Chapter 3

Conductivity of N and P Type Germanium

3.1 Objective

3.1.1 Room Temperature Conductivity

Determine the room temperature resistivity $\rho = 1/\sigma$ of the two samples marked A and B, and verify that the contacts to the semiconductor are ohmic. *Familiarize yourself with the apparatus before you begin. Make sure you know current and voltage limits, etc. so you do not damage anything.*

3.1.2 Conductivity as a Function of Temperature

Determine the variation of conductivity in a doped semiconductor over the temperature range 0°C to 125°C, and relate these results to the energy gap of the semiconductor.

Compare your values for the energy gap of samples A and B with the accepted value for Germanium.

Make sure you know current and voltage limits, etc. so you do not damage anything.

3.1.3 The Hall Effect

Use the Hall effect and previous results to determine the mobility and carrier concentrations for both samples.

Familiarize yourself with the apparatus before you begin. Make sure you know current and voltage limits, etc. so you do not damage anything.

3.2 Background

3.2.1 Conductivity

For a sample of n-type semiconductor, the electrical conductivity σ is given by

$$\sigma = n_e e \mu_e \tag{3.1}$$

where n_e is the density of carriers (electrons), e is the charge of an electron, and μ_e is the mobility of the electrons. For a p-type material, the conductivity is given by

$$\sigma = n_h e \mu_h \tag{3.2}$$

where n_h is the density of carriers (holes) and μ_h is the hole mobility.

3.2.2 Temperature Effects

1. At low temperatures, most of the donors (for n-type) or acceptors (p-type) in a semiconductor are un-ionised. In this region any increase in temperature will ionise additional impurities, thus causing the density of carriers to quickly increase.

2. Above some particular temperature, virtually all of the donor and/or acceptors will become ionised. A temperature range exists in which the carrier density remains virtually constant, and is determined strictly by the doping levels.

3. As the temperature increases still further, the mean thermal energy (kT) becomes comparable in magnitude to the energy gap of the (intrinsic) semiconductor material. Significant numbers of electron-hole pairs are thus created.

In this experiment, the latter two regions will be explored. These two domains are referred to as **extrinsic** and **intrinsic**, respectively.

Recall that conductivity is equal to the product of three factors: charge, carrier density, and mobility. The temperature dependence of the mobility must also be accounted for in $\sigma(T)$.

3.2.3 Extrinsic Range

In this domain, impurity scattering of carriers can be shown to lead to a relationship of

$$\mu \propto T^{+3/2}$$

Since the carrier density is essentially independent of temperature in this range, the conductivity will have a temperature dependence of:

$$\sigma \propto T^{+3/2} \tag{3.3}$$

3.2.4 Intrinsic Range

In this domain, lattice scattering is the dominant process affecting the carrier mobility, with the result that

$$\mu \propto T^{-3/2}$$

However, the carrier density has a temperature dependence of the form:

$$n_i = p_i \propto T^{3/2} e^{-E_g/2kT}$$

where E_g is the semiconductor energy gap, k is Boltzmann's constant and T is the absolute temperature in Kelvins. Combining these equations leads us to predict a temperature dependence of the conductivity given by

$$\sigma \propto e^{-E_g/2kT} \tag{3.4}$$

3.2.5 Hall Effect

When a semiconductor is subjected to a magnetic field oriented along a perpendicular to the face of the sample holder and a bias current is applied as in the previous experiments, the **Hall voltage** will be measured *across* the sample; see Figure 3.1.

From the theory of the Hall Effect, it may be shown that the Hall voltage, V_H, is given by:

$$V_H = \begin{cases} -\frac{1}{n_e e}\frac{B_z I_x}{t} & \text{for electrons} \\ \\ +\frac{1}{n_h e}\frac{B_z I_x}{t} & \text{for holes} \end{cases}$$

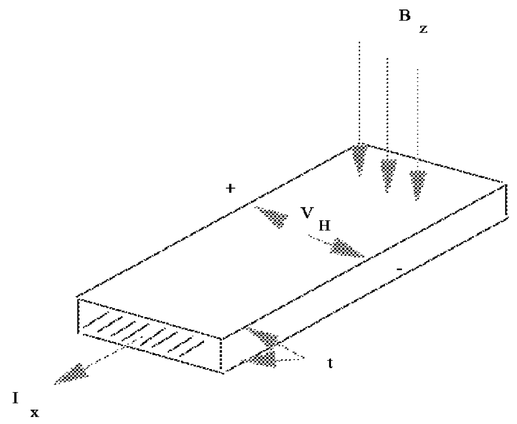

Figure 3.1: Hall Effect

where n_e (n_h) is the carrier density for electrons (holes), I_x is the bias current, t is the sample thickness along the magnetic field direction, e is the electronic charge, and B_z is the applied magnetic field(in the z direction). Obviously the polarity of the Hall voltage is a direct indication of the type of carrier (electrons or holes) in an unknown semiconductor. In addition, these equations imply that the carrier density can be determined if V_H, I_x, B_z and t are known.

A quantum mechanical calculation of the Hall voltage for Germanium introduces a refinement in the above equations, namely:

$$V_H = \begin{cases} \frac{-0.93}{n_e e} \frac{B_z I_x}{t} & \text{for electrons} \\ \\ \frac{+1.40}{n_h e} \frac{B_z I_x}{t} & \text{for holes} \end{cases}$$