HALL MEASUREMENTS IN SEMICONDUCTORS

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ABSTRACT

An experiment to compare resistivity and carrier concentration results for p-type silicon using four point probe and Hall measurements is described. The effects of current magnitude and magnetic field magnitude on the results obtained using Hall measurements were also investigated. The Hall data and four point probe data was in close agreement for both carrier concentration and resistivity for specified ranges of current and magnetic field.

INTRODUCTION

Hall measurements and four point probing are techniques used to measure the material properties of resistivity, carrier concentration and carrier mobility in semiconductors. Both methods provide information about the electrically active impurity profiles. While four point probing is much easier to perform, its application to compensated samples is hampered by the fact that two of the properties must be measured directly. In this way Hall measurements can be applied as an alternative method of characterizing semiconductor samples.

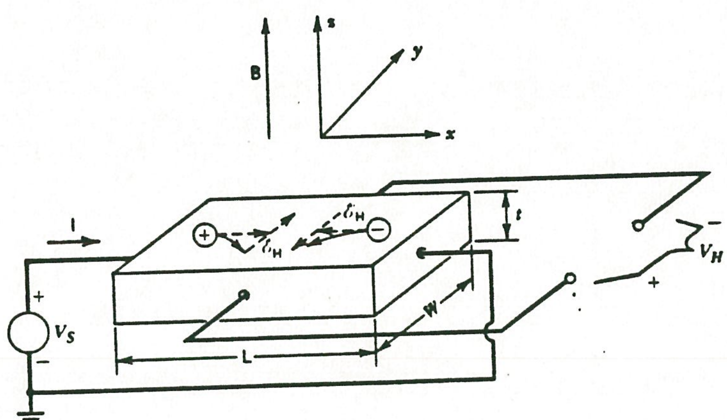


Figure 1. Schematic of the Hall effect.[1]

Hall measurements make use of the Hall effect to directly determine both the resistivity and electrically active carrier concentration in the sample. From those values the carrier mobility can be evaluated. The Hall effect is demonstrated by referring to Figure 1. Consider a uniformly doped sample of thickness t, width W and length L, through which a current I flows. By applying a uniform magnetic field B perpendicular to the current, a magnetic force is exerted on the charge carriers in the y direction. For equilibrium, a net force of zero in the y direction must exist on the carriers. Hence, an electric field

$\vec{E}$, is established which counters the magnetic force. This effect, known as the Lorentz force is demonstrated in Equation 1,

$$F = 0 = q\vec{E} + q(\vec{v}_d \times \vec{B}) \quad . \quad (1)$$

Since all vector values are applied perpendicularly, Equation 1 can be reduced to scalar values and yields,

$$qE_H = qv_dB$$

or

$$E_H = v_dB \quad . \quad (2)$$

Equation 2 can be easily manipulated to provide a measurable quantity, the induced Hall voltage,

$$V_H = E_HW = v_dBW \quad . \quad (3)$$

Since the drift velocity in a semiconductor is

$$v_d = I/nq(tW) \quad . \quad (4)$$

where n is the carrier concentration, then Equation 4 can be substituted in Equation 3 to provide the Hall voltage in terms of the measurable quantities B, I and t and thus

$$V = IB/nqt \quad . \quad (5)$$

The Hall voltage is measured using a high impedance voltmeter from which the carrier concentration n is evaluated in Equation 5.

Resistivity can be found by removing the magnetic field and reconnecting the leads so that the terminals, thru which the current is supplied and the voltage is measured, are adjacent as in Figure 2.

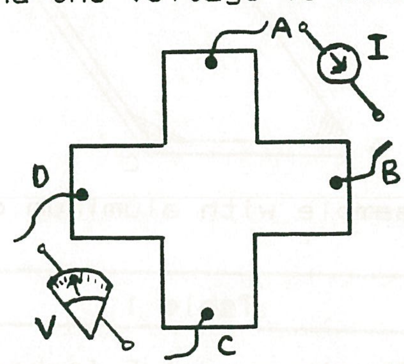


Figure 2. Example of Van der Pauw sample.

