The Hall Effect and Properties of Semiconductors

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Abstract

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1 Introduction

Some very interesting characteristics of crystals can be analyzed experimentally. Such characteristics are the resistivity of a crystal as a function of temperature, the hall voltage (this potential difference created by the separation of charges in the crystal when a magnetic field is applied on the crystal) as a function of temperature and how the intensity of the magnetic field affects the resistance of the crystal. In this experiment we will choose the germanium semiconductor as our crystal to analyze.

In order to do analyze this characteristics we need to understand the theory behind them. The resistance of semiconductors like germanium is dependent on temperature. Indeed when negative carriers with density n and charge $e$for each charge, the current density $\mathbf{J}$ relates to the mean velocity $\mathbf{v}$ of the charge carriers by : $= en\mathbf{v}$. It also relates to the conductivity $\sigma = {}^{1}/_{\rho}$ by the equation $\mathbf{J} = \sigma\mathbf{E}$. For semiconductors it can be shown that the mean velocity is approximately equal to $\mathbf{v} \approx \frac{e\lambda}{2\sqrt{3}}$ where λ is the mean free path of the carriers, k is he Boltzmann constant, T is the temperature of the sample and m is the effective carrier mass. Using this relation and the fact that λ goes like ${}^{1}/_{kT}$ we find that the resistance$R$ is related to the temperature T in a way that $R \propto T^b$. (how can I get more precise without taking to much space) However equation this equation is valid only if the number of carriers remains constant. The electrons in the semiconductor have access to different levels of energy. In semiconductors, these levels are grouped in bands: The Conduction Band and the Valence Band. For insulators electrons are in the Valence Band, the energy gap between Conduction and Valence Band is large and leaves no possibility for electrons to move around. In semiconductors, the energy band gap is much smaller and the majority of the electrons will be in the valence band but some will reach the conduction band and be charge carriers. At higher temperatures, we reach the limit where the carrier density varies with temperature. In this case the conductivity follows Maxwell distribution with an exponential $R \propto e^{a/T}$. To conduct an experiment that would show this result we use a sample of germanium (Figure ....) connected to a thermocouple that measures the temperature of the crystal. The sample is cooled down with liquid nitrogen to approximately 150K. The temperature increase to room temperature and then a Dc power supply is used to power a heated connected to the sample to increase the temperature up to 383K. During the entire process a current source supply a constant current of 1mA to the crystal allowing us to measure different voltages (Figure ......). A digital multimeter (DMM) reads the different voltages of interest for the experiment and reads the temperature and current through the sample. These values are displayed on the apparatus and can be seen on a computer.

Before introducing next characteristic we are interested in the experiment, a common physical quantity, the mobility μ of the charge carriers, is defined as $\mu = \frac{\mathbf{v}}{\mathbf{E}} = \frac{\sigma}{ne}$. When a magnetic field is applied while current is driven through the sample, a force is induced separating the carriers in such a way that a potential difference is created across the sides of the sample. This potential is called the Hall Voltage V_H. This effect can also be quantified by the Hall coefficient defined to be $R_H = \frac{E_y}{J_x B} = \frac{V_H d}{IB} = \frac{1}{ne}$, where E_y is the magnitude of the electric field created by the charge pile-up , J_x is the current density in the sample, B is the magnitude of the magnetic field and d is the thickness of the sample (for a rectangle model perpendicular to the field). Another way to quantify the effect is the Hall angle $\phi_H = \frac{V_y}{V_x} = \frac{E_y w}{E_x l} = \frac{w}{l}\mu_H B$, where V_x is the Hall voltage drop across a width w on the sample, and V_y is the voltage drop across a length l on the sample. E_x and E_y are the corresponding electric fields and μ_H corresponds to the mobility.

