Hall Effect

Physics 3600 - Advanced Physics Lab - Summer 2021
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I. INTRODUCTION (for the Hall effect see NIST and Hyperphysics)

For semiconductor devices, in addition to the semiconductor=s resistivity (ρ) and carrier mobility (μ), one of the most important adjustable properties is the carrier concentration (*n*/*p* for electrons/holes). This Lab has several objectives: measure the resistivity of a doped silicon wafer; demonstrate the Hall effect; and use the Hall effect to measure carrier concentration and type (*n* or *p*); and determine the carrier mobility.

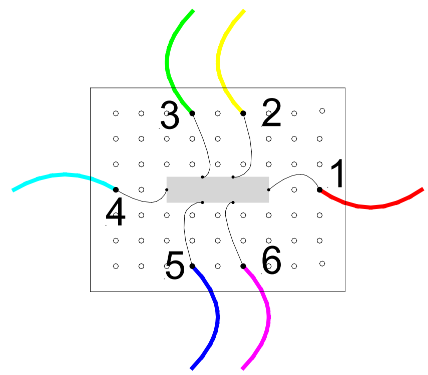
Beware of two things. (1) soldering to small indium contacts on the silicon wafer can be a real pain and cause some frustration, but keep at it. (2) You will probably not get very satisfying data, but that's the nature of these types of measurements.

II. APPARATUS

doped silicon wafer, pre-wired circuit board
carbide scriber, 2 soldering irons, indium solder, lead-tin solder, rubber cement, fine wire
electromagnet and power supply, current source (dc power supply), two multimeters (for V and I)
EasyPlot software

III. PROCEDURE

A. Each Group Makes a Hall Sample from a Silicon Wafer



1. Select a small piece of Si wafer without indium contacts.
   Measure the thickness with a micrometer.
   Don't be afraid to ask how to use the micrometer.

2. Select a silicon wafer with six indium contacts.
   Do not touch the silicon surface and leave finger grease
   Measure the width and length with a ruler.

3. Use a pre-wired circuit board that has 6 wires with different colored insulation.
   Write down the correspondence between the wire color and the numbers 1-6.

4. Glue your silicon sample onto the circuit board with a tiny amount of rubber cement.

5. Complete the wiring on the circuit board. If there are already fine wires on the board go ahead and use those. Otherwise, fasten one end of a fine wire by soldering it (with lead/tin solder) to each of the six insulated wires on the circuit board.

6. Now solder the free ends of each fine wire to an indium contact by gently applying heat for only a few seconds with the tip of the iron labeled **"indium"** to melt each indium contact to a fine wire.
Warning - too much heat for too long will make a bad Si contact. Gently touch the iron to the wire/indium.

7. Measure and record the resistances with an ohm meter from one colored wire to another and make sure they are less than 1 MΩ. If any contacts have larger resistance, resolder while monitoring the resistance. You may need to scratch the area again to remove the oxide first.

   a. List the resistances in the lab report.

8. Apply a current to the **two end contacts** with the 0-15 VDC power supply and monitor the current. The current must not generate more than 0.1 W of joule heating (compute $P=IV=I^2R$).

9. Measure current and voltage up to P~0.1 W. Plot $I(V)$ for current in **both** directions (±V on x-axis). Does the sample show "ohmic" behavior? Explain the $I(V)$ behavior.
   a. Plot the resistance versus voltage, R(V). Does R change with voltage?

You must show the TA your results and plots at the end of each section before proceeding to the next section.

B. 4-wire Method for Measuring Resistivity of a Doped Silicon Wafer

1. While applying a current to the two end contacts (1-4), compute the 4-wire **resistance** ($R=V/I$) from the voltage measured on each pair of INNER contacts (contacts 2-3 or 5-6 on the same side of the sample).

   a. For each pair of inner contacts, compute the resistivity ρ (and uncertainty) of the silicon wafer from
   $$R = \rho\, L / A,$$
   where L is the distance between two inner voltage contacts and A is the cross sectional area.

2. *Remove* the power supply and measure the resistance between the inner contacts with an ohm meter.
   a. Discuss the difference between the 4-wire resistance and that measured by the ohm meter (2-wire). (Search the web for a discussion of the "4-wire resistance method.)

