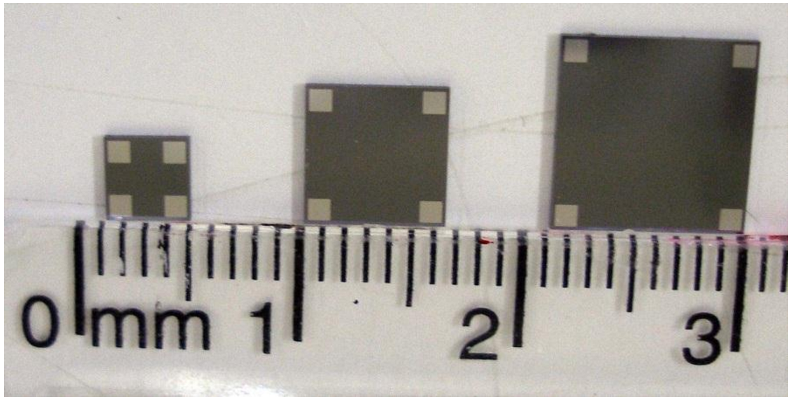
- Characterizes a sample of semiconductor material
  - can be successfully completed with a current source and a voltmeter.
- From the measurements made, the following properties of the material can be calculated:
  - The sheet resistance, from which the resistivity can be inferred for a sample of a given thickness.
  - The doping type (i.e. if it is a P-type or N-type) material.
  - The sheet carrier density of the majority carrier (the number of majority carriers per unit area).
    - Density of the semiconductor (doping level) can be found for a sample with a given thickness.
  - The mobility of the majority carrier.

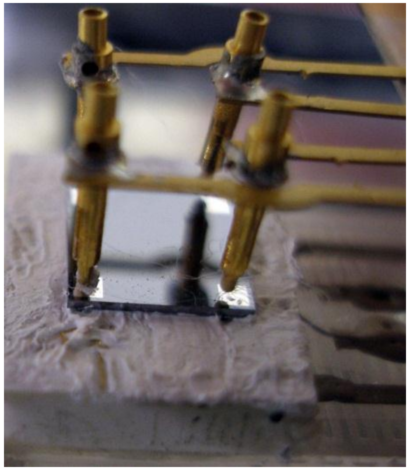
Taking Measurements

- Measurements require four ohmic contacts on the sample:
  - On or as close to sample boundary as possible
  - Infinitely small
    - Error is given by D/L
      - D = average diameter of contact
      - L = distance between contacts
  - Leads from contacts should be of the same batch of wires to minimize thermoelectric effects
  - All four contacts need to be same material

Taking Measurements

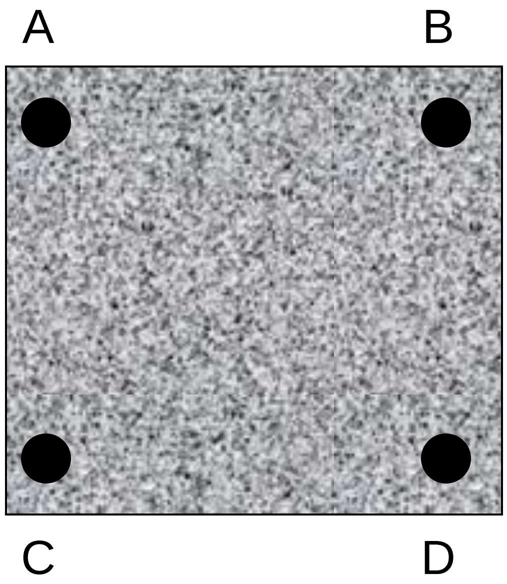






Taking Measurements

- Current I_{AB} is a positive DC current measured in amperes (A)
  - Injected into contact A
  - Take out of contact B
- Voltage V_{CD} is a DC voltage (V)
  - measured between contacts C and C with no externally applied magnetic field
- Sheet Resistance, R_S, is measured in Ohms (Ω)



