INTEGRATED HALL EFFECT SENSOR

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ABSTRACT

Experiments relevant to the development an integrated Hall effect sensor have been performed. Carrier concentrations calculated from the Hall voltage generated in samples of bulk silicon did not agree well with values measured by four point probe or Van der Pauw Techniques. However, the relationship between Hall voltage and magnetic field was highly linear and should produce a well behaved sensor. A sensor design has been proposed, but not fabricated.

INTRODUCTION

Hall Effect sensors are integrated circuits that produce a voltage proportional to the magnetic field through the circuit. They are used in contactless switches and proximity detectors. The devices operate on the Hall effect, which is illustrated in Figure 1. A current I flows through a uniformly doped sample of

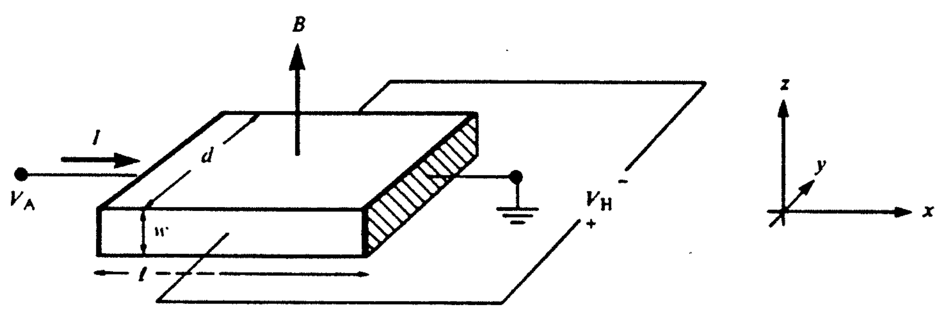

Figure 1: The Hall Effect voltage [1].

thickness t, width W, and length L. The application of a uniform magnetic field, B, perpendicular to the current causes a Lorentz force to be exerted on the carriers in the y direction. This force is governed by

$$\vec{F} = q\vec{E} + q(\vec{V}d \times \vec{B}) \qquad (1)$$

were Vd is the drift velocity of the carrier. Since the net force is zero in equilibrium, an electric field E must counter the magnetic force in the y direction. Setting F equal to zero in Equation 1 and using the fact that the vector quantities are mutually perpendicular leads to

$$E = (Vd)B. \quad (2)$$

The small but measurable potential difference associated with this field, called the Hall voltage, Vh, is given by

$$Vh = EW = (Vd)BW. \quad (3)$$

The drift velocity of carriers in a semiconductor is

$$Vd = I/nqtW \quad (4)$$

were n is the carrier concentration. Substituting for Vd in Equation 3 yields

$$Vh = IB/nqt \quad (5)$$

If I, B, and t are known, the carrier type and concentration can be determined from the Hall voltage. This information can be compared to data obtained by four point probe and Van der Pauw techniques. If I, n, and t are known, then the Hall voltage is proportional to the magnetic field. Hall sensors make use of this relationship.

The general design of an integrated Hall sensor is shown in Figure 2. It consists of a uniformly doped, isolated n-region similar to that shown in Figure 1. Contacts are fabricated in an appropriate geometry on the region to allow connection of a current source and voltmeter.

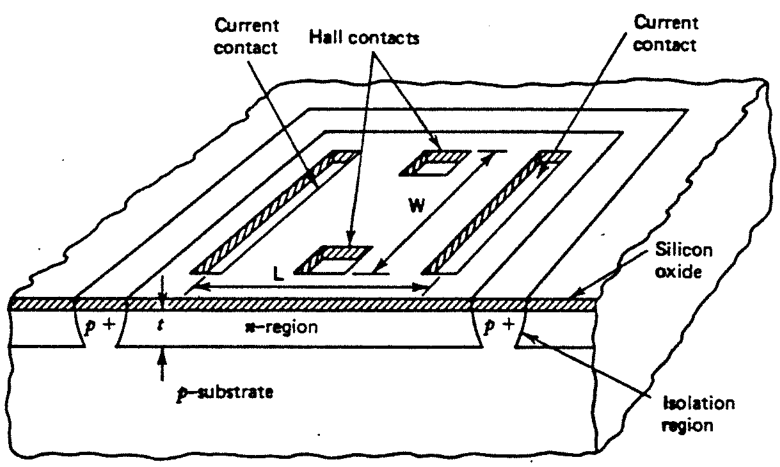

Figure 2: Typical Hall sensor [2].

Tony Scelsi, a former RIT student, devised a procedure to obtain Hall voltage measurements on bulk samples of p-type silicon [3]. This project involved replicating Scelsi's experiment with p-type samples, refining his technique, extending it to n-type samples, and fabricating a Hall sensor.

