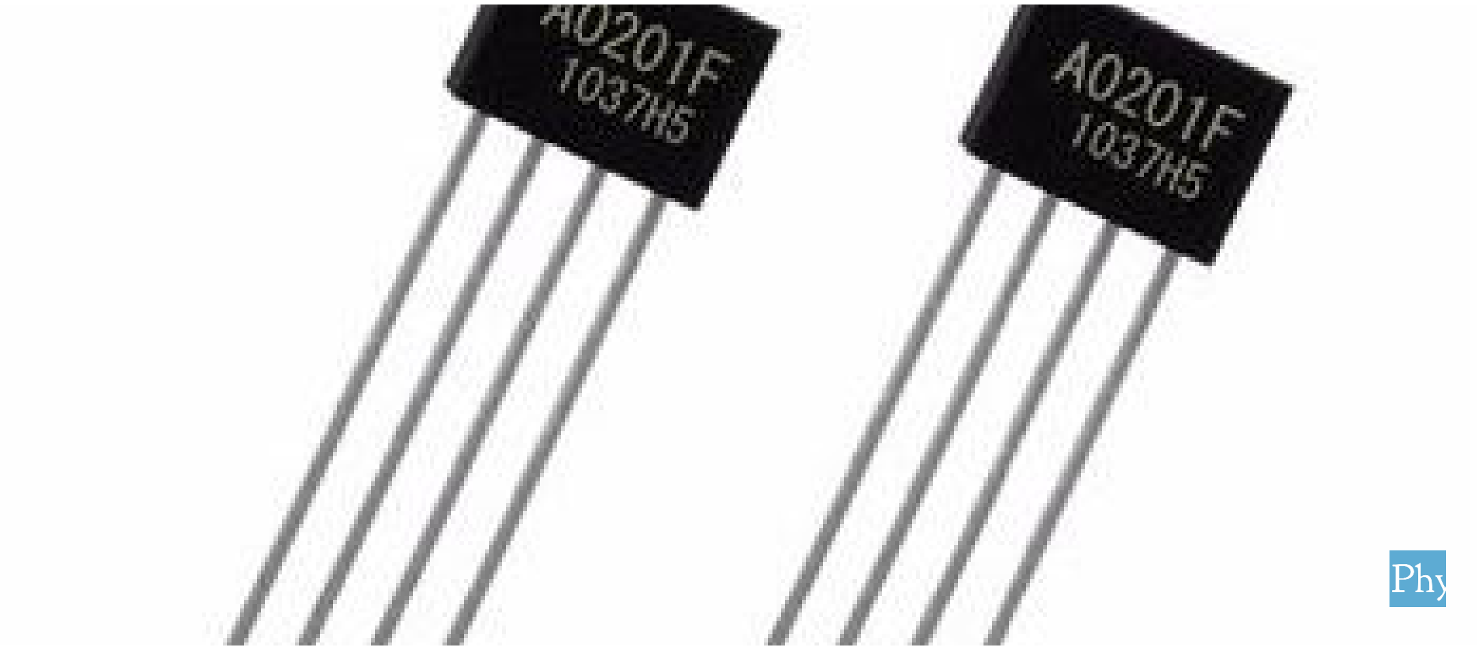
Hall effect in n- and p-germanium (PC)



Physics | Modern Physics | Solid state physics

Difficulty level	Group size	Preparation time	Execution time
hard	2	45+ minutes	45+ minutes

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General information

Application

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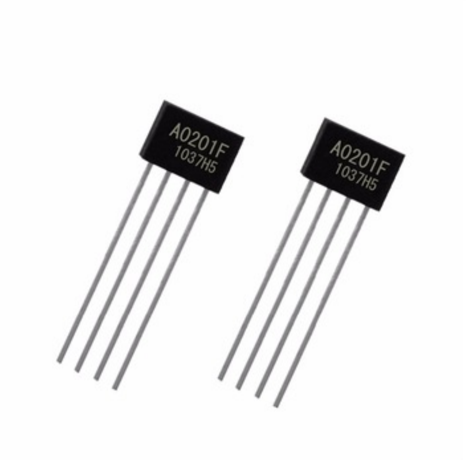


Hall effect sensor

A Hall effect sensor consists basically of a thin piece of rectangular p-type semiconductor material such as gallium arsenide (GaAs), indium antimonide (InSb) or indium arsenide (InAs) passing a continuous current through itself.

This electronic device is used to detect the Hall effect and measure the magnitude of a magnetic field.

The Hall Effect sensors are in high demand and used widely in proximity sensors, switches, wheel speed sensors and positioning sensors etc.