This method of measuring resistivity, ρ, in a sample was introduced by Van der Pauw and is mathematically evaluated to be,

$$\rho = (\pi d/\ln 2)(V_{DC}/I_{AB}) \quad . \quad (4)$$

This result stems from the restriction that the sample be symmetrical and provide equal path lengths through which the

current and voltage flow. A small correction factor determined by Chang should also be included to account for the finite contact size relative to the sample size [2].

The third property of the sample, the Hall mobility u_H, can be found using the results already determined and is given by,

$$u_H = R_H/\rho$$

where R_H is the Hall coefficient (1/nq). The value of u_H only has real significance in single carrier systems where it can be easily related to the carrier mobility, u, by a known proportionality factor, r, for the given material [3].

The application of Hall measurements has proven useful in the field of microelectronics to fabricate some unconventional integrated circuits. Hall sensors react to magnetic fields which induce a detectable voltage. The absence or presence of this voltage can be used to note the position of the sensor. Due to this fact, Hall sensors have found widespread use in keyboard switch applications.

This project was a preliminary investigation to determine the capability of detecting the low voltage levels which Hall sensors use. Positive results should indicate the feasibility of manufacturing functional Hall sensors.

EXPERIMENT

The experiment involved the fabrication of two identical devices used to measure induced Hall voltages in p-type semiconductors. As seen in Figure 3, square geometries were chosen with corner contacts to ensure the current applied and voltage measured were perpendicular to each other. Table 1 contains information pertaining to the devices.

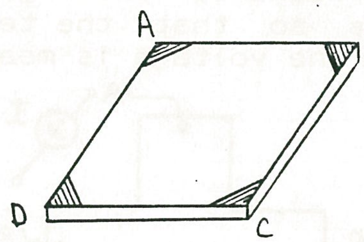
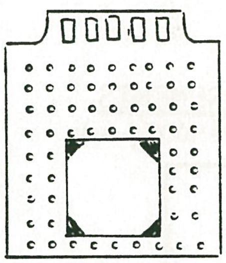


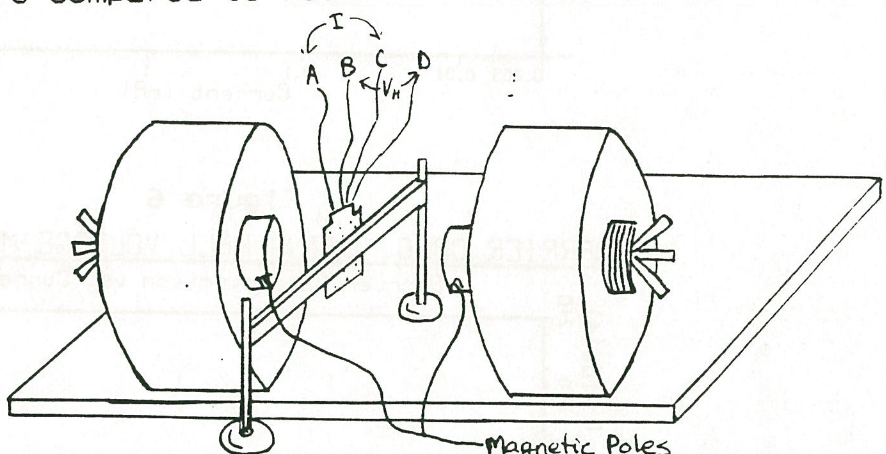
Figure 3. Hall sample with aluminum contacts A,B,C,D.

