Temperature dependance of the resistance of germanium

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Abstract

In this report we go over how we fit a power and exponential functions to the resistance of a germanium sample at different temperatures (from 140K to 390K). The two fits, $0.00554(4)\Omega\mathrm{K}^{-3/2} \times (T - 120(1)\mathrm{K})^{3/2}$ and $12660(20)\Omega \times \exp(-0.026360(2)\mathrm{K}^{-1}T)$, with χ^2 of 2.1 and 7656, will allow us to compute the band gap of the germanium sample in a further experiment. The exponential fit to the high temperature region of the resistance is not reliable and further error analysis is required.

Contents

1 Introduction

The resistance of semiconductors like germanium is dependant on temperature. For negative charge carriers with density n and charge e for each charge, the current density related to the mean velocity $\mathbf{v}$ of the charge carriers by: $\mathbf{J} = en\mathbf{v}$.

For semiconductors the mean velocity is approximated to be:

$$\mathbf{v} \approx \frac{e\lambda\mathbf{E}}{2\sqrt{3kT \times m}}, \tag{1}$$

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 Eq. 1 and the fact that λ goes like $^1/_{kT}$ we find that the resistance$R$ is related to the temperature T.

$$R = a \cdot T^b \tag{2}$$

However equation 2 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. This experiment is a step towards measuring the band gap of germanium.

2 Function of resistance against temperature

To measure the resistance against the temperature, we will use the setup displayed in Fig. 1. A germanium sample is held in a thermos initially filled with liquid nitrogen. It is connected to a thermocouple, in turn plugged into a cold-junction compensator, and a digital voltmeter connected to a computer. The thermocouple allows us to measure the temperature of the sample, and the voltmeter gives the potential across the different junctions illustrated in Fig. 2. On the computer, homemade programs[1] called `hall` and `hall_process` allow us to, respectively, collect data from the voltmeter, and format the data into several more manageable files.