Other information (1/3)

Prior knowledge

P-type and n-type semiconductors are created by doping an intrinsic semiconductor with an electron acceptor and electron donor element during manufacture, respectively. The term n-type comes from the negative charge of the electron. In p-type semiconductors, holes are the majority carrier and electrons are the minority carriers, opposingly, in n-type semiconductors, electrons are the majority carriers and holes are the manority carriers.

Scientific principle

The resistivity and Hall voltage of a rectangular germanium sample are measured as a function of temperature and magnetic field. The band spacing, the specific conductivity, the type of charge carrier and the mobility of the charge carriers are determined from the measurements.

Other information (2/3)

Learning objective

To understand electrical conduction mechanisms in doped germanium with the Hall effect.

Tasks

- The Hall voltage U_H is measured at room temperature and constant magnetic field as a function of the control current I_p.
- The voltage across the sample U_p is measured at room temperature and constant control current as a function of the magnetic induction B.

Other information (3/3)

Tasks

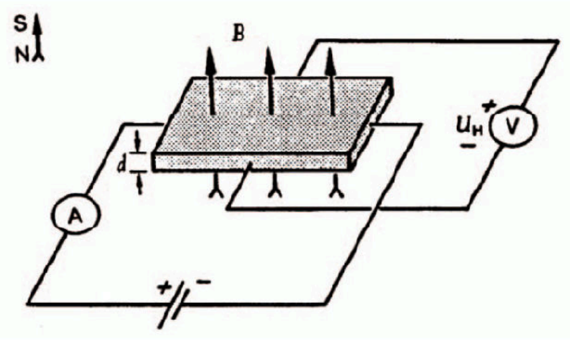
- The voltage across the sample U_p is measured at constant control current as a function of the temperature T. The band spacing of p- and n-germanium is calculated from the measurements.
- The Hall voltage U_H is measured as a function of the magnetic induction B, at room temperature. The sign of the charge carriers and the Hall constant R_H together with the Hall mobility μH and the carrier concentration p are calculated from the measurements.
- The Hall voltage U_H is measured as a function of temperature T at constant magnetic induction.

Safety instructions

For this experiment the general instructions for safe experimentation in science lessons apply.

Be aware of the values of magnetic field, the flowing current and the temperature to avoid damaging the semiconductor material.

Theory (1/5)



Hall effect on a rectangular specimen

If a current I flows through a conducting strip of rectangular section and if the strip is traversed by a magnetic field at right angles to the direction of the current, a voltage - the so-called Hall voltage - is produced between two superposed points on opposite sides of the strip.

This phenomenon arises from the Lorentz force: the charge carriers giving rise to the current flowing through the sample are deflected in the magnetic field BB as a function of their sign and their velocity *v*:

$$\vec{F} = e(\vec{v} \text{ x } \vec{B})$$

where *F* is the force acting on charge carriers and *e* is elementary charge.

Theory (2/5)

Since negative and positive charge carriers in semiconductors move in opposite directions, they are deflected also in opposite directions.

The type of charge carrier causing the flow of current can, therefore, be determined from the polarity of the Hall voltage, knowing the direction of the current and that of the magnetic field.

That means: if the direction of the current and magnetic field are known, the polarity of the Hall voltage tells us, whether the current is predominantly due to the drift of negative chrgers or to the drift of positive chargers.

For both n-Germanium and p-Germanium, there is a linear relationship between the Hall voltage U_H and the control current I_p :

$$U_H = \alpha I_p$$

Theory (3/5)

The change in resistance of the sample due to the magnetic field is associated with a reduction in the mean free path of the charge carriers. Since the current is constant during the measurement, the change of resistance is calculated as

$$\frac{R_m - R_0}{R_0} = \frac{U_m - U_0}{U_0}$$

where R_m , U_m are resistance and voltage of the sample with the existence of a magentic field and are the resistance R_0 , U_0 and voltage of the sample when the magnetic field B = 0.

In the region of intrinsic conductivity, we have

$$\sigma = \sigma_0 . exp(\frac{E_g}{2kT})$$

where σ = conductivity, E_g= energy of bandgap, k = Boltzmann constant, T = absolute temperature.

Theory (4/5)

By taking the logarithm of both sides of the above equation, we get

$$ln\,\sigma = ln\,\sigma_0 + \frac{E_g}{2k} T^{-1}$$

If the logarithm of the conductivity $ln\,\sigma$ is plotted against the reciprocal of the temperature T^{-1} , a linear relationship is obtained with a slope from which can be determined.

