FAKULTÄT FÜR PHYSIK
Praktikum Moderne Physik

Praktikum: P4 Gruppe: 22 ■ Mo ☐ Mi **WS20/21**

Zutreffendes bitte ausfüllen

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Versuch: Tiefe Temperaturen

Betreuer: Daria Gusenkova Durchgeführt am: 18.01.202

Wird vom Betreuer ausgefüllt.

1. Abgabe am: ____________

Rückgabe am: ____________ Kommentar:

2. Abgabe am: ____________

Ergebnis: + / 0 / - Handzeichen: ____________

Datum: ____________ Kommentar:

Contents

1. Theory & Preparation

1.1 Aim of the experiment

The low temperature properties of different solids are determined in the experiment. Especially the electrical resistance of metals, semiconductors and superconductors. We expect a phase shift for the superconductor which requires special consideration.

1.2 Electrical resistance of metals

A simple description with the Drude model can be used for metals. The electrons are accelerated in an electric field and scattered at the atomic cores after a mean free path. It follows for the electrical conductivity:

$$\sigma = \frac{ne^2\tau}{m_e} \tag{1.1}$$

where n is the charge carrier density, τ is the mean free time, and e is the elementary charge. The temperature dependent conductivity follows from the mean free time τ. This is due to the scattering of electrons by phonons and impurities in the lattice. The resistivity is given by $\sigma = \frac{1}{\rho}$ to Matthiessen's rule:

$$\rho = \rho_{ph}(T) + \rho_{im} \tag{1.2}$$

The scattering at impurities is independent of temperature and is reflected in a constant residual resistance. The following temperature dependencies apply to phonon scattering:

- For high temperatures ($T > \Theta_D$, with Θ_D Debye temperature).

$$\rho_{ph} \propto T \tag{1.3}$$

- For low temperatures ($T < \Theta_D$)

$$\rho_{ph} \propto T^5 \tag{1.4}$$

Where for high temperatures, according to Grüneisen-Bornelius, one can determine the Debye temperature with:

$$R_T = 1,17\frac{R(\Theta_D)}{\Theta_D}T - 0,17 \cdot R(\Theta_D) \tag{1.5}$$

1.3 Semiconductors

Semiconductors are very different from normal conductors like metals. For $T \to 0$ the valence band is completely filled and the conduction band is empty. One can distinguish between intrinsic and extrinsic semiconductors.

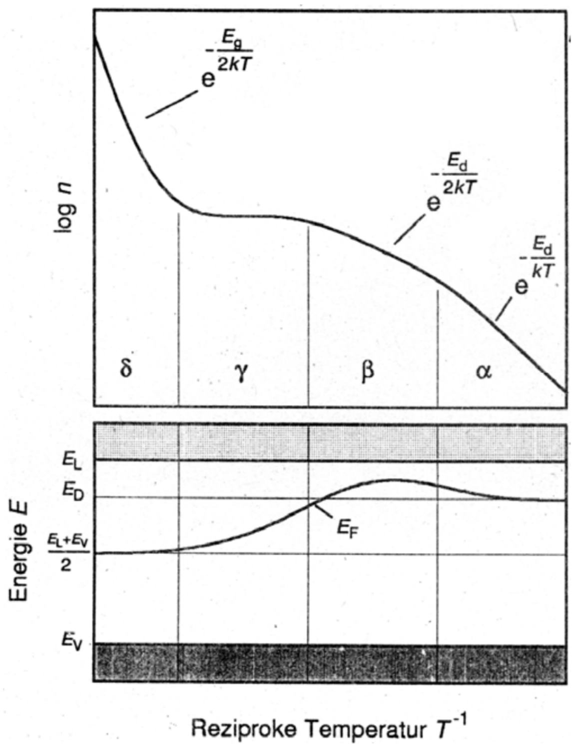

Figure 1.1: Temperature dependent charge carrier concentration in extrinsic semiconductors.

1.3.1 Intrinsic semiconductor

Since neither a full valence band nor an empty conduction band contributes to charge transport, the electrons have to overcome an energy gap E_{gap} to the next band. This is done by thermal excitation, which is obviously temperature dependent. Thus for the electrical conductivity follows:

$$\sigma_{tot} = \sigma_e + \sigma_h = n_i e(\mu_e + \mu_h) \tag{1.6}$$

where n_i corresponds to the electron / hole density and μ to the corresponding mobility. In the end, the following equation is obtained:

$$\sigma_i = C_i \exp\left(-\frac{E_{gap}}{2k_B T}\right) \tag{1.7}$$

Thus, the electrical conductivity approaches the constant C_i asymptotically.

1.3.2 Extrinsic semiconductor

By doping a semiconductor, its conductivity can be strongly increased. In this process impurities of the neighboring main group are added. These atoms either donate electrons (donors) or accept electrons (acceptors) and produce a n/p doped semiconductor. Sub-energy levels are created in the band gap which can be excited more easily. This results in a complicated temperature profile with $\sigma = en\mu$.

1.4 Superconductors

1.5 Experimental setup

2. Experiment & Evaluation

2.1 Experimental setup

2.2 Conclusion