Table 1		
length	=	1.5 inches
width	=	1.5 inches
thickness	=	20 mils (508 um)
ρ	=	10-20 ohm-cm
carrier	=	p-type

The square geometries were cut from the wafers using a Tempress Model 602 saw. Following a RCA clean, aluminum was

deposited on the corners using a CVC evaporator to form the equally sized triangular contacts and sintered at 450 C. Finally the squares were mounted on perferated plastic board and wire leads were connected to the contacts using silver paint. The set-up for the measurement of the Hall voltage is shown in Figure 4. A Keithley 220 Programmable Current Source with a voltage limit of 10 volts was used. The carrier concentration as a function of the magnetic field and current supplied was deduced using equation 5. The resistivity was measured by simply turning off the magnet and reconnecting the leads as mentioned earlier. Both the resistivity and carrier concentration determined using Hall measurements were compared to results obtained using a four point probe.


A) Mounted Sample



B) Experimental Set-up

Figure 4.

RESULTS/DISCUSSION

The resistivity values obtained using four point probe and Van der Pauw measurements are shown in Figure 5. A consistent Van der Pauw resistivity was found for a current ranging between 0.05 mA and 10.0 mA. Below 0.05 mA the sensitivity of the equipment was not high enough to supply an accurate voltage measurement. Above 10.0 mA the current supply was limited by a maximum voltage so the sample in fact did not see currents above 10.0 mA. This explains the drop in resistivity in Figure 5 and that data should be disregarded. Table 2 supplies the measured resistivity values and exemplifies the close correlation between the two measurement techniques.

Table 2: Resistivity	
Four Point Probe	= 21.9 ohm-cm
Hall (Van der Pauw)	= 20.7 to 22.3 ohm-cm

The measured carrier concentration as a function of current is shown in Figure 6. For a magnetic field of 4000 Gauss, the carrier concentration was relatively constant for a current supply between 0.05 mA and 10.0 mA. The carrier concentration

Figure 5

RESISTIVITY USING HALL MEASUREMENTS

Resistivity vs. Current

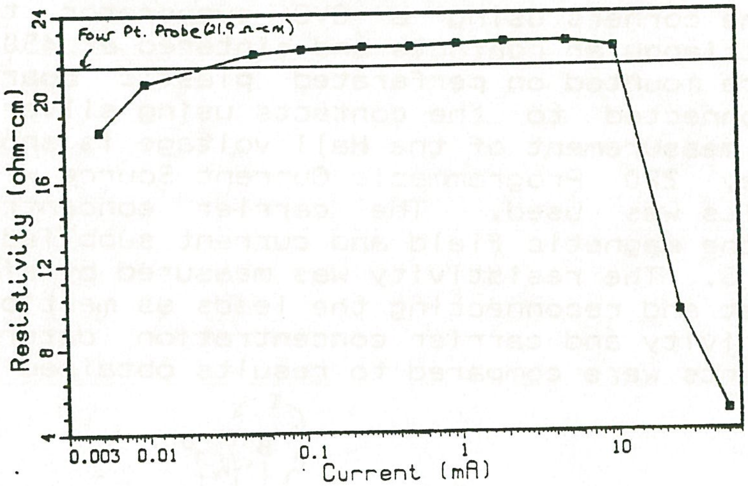


Figure 6

CARRIER CONC. USING HALL VOLTAGE MEASUREMENTS

Carrier Concentration vs. Current (B = 4000 gauss)