Taking Measurements

- Ohm's Law:

$$R_{AB,CD} = V_{CD} / I_{AB}$$

  - calculates the resistance along one edge

    e.g. Vertical edge: $R_{AC,BD}$ and Horizontal edge: $R_{AB,CD}$

- Actual sheet resistance is related to these resistances by the van der Pauw formula:

$$e^\wedge\left(\frac{-\pi R_{AB,CD}}{R_s}\right) + e^\wedge\left(\frac{-\pi R_{AC,BD}}{R_s}\right) = 1$$

  - Obtain a more precise measurement of Rs by taking several reciprocal measurements and averaging

Hall Measurements

- When a charged particle (e.g. electron) is placed in a magnetic field, it experiences a Lorentz force proportional to the strength of the field and the velocity at which it is traveling through the field.
  - Force is strongest when the field is perpendicular to the direction of motion.
- Applying a current results in a steady flow of electrons through the material
  - Applying an external magnetic field will result in an accumulation of electrons at one edge of the sample
    - Creates a potential difference across the material

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Hall Measurements

- Magnitude of the Hall voltage (V_H):

$$V_H = \frac{IB}{qn_s}$$

  - I = current (A)
  - B = strength of magentic field
  - q = Elementary Charge (1.602 x 10^{-19} coulombs)
  - n_S = sheet density of the majority carrier

Making the Hall Measurements

- Two types of measurements need to be made:
  - One in a magnetic field in the positive field direction
  - One in a magnetic field in the negative field direction
- Constants:
  - Direction of magnetic field
  - Magnitude of injected current
- Overall Hall voltage can be calculated
  - Polarity of the V_H indicated the type of material
    - Positive = P-Type
    - Negative = N-Type

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Components in a Hall System

- Pure high-pressure gas (greater than 1800 psi)
  - Gas Lines, Pressure Gauge, etc
- Filter/Dryer Apparatus
- Refrigerator
- Computer (not included)
- Temperature controller
- Circuit Breakout Box
- Vacuum Pump (not included)
- Hall Vacuum Chamber
- Hall Electronics and Software
- Magnet (optional)
- Magnetic Power Supply (optional)

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Gas, Lines, Gauges, etc

- 99.998% Prepurified Nitrogen at 2640 psi or higher
- High Pressure Nitrogen Regulator
- High Pressure Nitrogen Lines (supplied)
- Gas Flow Meter (supplied)

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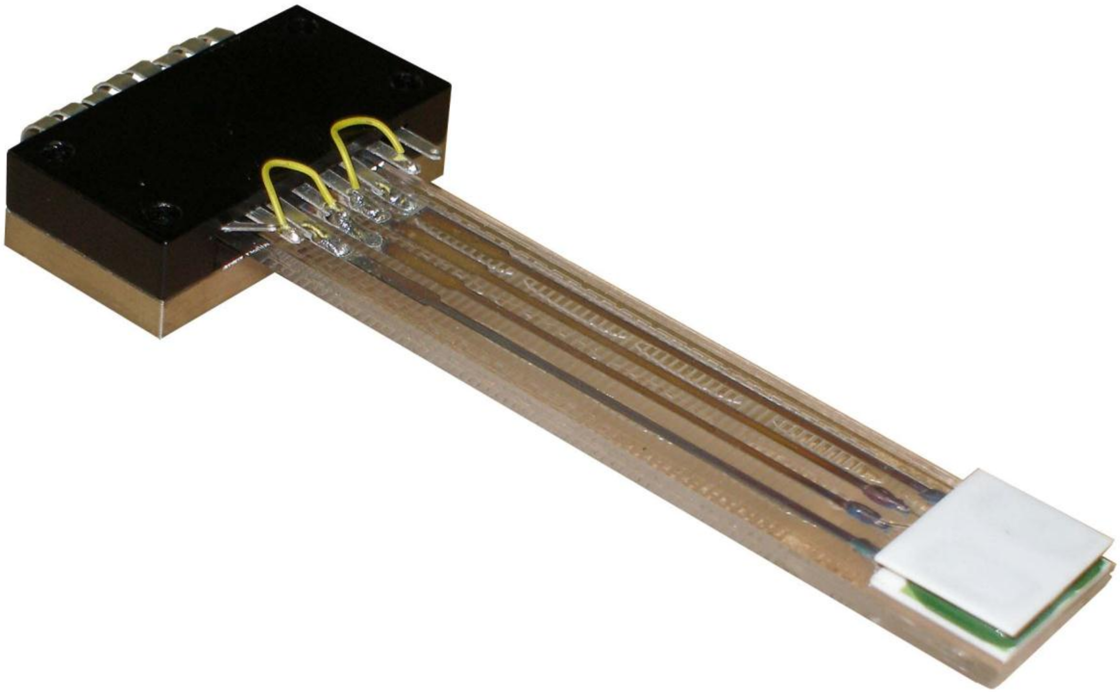
Filter/Dryer Systems