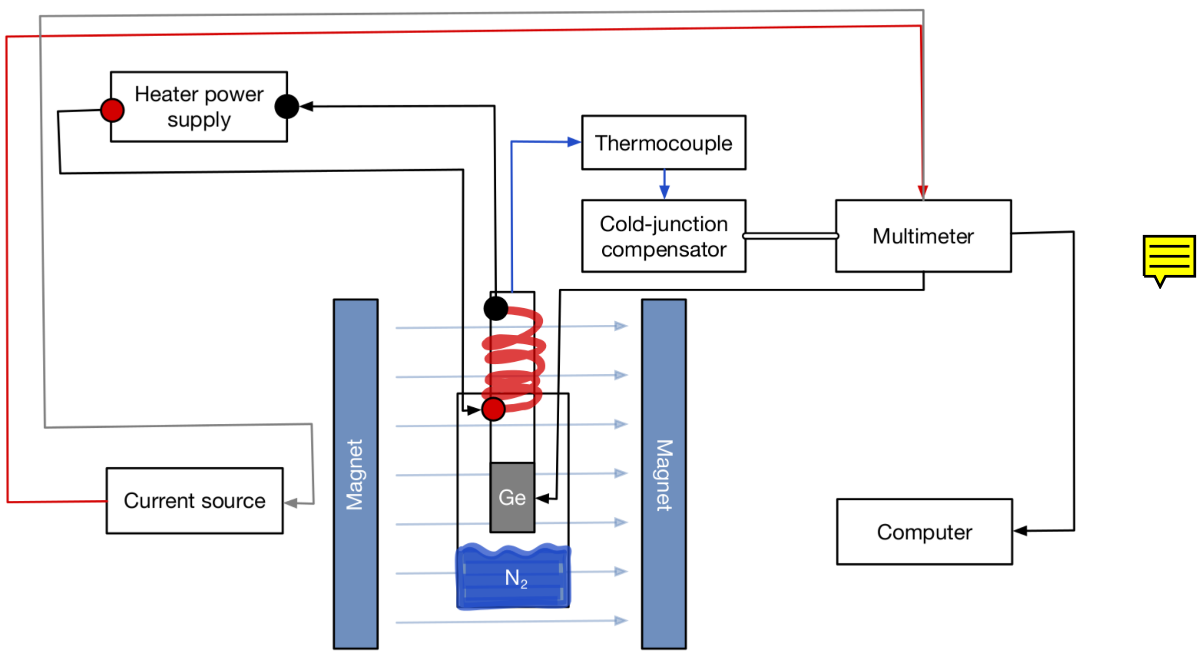

Figure 1: Apparatus and connections for the measurement of potential across the germanium sample as it warms from being cooled with liquid nitrogen.

To run the experiment, we turned on the current source at a constant $I_{fixed} = 100\text{mA}$, thermocouple, and multimeter. We cooled down the germanium sample with liquid nitrogen until the temperature stabilized, around 140K. During the experiment, we made sure the nitrogen could evaporate from the thermos, otherwise the sample wouldn't warm back up to

[1]Thanks Mark!

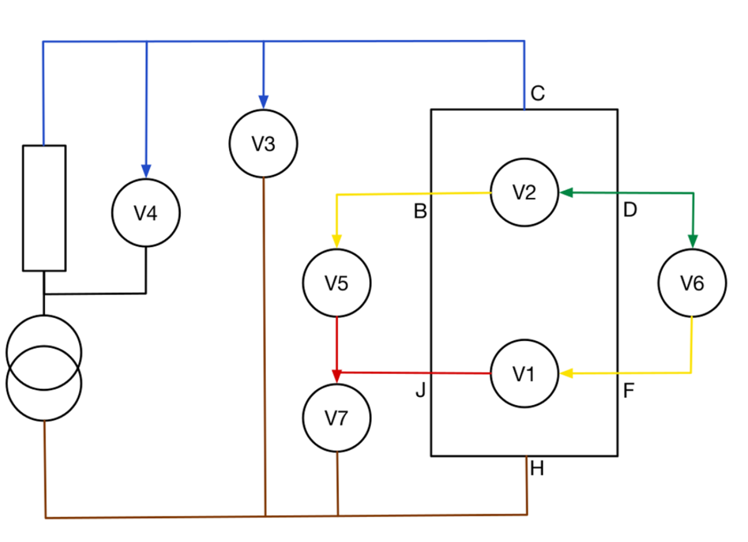

Figure 2: Points on the sample holder circuit where the potential is measured. V_5 and V_6 measure the potential across the germanium sample, and should in theory give the same result. In practice, systematic error due to the shape of the sample may make them different.

room temperature in any reasonable time. We did this by taking a paper towel to brush off the ice forming around the thermos. We used `hall` to check on the temperature. Once the temperature had stabilized, we restarted `hall` to get a data file with only the data we needed. When the temperature had reached 250K, we turned on the heater with a low potential to help bring the sample up to 400K. We raised the heater voltage each time the temperature stabilized again. Once the heater's power source had been set to its maximal output and an equilibrium had been reached, we turned off the current source, thermocouple, multimeter and heater.

To estimate the error on the measurements, we took another series of potential measurements at room temperature, and one with the heater on at equilibrium. The standard deviation of the potential at those temperature was then be used as the error for low and high temperatures, respectively. This gave a statistical uncertainty of 0.005V for low temperatures, and 0.00002V for high temperatures.

Plotting potential against temperature gave us vaguely bell shaped curves, as shown in Fig. 3. We fit a power function of the form $a(x - x_0)^{3/2}$ to the left side, and an exponential function $a \exp bx$ to the right side. The results for resistance $R = V/I$, against temperature on V_6 are shown in Fig. 4. The obtained functions are $0.00554(4)\Omega\text{K}^{-3/2} \times (T -$

$120(1)\mathrm{K})^{3/2}$ and $12660(20)\Omega \times \exp(-0.026360(3)\mathrm{K}^{-1}T)$, with χ^2 of 2.1 and 7656 respectively. The power fit is good and can be used for the further parts fo the experiment. The exponential fit is not reliable, considering its large χ^2, and the error analysis on it should be reviewed before we move on.