C. Thermoelectric Determination of the Carrier Type

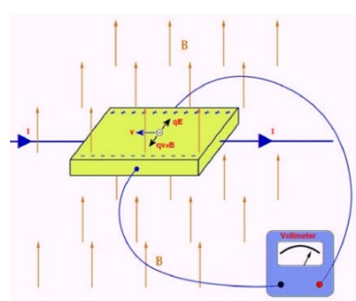
The "carrier type" of a semiconductor is either *n*-type for electrons, or *p*-type for holes.

1. Connect a voltmeter across the two outer contact wires. Note which contact is connected to the POSITIVE input to the voltmeter and identify it in your lab report.

2. Bring the hot soldering iron tip momentarily <u>**CLOSE TO**</u> one contact and note the voltage sign (+ or -).

   a. Does the voltage of the hot end of the silicon go momentarily positive or negative when it heats up? Do the same for the other end of the sample.
   b. Explain what you observe and how it relates to the diffusion of hot carriers.

D. Hall Effect, Carrier Concentration and Mobility



In the Hall Effect, mobile charge carriers moving with velocity (***v***) in an electrical current (I_S) experience a force Lorentz from an applied magnetic field (**B**). This force, $\boldsymbol{F} = q\,(\boldsymbol{v} \times \mathbf{B})$, pushes the moving charges at right angles to the current. As charge builds up on one side of the sample it produces a Hall voltage. Note that $q=-e$ for electrons and $q=+e$ for holes, where e the magnitude of the electron charge in coulombs. This voltage is perpendicular to both the current direction and the magnetic field direction,

$$V_H = (B\, I_s) / (ned),$$

where n is the density of charge carriers in m^{-3}, B the field in tesla, I_s the current in amps, and d the sample thickness in meters.

1. Calibrate the electromagnet with the Gaussmeter, by measuring B versus magnet current, $B(I_m)$.
   a. Curve fit the data to

$$B(I_M) = \alpha I_m .$$ MAXIMUM magnet current is ±3 amps.

2. Apply and measure the current through the two end contact wires.
   The current must not generate more than ~0.1 W.

3. Connect a voltmeter **ACROSS** the narrow width of the sample (2-6 or 3-5) for each pairs of contact wires.
   a. Report these values. Select the Hall pair having the lowest voltage.

4. Measure Hall voltage

Place the sample between the magnet poles, equidistant from the 2 poles faces.
Measure simultaneously the Hall voltage (V_H) and the sample current (I_S) as a function of the magnet current (I_M). Do both field directions (to reverse the field set I_M=0 and reverse the magnet wires).

a. Plot $V_H(I_M)$ as a function of the magnet current I_M and determine dV_H/dI_M.
b. Plot $V_H(B)$ as a function of magnetic field B by transforming the x-axis of the $V_H(I_M)$ plot using α.
c. Does the $V_H(B)$ data go through the origin. If not, why not.

5. Determine the carrier type from the Hall voltage

Note the direction of the magnetic field vector, **B**, as indicated on the magnet using positive magnet current.
Note the direction of positive current going through the silicon, I_S.
Note the change in the Hall voltage produced as B is increased.

Draw a diagram in you lab notebook of the setup, noting the three vector directions (**B**, I_S, $\mathbf{V}_H$).

a. Put a diagram in your lab report.
b. Determine the type of carriers (electrons or holes) from $\boldsymbol{F} = q\,(\boldsymbol{v} \times \mathbf{B})$ and the "right hand rule."
c. Discuss the results.

6. Determine the carrier density

a. Compute the carrier concentration , *n*, from the $dV_H(B)/dB$ slopes.

7. Determine carrier mobility

a. Compute the carrier mobility (μ) from the carrier concentration and resistivity using $\rho = 1/(n\, e\, \mu)$.

IV. SUMMARY

1. Make a table listing the final values and uncertainties for both samples:
   (a) resistivity ρ in **<u>Ωcm</u>** units; (b) carrier concentration in **<u>cm^{-3}</u>**; and (c) mobility μ in **<u>cm^2/Vs</u>**.

2. Does the mobility value (μ) change when the doping concentration (*n*) changes?

3. Compare the measured mobility to an accepted value for electrons or holes in silicon.
   What is the largest source of error?

Optional - Measure the resistivity using the van der Pauw technique and an appropriate sample geometry.