The Joule-Thomson Refrigerators



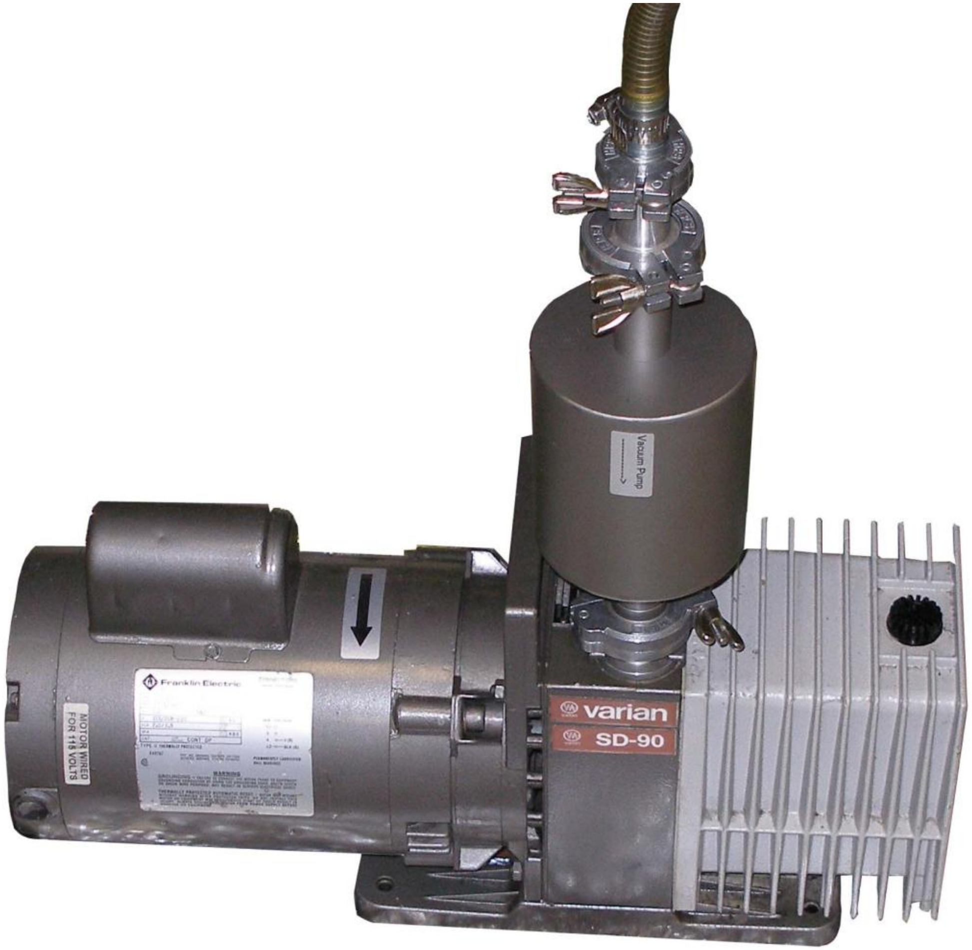
R2500-XX

Computer System

- Pentium Processor, 1 GHz minimum
- CD-ROM Drive (4x)
- 250 MB RAM
- 50 MB free on hard drive
- 2 RS232 Serial Ports