With the directions of control current and magnetic field, the charge carriers giving rise to the current in the sample are deflected towards the front edge of the sample. Therefore, if (in an n-doped probe) electrons are the predominant charge carriers, the front edge will become negative, and, with hole conduction in a p-doped sample, positive.

Theory (5/5)

The conductivity σ_0 , the charge carrier mobility μ_H , and the charge carrier concentration *p* are related through the Hall constant R_H :

$$R_H = \frac{U_H}{B} . \frac{d}{l}$$

$$\mu_H = R_H . \sigma_0$$

$$p = \frac{1}{e} . R_H$$

The conductivity at room temperature is calculated from the sample length *l* , the sample cross-section *A* and the sample resistance *R* as follows:

$$\sigma_0 = \frac{l}{R.A}$$

Equipment

Position	Material	Item No.	Quantity
1	PHYWE Hall-effect unit HU 2	11801-01	1
2	Hall effect, p-Ge, carrier board	11805-01	1
3	Hall effect, n-Ge, carrier board	11802-01	1
4	measureLAB, multi-user license	14580-61	1
5	Hall probe, tangential, protection cap	13610-02	1
6	PHYWE Power supply, 230 V, DC: 0...12 V, 2 A / AC: 6 V, 12 V, 5 A	13506-93	1
7	Coil, 600 turns	06514-01	2
8	Iron core, U-shaped, laminated	06501-00	1
9	Pair of pole pieces, plane, 30 x 30 x 48 mm	06489-00	1
10	Tripod base PHYWE	02002-55	1
11	Right angle clamp expert	02054-00	1
12	Support rod, stainless steel, l = 250 mm, d = 10 mm	02031-00	1
13	Connecting cord, 32 A, 500 mm, red	07361-01	2
14	Connecting cord, 32 A, 500 mm, blue	07361-04	1
15	Connecting cord, 32 A, 750 mm, black	07362-05	2

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Setup and procedure

Setup (1/4)

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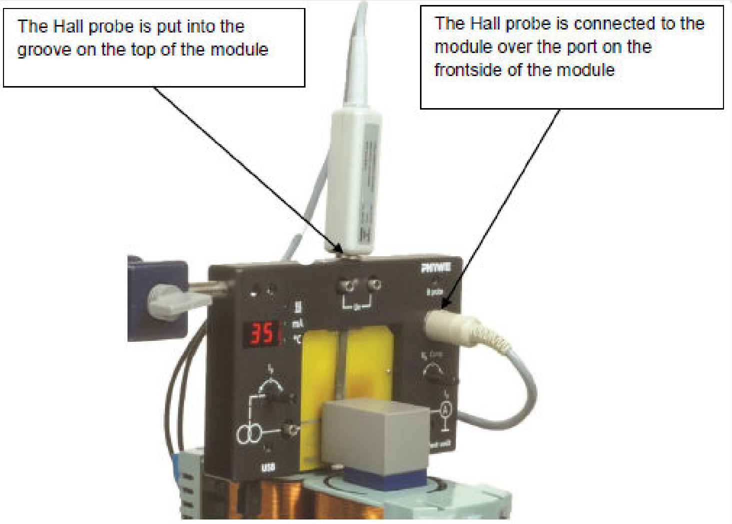
Experimental set-up

The test specimen has to be put into the hall-effect-module via the guide-groove. The module is directly connected with the 12V~ 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 center between the pole pieces.

The USB port on the bottom of the module is used to connect the module to the Laptop with a USB cable.

Setup (2/4)



The Hall probe is put into the groove on the top of the module

The Hall probe is connected to the module over the port on the frontside of the module

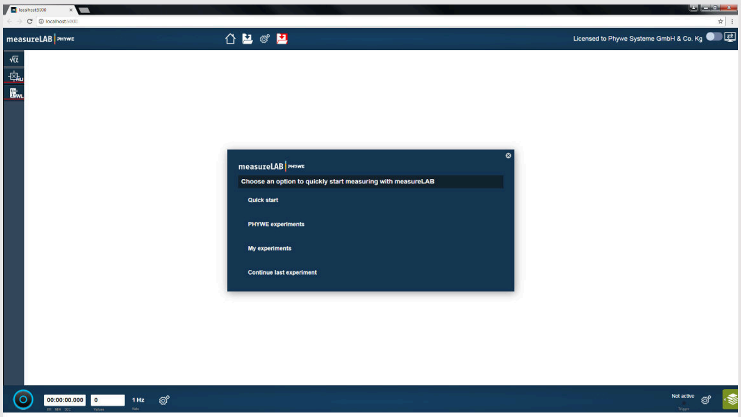
Connection of the Hall probe to the module

The different measurements are controlled by the software measureLAB.

