I. Introduction

For semiconductor devices, in addition to the semiconductor’s resistivity ($\rho$) and carrier mobility ($\mu$), one of the most important adjustable parameters 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 type ($n$ or $p$), concentration, and mobility.

II. Apparatus

- doped silicon wafer, electromagnet
- carbide scriber, soldering iron, indium solder, rubber cement, fine wire
- current source (dc power supply on protoboard), two multimeters (current and volt meters)

III. Procedure

A. Make a Hall Sample from a Silicon Wafer

- Select a circuit board (4-5 cm square)
- Solder six 6-inch long wires solidly to it.
- Obtain a cleaved section of a silicon wafer, approximately (5mm x 15mm).

Do not get finger grease on the silicon surface

- Measure the width and thickness (cross-sectional area $A$ for current flow) of your sample.
- Next, make six electrical contacts to the silicon sample. Glue the sample onto the circuit board with small amount of rubber cement. At six places on the sample, one on each end and two on each edge, make several very light circular scratches with the scribe. Keep the pairs across the narrow direction exactly across from each other. Solder TINY (<1mm) indium blobs (contacts) to the six spots with the soldering iron labeled “indium”.
- Now complete the wiring on the circuit board. Make up six fine wires 4-6 cm long. Fasten one end of each small wire by soldering it (with lead/tin solder) to each of the six large wires on the circuit board. Then gently lay the six fine wires across the four indium contacts. If necessary, tape the fine wires to the circuit board. Gently apply a small amount of heat with the tip of the indium soldering iron to melt each indium contact to a fine wire. Label each contact (A,B,C...).
- Check the resistance with an ohm meter from one large wire to another and make sure they are less than a 1 megohm. If any contacts have larger resistance, then resolder while monitoring the resistance. Record the resistances in the lab report.
B. 4-wire Method for Measuring Resistivity of a Doped Silicon Wafer

Apply a current to the two end wires with the 0-15 VDC power supply and a CURRENT meter in series. The current must not generate more than 0.1 W of joule heating (compute $P=IV=FR$).

- Measure current and voltage up to $P=0.1$ W. Plot $I(V)$ for current in both directions. Does the sample show “ohmic” behavior?

(1) Measure the Resistivity

- From the measured voltage of each pair of inner contacts, compute the 4-wire resistance ($R=V/I$).
- For each pair of inner contacts, compute the resistivity $\rho$ (and uncertainty) of the silicon wafer from
  \[
  R = \frac{\rho L}{A},
  \]
  where $L$ is the distance between two inner voltage contacts and $A$ is the cross sectional area.

Remove the power supply and measure the resistance between the inner contacts with an ohm meter.
- 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.

- Check for photoconductivity. Does the voltage change when you shine a flashlight on the silicon?

(2) Thermoelectric Determination of the Carrier Type

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

Connect a voltmeter across the two outer contact wires. Bring the hot soldering iron tip momentarily close to one end of the sample and note the voltage produced (in mV).
- 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.
- Explain what you observe and how it relates to the diffusion of carriers from one end to the other.

C. Hall Effect, Carrier Concentration and Mobility

- Calibrate the electromagnet with the Gaussmeter, measuring field versus magnet current, $B(I_m)$. MAXIMUM magnet current is ±3 amps.

(1) Measure Hall Voltage

Apply a current to the two end contact wires again. The current must not generate more than 0.1 W.
- Measure the voltages across the narrow width of the sample on the two pairs of contact wires. Select the Hall pair with the smallest voltage.

Place sample between the magnet poles, equidistant from the 2 poles faces.
- Measure the Hall voltage as a function of the applied magnetic field, $V_{H}(B)$, for both field (current) directions. Curve fit $V_{H}(B)$ to find the slope $dV_{H}/dB$. 

(2) Determine the Carrier Density

Compute the carrier concentration \( n \) in \#/m\(^3\) from

\[
V_H = \left( \frac{1}{ne} \right) \frac{BI}{d},
\]

where \( e \) the electron charge in coulombs, \( B \) the field in tesla, \( I \) the current in amps, and \( d \) the sample thickness in meters. Note that the carrier concentration can vary by many orders of magnitude depending on the amount of doping atoms.

(3) Determine Carrier Mobility

Compute the carrier mobility \( \mu \) from the carrier concentration and resistivity using

\[
\rho = \frac{1}{ne \mu}.
\]

(4) Determine the Carrier Type from the Hall Voltage

Note the direction of the magnetic field vector, \( B \), which comes out of the North pole piece. Note the direction of positive current, \( I \), going through the silicon. Note the change in the Hall voltage produced at the top contact wire as \( B \) is increased.

- Draw a diagram in you lab notebook of the setup, noting the three vector directions (\( B \), \( I \), \( V_H \)).
- Determine the type of carriers (electrons or holes) from the “right hand rule.”
- Discuss the results.

D. Conclusions

- Make a table listing the final values and uncertainties for resistivity in \( \Omega \text{cm} \) units, carrier concentration in \( \text{cm}^{-3} \), and mobility in \( \text{cm}^2/\text{Vs} \).
- Compare the measured mobility to an accepted value for electrons or holes in silicon.

Optional

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