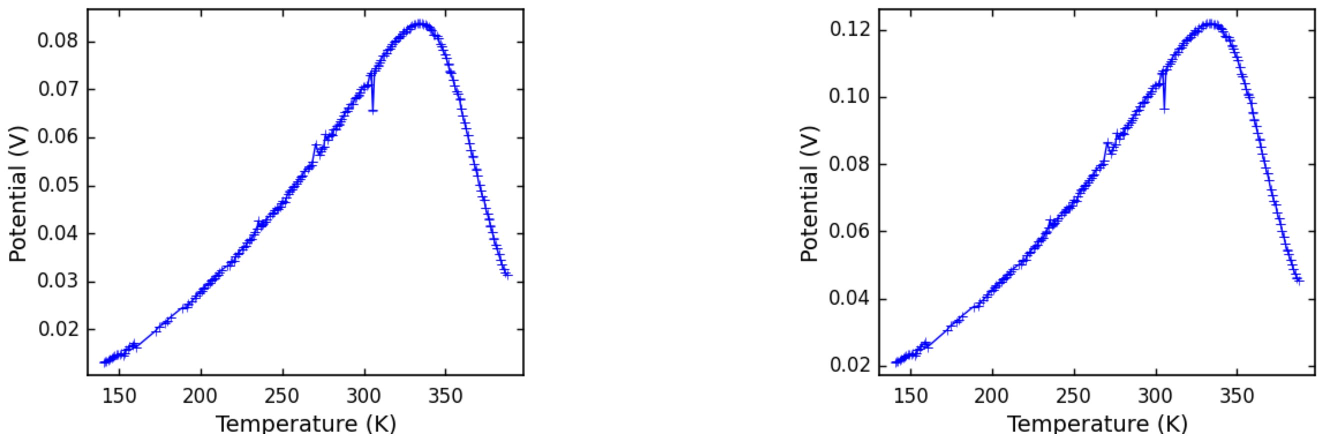

Figure 3: Potential V_5 (on the left) and V_6 (on the right) against temperature

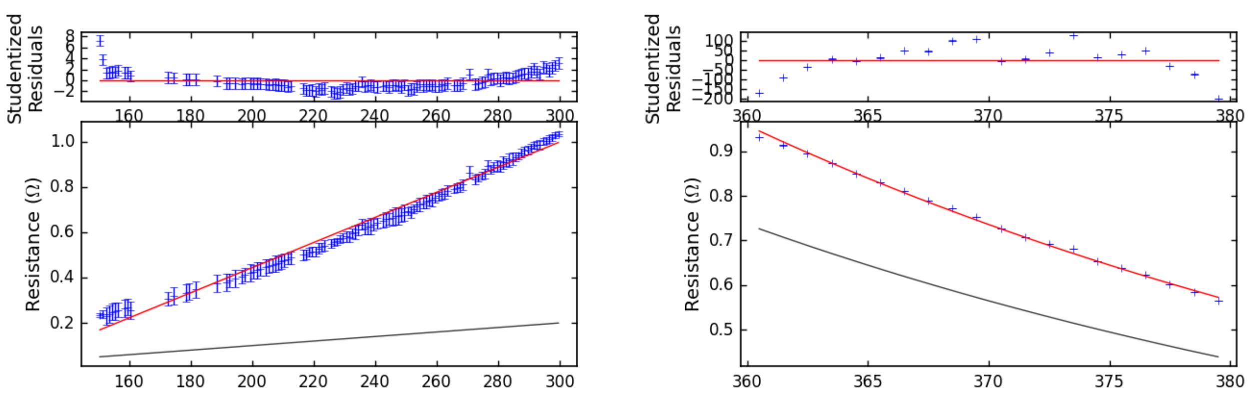

Figure 4: Results for the power (left) and exponential (right) fits of the sample resistance against temperature

References