EXPERIMENT

The samples were prepared by cutting a square geometry from a wafer and creating aluminum contacts in the corners as shown in Figure 3. In order to make ohmic contact to n-type silicon it was necessary to perform a phosphorous predeposit in the contact regions before depositing the aluminum, creating a heavily doped p+/n+ junction. The square was mounted on perforated plastic board and wire leads were connected to the contacts using silver paint.

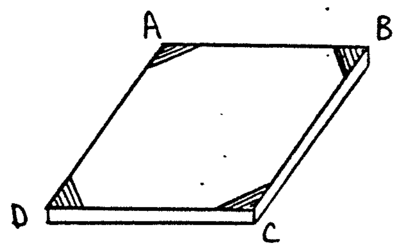

Figure 3: Typical sample with aluminum contacts [3].

The experimental set-up used for making Hall measurements is shown in Figure 4. A Kiethley 220 Programmable current source with a voltage limit of 10 volts was connected across diagonal contacts on the sample. A Kiethley 197 autoranging microvolt digital multimeter was connected across the remaining two contacts to measure the Hall voltage. Van der Pauw resistivity measurements were made with the magnet off and the current source connected across adjacent contacts. The Hall voltage was measured as the current and magnetic field were varied. From this data the carrier concentration, which is expected to be cons ant, was calculated and compared to that found by four point probe and Van der Pauw measurements.

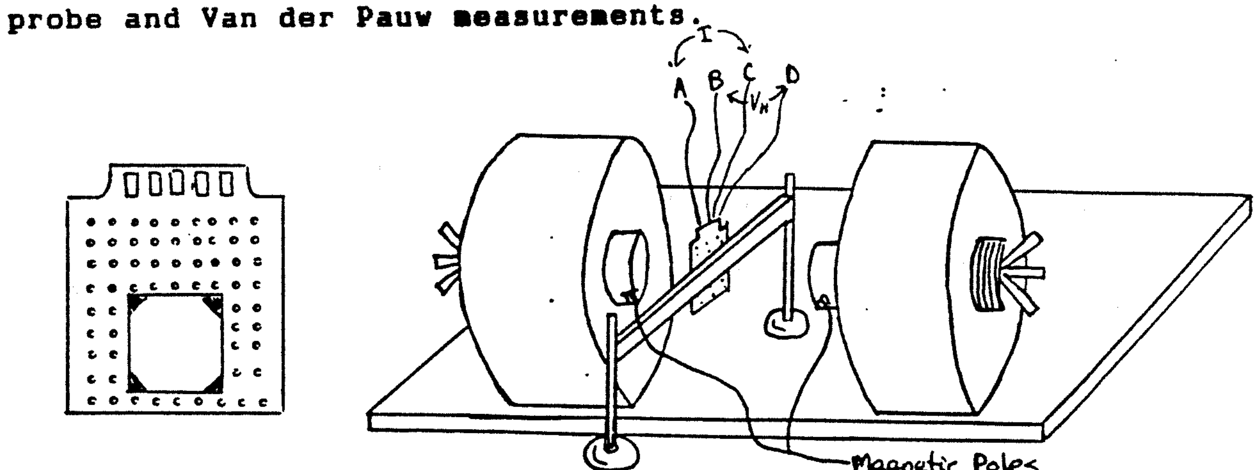

Figure 4 [3]

RESULTS/DISCUSSION

Scelsi reported that the carrier concentration of the p-type samples varied unexpectedly with magnetic field in a manner that was neither liner nor logarithmic [3]. This relationship was

observed again when the experiment was replicated. An offset voltage was observed when there was a current through the sample but no magnetic field, and is most likely an IR voltage drop caused by the contacts not being aligned on an equipotential field line. When the offset voltage was subtracted from the measured voltage, the carrier concentration became independent of magnetic field. Figure 5 shows a comparison of the calculation results for corrected and uncorrected data.