The magnetic field is measured via a Hall probe, which is connected to the module over the port on the frontside of the module, and it can be directely put into the groove on the top of the module, to ensure that the megnetic flux is measured directely on the test specimen.

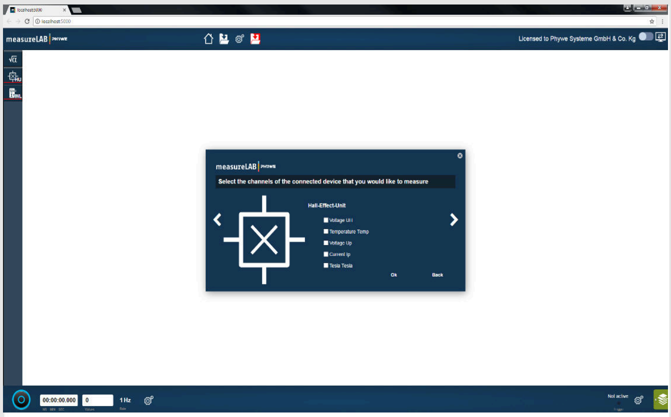
To start the measurements, start the software "measureLAB" and choose the option "Quick start" from the main page. You will recieve the start-screen, which appears before every measurement.

Setup (3/4)



Choose an option to quickly start measuring with measureLAB

Main page of measureLAB



Select the channels of the connected device that you would like to measure

Hall-Effect-Unit

☐ Voltage UH
☐ Temperature Temp
☐ Voltage Up
☐ Current Ip
☐ Tesla Tesla

Start-screen that appears before every

Setup (4/4)

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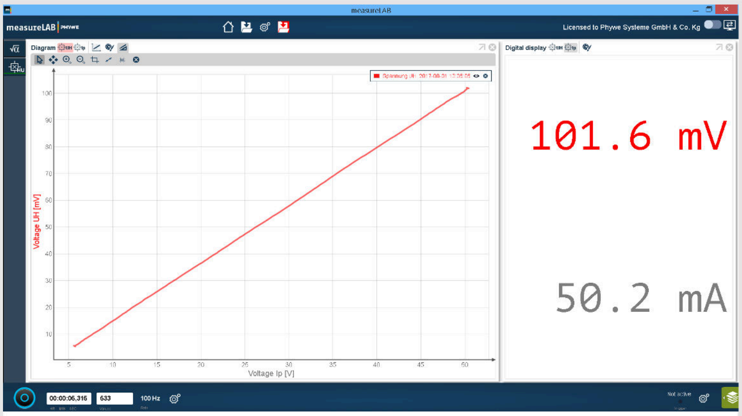

Example of measurement parameters

Here you can choose which parameters have to be measured, displaced, etc.

For example, choose the Hall voltage U_H as a function of the current I_p, and click ok, then you will receive the measurement screen. On this screen, you can start the measuement by clicking on the blue bottom in the lower right corner of the screen.

The measured values will appear graphically on the "Diagram" and as digital values on the "Digital display",

Procedure (1/3)

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Task 1:

Choose the Hall voltage U_H , the current I_P and the magnetic field "Tesla" as measurement parameters from the start screen and click "Ok". Set the current and the magnetic field to zero and calibrate the Hall voltage U_H to zero. Now, set the magnetic field to a value of 250 mT by changing the voltage and current on the power supply. Determine the Hall voltage U_H as a function of the current I_P from -30 mA to 30mA in steps of 5 mA. You will receive a typical measurements for n- and p-Germanium.

Task 2:

Choose the sample voltage U_p , the current I_P and the magnetic field "Tesla" as measurement parameters from the start screen and click "Ok". Set the control current I_P to 30 mA. Determine the sample voltage U_p as a function of the positive magnetic induction B up to 300 mT. Calculate the change in resistance of the specimens from the measurements and plot the results on graphs.

Procedure (2/3)

Task 3:

Choos the sample voltage U_p , the current and the temperatue "Temp" as measurement parameters from the start screen and click "Ok". At the beginning, set the current I_P to a value of 30 mA. The magnetic field is off. The current remains nearly constant during the measurement, but the voltage U_P changes according to a change in temperature *T*. 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 °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 140°C to room temperature. Typical curves will be obtained.

