Band gap of Germanium (Item No.: P2530402)

Curricular Relevance

Area of Expertise: Physics

Education Level: University

Topic: Modern Physics

Subtopic: Molecule and Solid State Physics

Experiment: Band gap of germanium

Difficulty	**Preparation Time**	**Execution Time**	**Recommended Group Size**
Difficult	1 Hour	2 Hours	2 Students

Additional Requirements:

Experiment Variations:

Keywords:

Semiconductor, band theory, forbidden band, intrinsic conduction, extrinsic conduction, impurity depletion, valence band, conduction band

Overview

Short description

Principle

The conductivity of a germanium testpiece is measured as a function of temperature. The energy gap is determined from the measured values.

Fig.1: Experimental set-up for the determination of the band gap of germanium

Equipment

Position No.	Material	Order No.	Quantity
1	PHYWE Hall-effect unit HU 2	11801-01	1
2	Intrinsic conductivity Ge, carrier board	11807-01	1
3	Digital multimeter 2005	07129-00	2
4	PHYWE power supply, 230 V, DC: 0...12 V, 2 A / AC: 6 V, 12 V, 5 A	13506-93	1
5	Tripod base PHYWE	02002-55	1
6	Support rod, stainless steel, l = 250 mm, d = 10 mm	02031-00	1
7	Right angle clamp PHYWE	02040-55	1
8	Connecting cord, 32 A, 250 mm, red	07360-01	1
9	Connecting cord, 32 A, 250 mm, blue	07360-04	1
10	Connecting cord, 32 A, 500 mm, black	07361-05	2

Tasks

1. The current and voltage are to be measured across a germanium test-piece as a function of temperature.
2. From the measurements, the conductivity σ is to be calculated and plotted against the reciprocal of the temperature T. A linear plot is obtained, from whose slope the energy gap of germanium can be determined.

Set-up and procedure

Set-up

The experimental set-up is shown in Fig.1. The test specimen has to be put into the hall-effect-module via the guide-groove. The module is directly connected with the $12\,\mathrm{V}\sim$ output of the power unit over the ac-input on the backside of the module.

The plate has to be brought up to the magnet very carefully, so as not to damage the crystal in particular, avoid bending the plate. It has to be in the centre between the pole pieces.

The Hall voltage and the voltage across the sample are measured with a multimeter. Therefore, the sockets on the front-side of the module are used. The current and temperature can be easily read on the integrated display of the module.

The magnetic field has to be measured with the teslameter via a Hall probe, which can be directly put into the groove in the module as shown in Fig. 1. So, you can be sure that the magnetic flux is measured directly on the Ge-sample.

Procedure

At the beginning, set the current I_p to a value of $5\,\mathrm{mA}$. The current I_p remains nearly constant during the measurement, but the voltage changes U_p according to a change in temperature T. Set the display in the temperature mode and be sure, that the display works in the temperature mode during the measurement. Start the measurement by activating the heating coil with the ”on/off”-knob on the backside of the module. The specimen will be heated to a maximum temperature of around $145-150\,^\circ\mathrm{C}$ and the module will stop the heating automatically. Determine the cooling curve of the change in voltage U_p depending on the change in temperature T for a temperature range from $145^\circ\mathrm{C}$ to room temperature. You will recieve a typical curves as shown in Fig. 2 below.

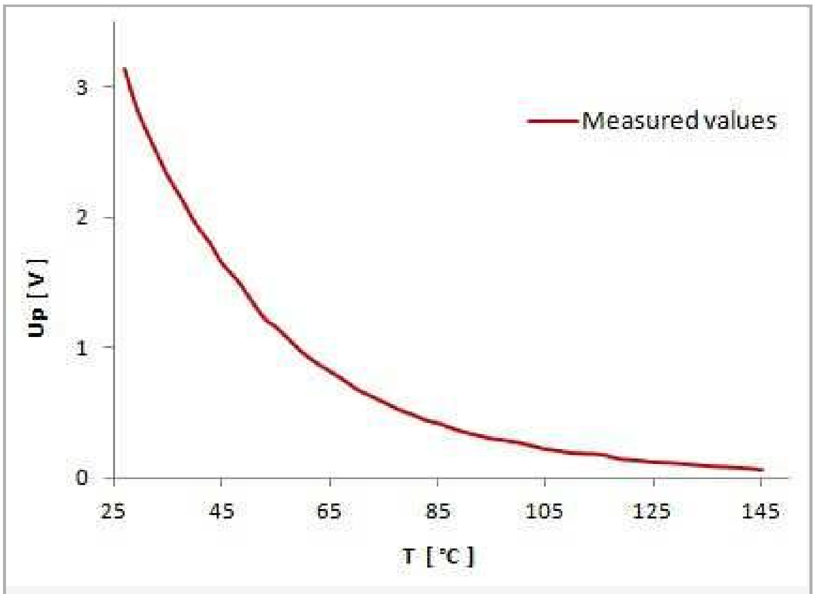

Fig.2: Typical measurement of the probe-voltage as a function of the temperature

Theory and evaluation

The conductivity s is defined as following:

$$\sigma = \frac{1}{\rho} = \frac{l \cdot I}{A \cdot U}\left[\frac{1}{\Omega \mathrm{m}}\right]$$

with ρ = resistivity, l = length of test specimen, A = cross section, I = current, U = voltage. (Dimensions of Ge-plate $20 \times 10 \times 1\,\mathrm{mm}^3$)