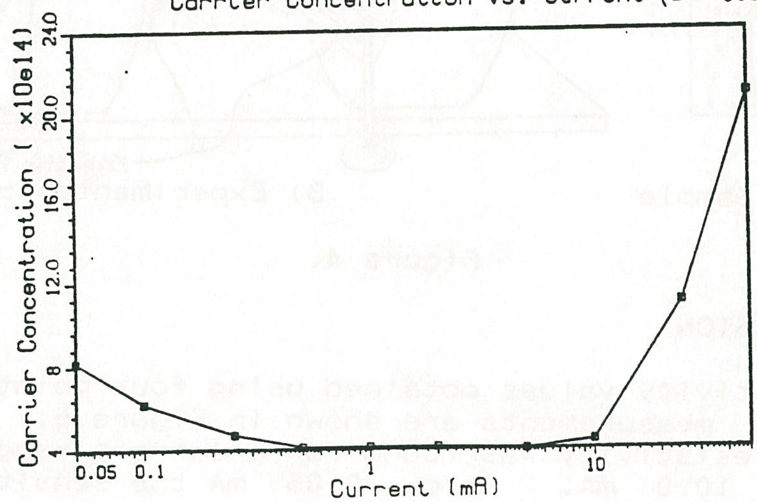
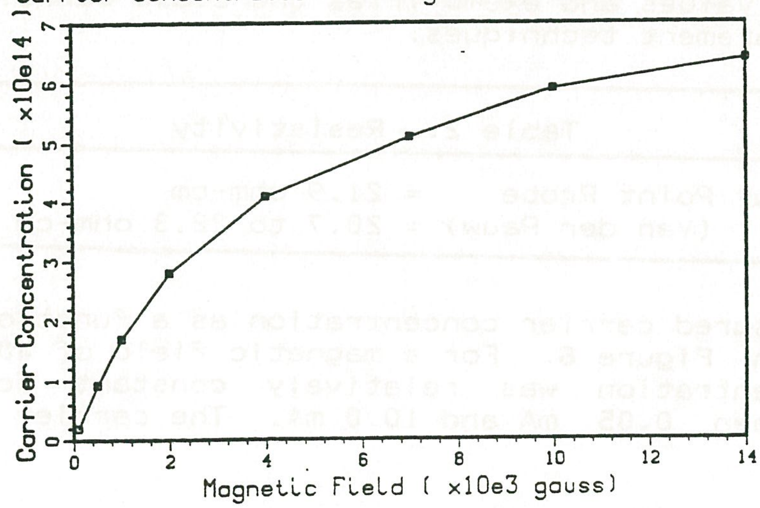


Figure 7

CARRIER CONC. USING HALL MEASUREMENTS

Carrier Concentration vs. Magnetic Field (I = 1.0 mA)



outside this range varied due to the same reasons the resistivity varied. Table 3 supplies the measured carrier concentrations and again a close correlation existed between the two measurement techniques. The graph in Figure 6, for a magnetic field of 4000 Gauss, typified curves for other magnetic fields.

Table 3: Electrically Active Carrier Concentration (B = 4000 Gauss)	
Four Point Probe	= 2.0×10^{14} cm^{-3}
Hall	= 4.1×10^{14} cm^{-3}

Figure 7 demonstrates the carrier concentration as a function of magnetic field for a current supply of 1.0 mA. As the magnetic field increased the carrier concentration increased in a non-linear yet non-logrithmic fashion. The reason for this remains unresolved at this point. Similar results occurred for other constant current supplies.

Overall, the resistivity and carrier concentration values obtained using Hall measurements matched closely to those values obtained using a four point probe. Given the existing equipment, Hall measurements can be used to provide a close estimate for the carrier concentration and resistivity in a semiconductor. The data suggests that the generated Hall voltages were in fact real with only slight inaccuracies that may have resulted from spurious emf's, contact resistance, lack of perpendicularity of the magnetic field and current flow, and finite contact sizes. Magnetoresistance and scattering showed no evident effect on the material parameters for the p-type silicon. Based on these results the capability to fabricate and test diffused Hall sensors with the existing equipment may be possible. Only a more sensitive voltmeter (0.1 to 1.0 mV range) and modifications to the set-up are needed to accomodate the smaller sample. However, lattice scattering, finite contact size and magnetoresistance may introduce problems due to the conduction nature of the diffused n-type silicon needed in a Hall sensor.

CONCLUSIONS

An experiment set up to obtain resistivity and carrier concentration from Hall measurements has been described and shown to correlate well with four point probe measurements. Based on these results, the manufacture and testing of functional Hall sensors should be possible.

ACKNOWLEDGEMENTS

Thanks to Mike Jackson for his advice and help obtaining supplies and Dr. Peter Cardegna, in the Physics department, for his advice and cooperation.

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