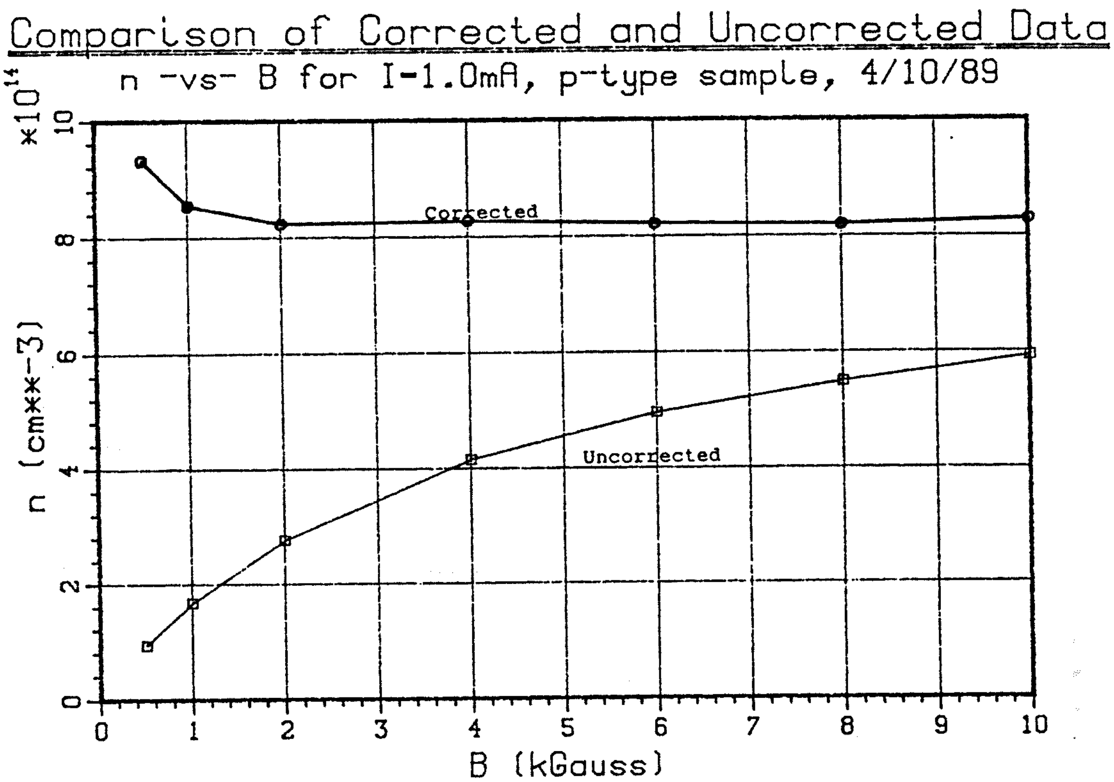

Figure 5

Figures 6 and 7 show typical results for carrier concentration calculated as a function of current and magnetic field, respectively, for an n-type sample. There is some scatter for small currents and magnetic fields because the Hall voltages generated were at the sensitivity limits of the milivoltmeter. Otherwise, the curves are reasonably flat. Unfortunately, as shown in Table 1, this concentration was far higher than that measured by four point probe and Van der Pauw techniques.

sample	4 pt probe	Van der Pauw	Hall effect
n p	1.0E15 2.0E14	7.0E15 1.8E14	2.2E16 8.5E14

Table 1: Carrier concentration in cm^{-3}.