The conductivity of semiconductors is characteristically a function of temperature. Three ranges can be distinguished: at low temperatures we have extrinsic conduction (range I), i.e. as the temperature rises charge carriers are activated from the impurities. At moderate temperatures (range II we talk of impurity depletion, since a further temperatue rise no longer produces activation of impurities. At high temperatures (range III), it is intrinsic conduction which finally predominates (see Fig. 3). In this instance charge carriers are additionally transferred by thermal excitation from the valence band to the conduction band. The temperature dependence is in this case essentially described by an exponential function.

$$\sigma = \sigma_0 \cdot \exp\left(-\frac{E_\mathrm{g}}{2kT}\right)$$

(E_g = energy gap, k = Boltzmann’s constant, T = absolute temperature).

The logarithm of this equation

$$\ln\sigma = \ln\sigma_0 - \frac{E_\mathrm{g}}{2kT}$$

is with $y = \ln\sigma$ and a linear equation on the type $y = a + bx$, where

$$b = -\frac{E_\mathrm{g}}{2k}$$

is the slope of the straight line.

With the measured values from Fig. 2, the regression with the expression

$$\ln\sigma = \ln\sigma_0 - \frac{E_\mathrm{g}}{2k} \cdot \frac{1}{T}$$

provides the slope $b = (4.05 \pm 0.06) \cdot 10^3\,\mathrm{K}$ (Fig. 4).

With the Boltzmann’s constant $k = 8.625 \cdot 10^{-5}\,\mathrm{eV}$, we finally obtain

$E_\mathrm{g} = b \cdot 2k = (0.69 \pm 0.01)\,\mathrm{eV}$. (Literature value $0.67\ \mathrm{eV}$)

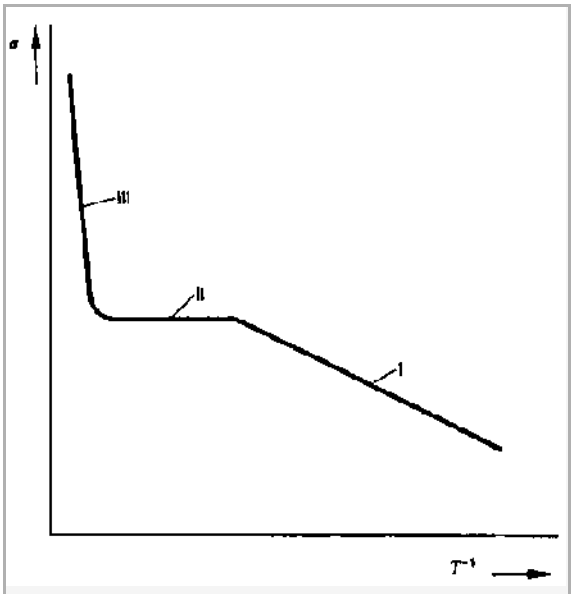

Fig.3: Conductivity of a semi-conductor as a function of the reciprocal of the temperature

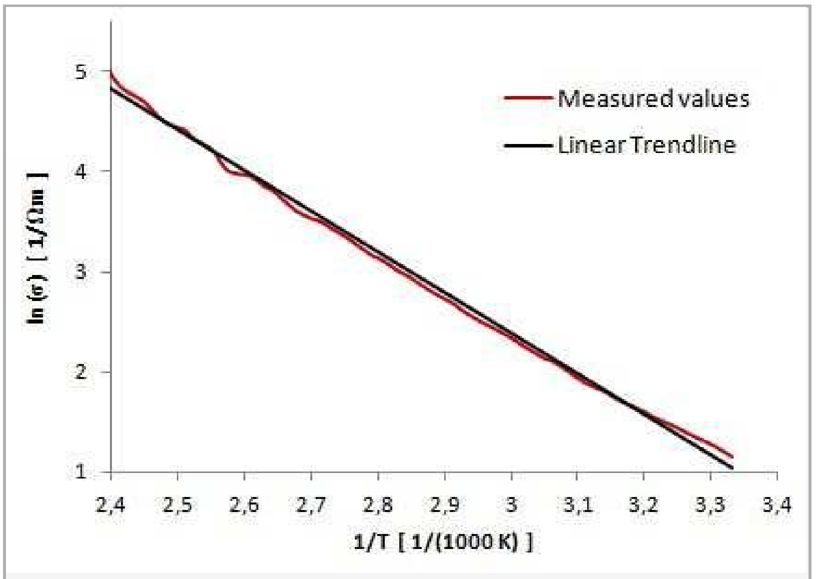

Fig.4: Regression of the conductivity versus the reciprocal of the absolute temperature