Circuit Breakout Box

Vacuum Pump and Accessory Kit

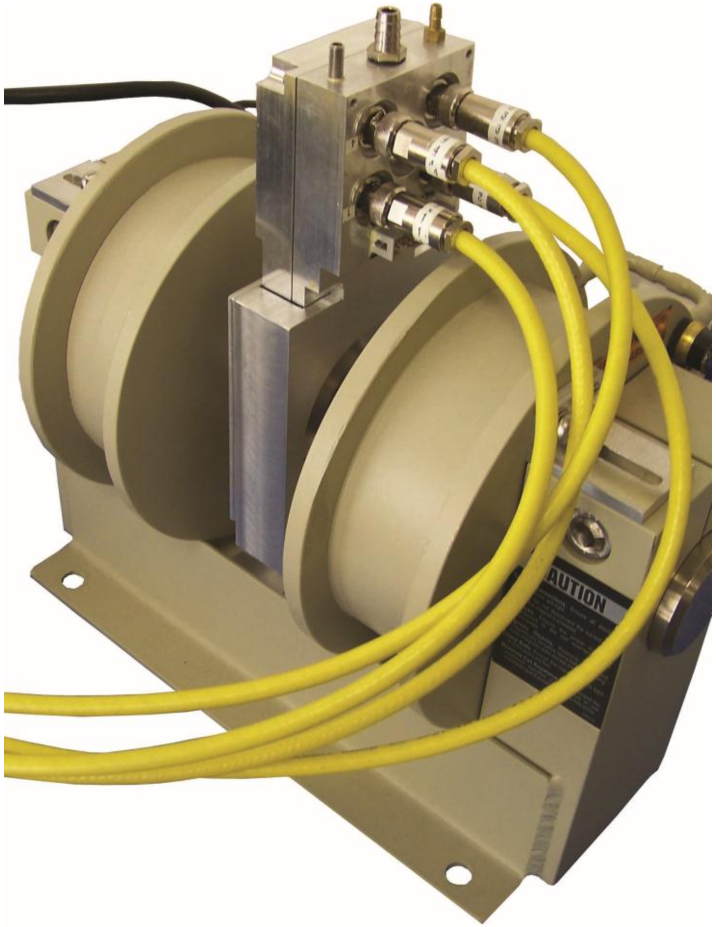


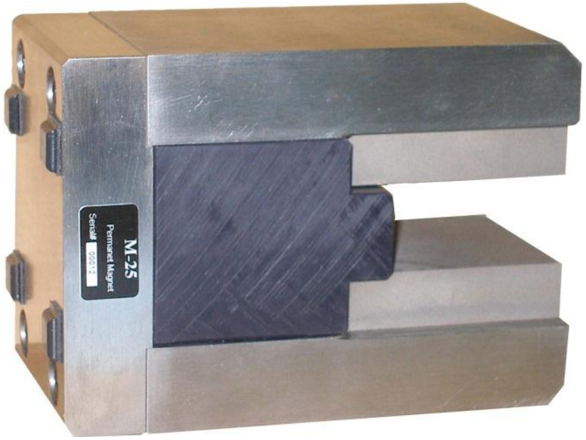
Hall Vacuum Chamber

Spring-Loaded Probes

Hall Electronics

Magnets and Power Supplies





Possible Temperature Ranges

Kelvin Scale

- 70 K to 580 K
- 80 K to 580 K
- 70 K to 730 K
- 80 K to 730 K
- 300 K to 730 K

Centigrade Scale

- - 200 °C to 305 °C
- - 190 °C to 305 °C
- - 200 °C to 455 °C
- - 190 °C to 455 °C
- 25 °C to 455 °C

K = °C + 273

Why do we care about the Hall Effect?

- Hall effect devices:
  - Immune to dust, dirt, mud, water
    - Better for position sensing
- Hall sensors:
  - Can easily detect stray magnetic fields
    - Work well as electronic compasses
- Hall effect current transducers:
  - High accuracy, environmentally hardy, low power consumptopn
    - Ideal solution for solar energy management

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