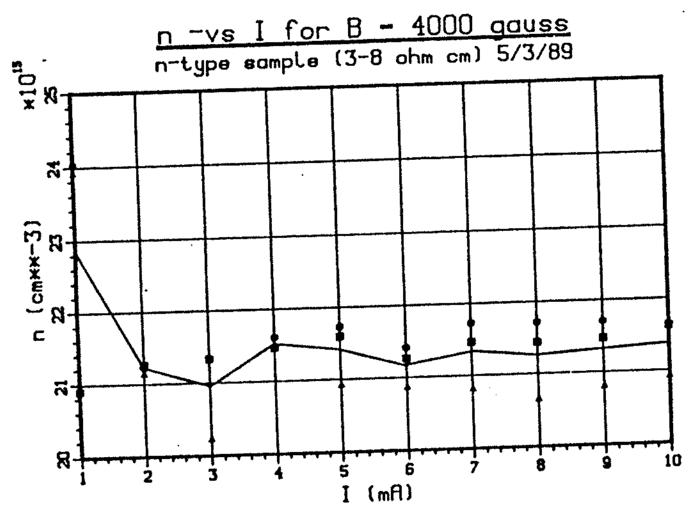

Figure 6

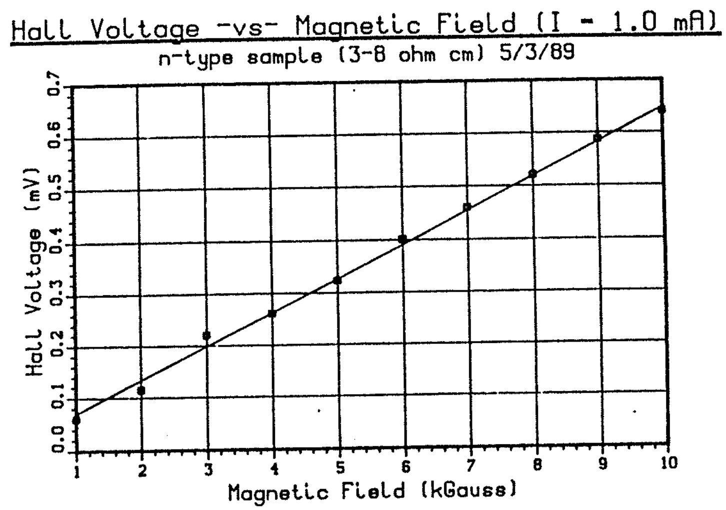

Figure 8

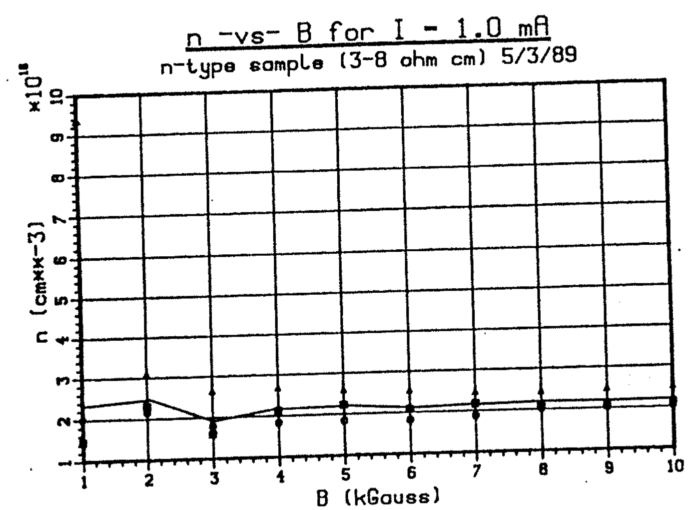

Figure 7

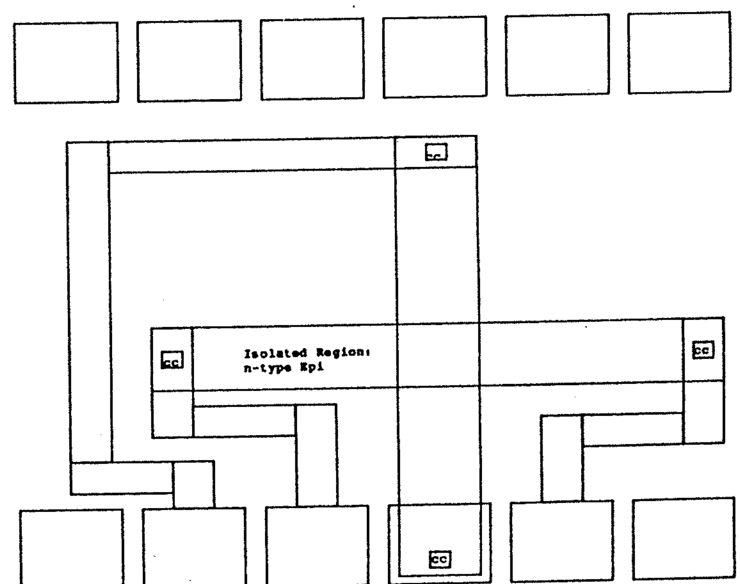

Figure 9

Figure 8 shows a typical relationship between Hall voltage and magnetic field. Since this curve is almost perfectly linear, Hall sensors should be very well behaved once they are calibrated. A proposed sensor design is shown in Figure 9. It is essentially a Greek Cross Van der Pauw structure that can be used for both resistivity measurements and Hall effect measurements. It is also proposed that a structure similar to that shown in Figure 2 be designed and fabricated.

CONCLUSIONS

Experiments relevant to the development of a Hall sensor were performed. Work performed by Tony Scelsi on p-type silicon was replicated and extended to n-type silicon. An explanation has been proposed for an anomalous result observed by Scelsi. The Hall effect measurement technique needs further refinement before it can be used as a characterization technique, but the relationship between Hall voltage and magnetic field is linear and should produce a well behaved sensor. A design for such a sensor has been proposed but not yet fabricated.

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REFERENCES

[1] Pierret, Robert, and Gerold Neudeck, ed. Modular Series on Solid State Devices, Volume VI. Addison-Wesley Publishing Company, Reading Massachusetts.

[2] Muller, Richard S. and Theodore I. Kamins. Device Electronics for Integrated Circuits, 2nd Ed. 1981.

[3] Scelsi, Tony. Hall Measurements in Semiconductors. EMCR660 Senior Research Paper, RIT, 1988