In a semiconductor the charge carriers can be negative carriers (carrier density n) or positive carriers (carrier density p). The force induced by the magnetic field, thus, push them in opposite direction along a y direction according to the sign of the carriers. Realizing that the net current must be zero and using the previous definition we can obtain an equation for the Hall coefficient in terms of the mobilities and the carriers densities:

$$R_H = \frac{\mu_+^2 p - \mu_-^2 n}{e(\mu_+ p - \mu_- n)} \tag{1}$$

These mobilities very with temperature. When $p > n$ we expect R_H to change sign at some temperature (as p increases and n decreases with increasing temperature). Such semiconductors are said to be $p-type$. Semiconductors which has $n > p$ are said to be $n-type$.

2 Potential error

3 Function of conductance against temperature

A graph of resistance against temperature was done when the voltage V5 (Reference to graph of voltages) is applied to the sample and another one when the voltage V6 is applied (Refer to graph in the appendix). At low temperature when the conduction is mainly due to extrinsic process the number of carriers is constant and we expect it to follow a power law $R \propto T^b$ (as discussed in the introduction). At high temperature, the carrier density varies with temperature and the electrical conductivity follow Maxwell distribution $R \propto e^{a/T}$. For both V5 and V6 we fitted the graph of resistance versus temperature in the low temperature region with a power law equation $a \times (x - x_0)^{3/2} + b$, where the parameters are a, x_0 , and b. Also we fitted the graph in a high temperature region with a exponential decay equation $a \times e^{bx}$, where the parameters are $a$and b.

The parameters for the power law fit were found to be $a =$ .... , $b =$ .... and $x_0 =$ .... and the chi square is $\chi^2 =$ .... (Is there a better way of stating this). The parameters for the exponential fit were found to be $a =$ .... , $b =$ .... and the chi square is $\chi^2 =$ ....

The conductance now is just the inverse of the resistance $G = \frac{1}{R} \propto \frac{1}{\rho}$. The graph of the conductance will just appear to be the inverse of the graph of the resistance versus temperature.

Therefore the to fit equations are the inverse of the equations used to fit the low and high temperature region of the graphs of resistance versus temperature. In the low region we used $\frac{1}{}$

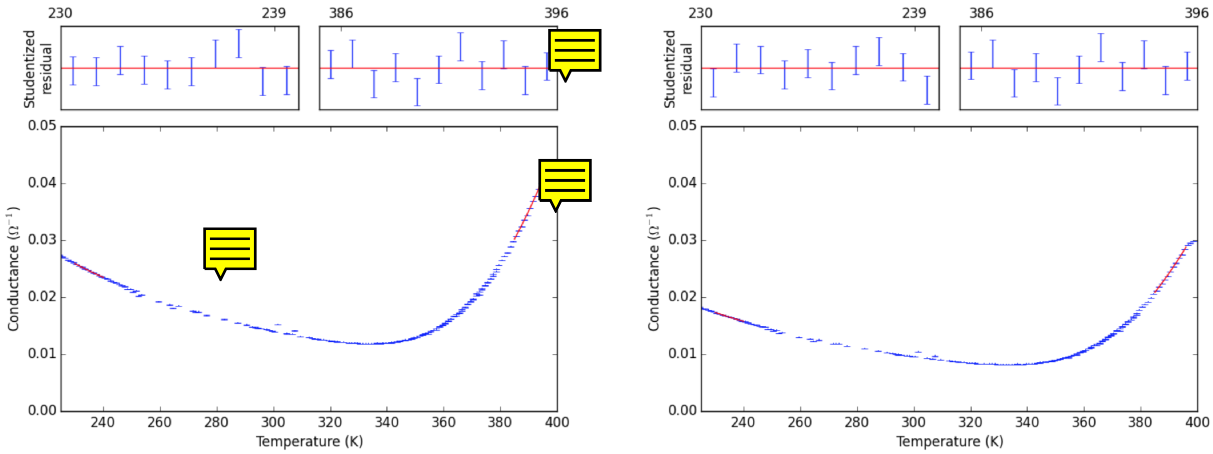

Figure 1: Fits at low and high temperature region for graphs of conductance versus temperature when V5 is applied and when V6 is applied.

4 Hall coefficient as a function of Temperature

5 Magneto-resistance against magnetic field intensity

6 Appendices

References