Exercise 01: Semiconductor properties

Task 1.1: Properties of germanium as semiconductor

The following problems explore fundamental semiconductor properties of germanium. Starting with atomic concentration and intrinsic resistivity, the tasks gradually introduce doping effects and compare the electrical behavior of intrinsic and extrinsic materials under simplified assumptions. Take the values from Tab. 1.1.1.

Intrinsic concentration n_i:	$2.5 \cdot 10^{13}$ 1/cm^3
Mobility μ_p:	$1800\ \frac{\mathrm{cm}^2}{\mathrm{Vs}}$
Mobility μ_n:	$3800\ \frac{\mathrm{cm}^2}{\mathrm{Vs}}$
Atomic weight a_ger:	$72.6\ \frac{\mathrm{g}}{\mathrm{mol}}$
Material density D_ger:	5.32 g/cm^3

Table 1.1.1: key figures of germanium at 300 K.

1.1.1 Using Avogadro's number ($N_{Av} = 6.02 \cdot 1023\ \mathrm{mol}^{-1}$), calculate the concentration of atoms in germanium.

1.1.2 Calculate the resistivity of intrinsic germanium at 300 K.

1.1.3 If a donor-type impurity is added to the extent of 1 part in 10^8 germanium atoms, find the resistivity.

1.1.4 If germanium were a monovalent metal, find the ratio of its conductivity to that of the n-type semiconductor in previous subtask.

Task 1.2: Energy level and silicon semiconductor behaviour.

1.2.1 Calculate the frequency of revolution for an electron in the ground state of hydrogen. For comparison, find the frequency emitted when an electron with the mass $m_\mathrm{e} = 9.11 \cdot 10^{-31}$ kg of falls from the state $n = 2$ to the ground state $n = 1$. Take in account, that $W_\mathrm{kin}(n) \propto \frac{1}{n^2}$ and the ground state orbit r corresponds to 0.0529 nm.

1.2.2 Find the room-temperature resistivity of an n-type silicon doped with 10^{16} phosphorus atoms/cm^3.

1.2.3 A sample of Si is doped with 10^{16} phosphorus atoms/cm^3. Find the Hall voltage in a sample with $l_\mathrm{w} = 500$ µm, $A = 2.5 \cdot 10^{-3}$ cm^2, $I = 1$ mA, and $B_\mathrm{z} = 10^{-4}\ \frac{\mathrm{Wb}}{\mathrm{cm}^2}$.

1.2.4 Assume that, in an n-type semiconductor at $T = 300$ K, the electron concentration varies linearly from 10^{18} 1/cm^3 to $7 \cdot 10^{17}$ 1/cm^3 over a distance of 0.1 cm. Calculate the diffusion current density if the electron diffusion coefficient is $D_n = 22.5\ \frac{\mathrm{cm}^2}{\mathrm{s}}$.

1.2.5 Minority carriers (holes) are injected into a homogeneous n-type semiconductor sample at one point. An electric field of 50 V/cm is applied across the sample, and the field moves these minority carriers a distance of 1 cm in 100 µs. Find the drift velocity and the diffusivity of the minority carriers. The temperature is 300 K.

Task 1.3: Quality assessment at doping of silicon semiconductor

A silicon semiconductor is to be doped for a specific application. To assess the doping quality, the resistivity of a sample is measured before and after the process. The assessment is performed at a temperature of $T = 300$ K.

Intrinsic concentration n_i:	$1.5 \cdot 10^{10}$ cm^3
Mobility μ_p:	$480\ \frac{\mathrm{cm}^2}{\mathrm{Vs}}$
Mobility μ_n:	$1350\ \frac{\mathrm{cm}^2}{\mathrm{Vs}}$

Table 1.3.1: key figures of silicon.

1.3.1 Calculate the expected resistivity of silicon before doping.

1.3.2 Calculate the expected resistivity of silicon at $T = 300$ K after doping with arsenic impurities with concentration $N_d = 2 \cdot 10^{16}$ cm^3.

Task 1.4: Hall sensor for magnetic field measurement

A bar of type p silicon, of thickness $d = 0.5$ mm, with impurity concentration $N_a = 10^{14}$ cm^3, is used as a Hall sensor. See also Fig. 1.4.1.

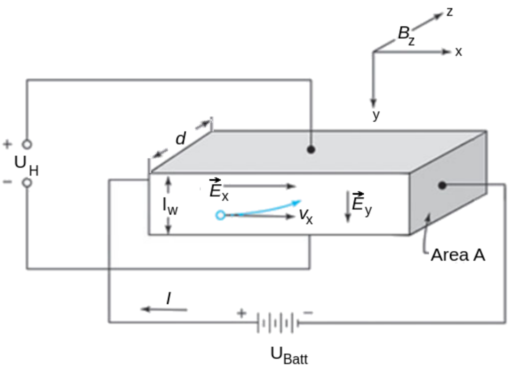

Figure 1.4.1: Silicon semiconductor bar as Hall-sensor.

1.4.1 Calculate the Hall voltage for a probe current of 100 mA and a magnetic field perpendicular to the plane of $B = 0.1$ T.

Remark: This example shows that for magnetic fields with intensities typical of those used in laboratories, the Hall voltage has a relatively high value for electronic circuits. This does not happen in metals, because the concentration of free electrons $\approx 10^{22}\,\frac{1}{\mathrm{cm}^3}$ is much larger than in semiconductors, and thus the voltage is quite small.