Procedure (3/3)

Task 4:

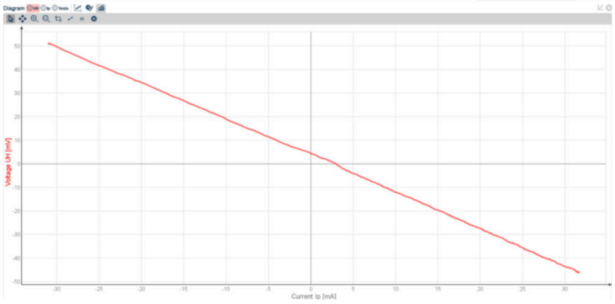
Choos the Hall voltage U_H , the current I_p and the magnetic field "Tesla" as measurement parameters from the start screen and click "Ok". Set the current I_p and the magnetic field to values of zero and calibrate the Hall voltage U_H to zero. Now, set the current to a value of 30 mA. Determine the Hall voltage U_H as a function of the magnetic induction *B*. Start with -300 mT by changing the polarity of the coil-current on the power supply and increase the magnetic induction in steps of nearly 20 mT. At zero point, you have to change the polarity again.

Task 5:
Choos the Hall voltage U_H , the current I_p , the temperature "Temp" and the magnetic field "Tesla" as measurement parameters from the start screen and click "Ok". Set the current to 30 mA and the magnetic induction to 300 mT. Following the same procedure in task 3, determine the Hall voltage U_H as a function of the temperature *T*.

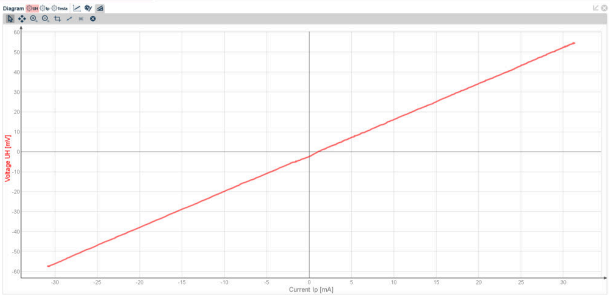
Evaluation (1/11)

Task 1:

Since the charge carriers in n- and p-Germanium are different, the trend of the linear relationship between U_H and I_p is reversed, with B = 250 mT and T = 300 K.



n-Germanium

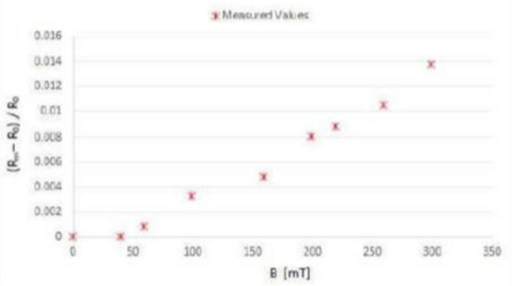


p-Germanium

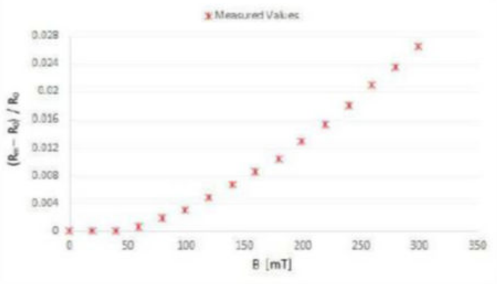
Evaluation (2/11)

Task 2:

The non-linear change in resistance as the field strength increases for n- and p-Germanium with $I_p = 30mA$ and $T = 300K$.



n-Germanium



p-Germanium

Evaluation (3/11)

Task 3:

The slopes of the regression lines are

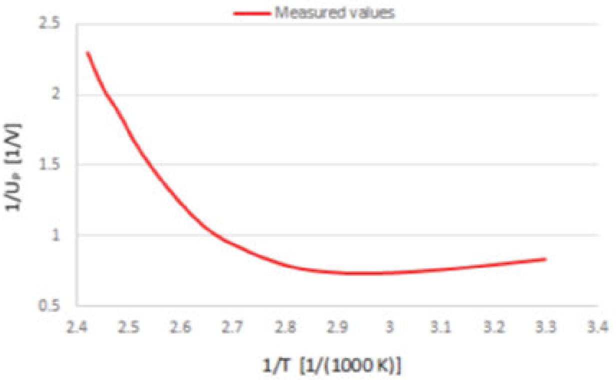
$b = -\frac{E_g}{2k} = -2.87.10^3$ with a standard deviation $s_b = \pm 0.3.10^3 K$ for n-Germanium, and
$b = -\frac{E_g}{2k} = -4.18.10^3$ with a standard deviation $s_b = \pm 0.07.10^3 K$ for p-Germanium.

Since $k = 8.625.10^{-5} \frac{eV}{K}$, we get

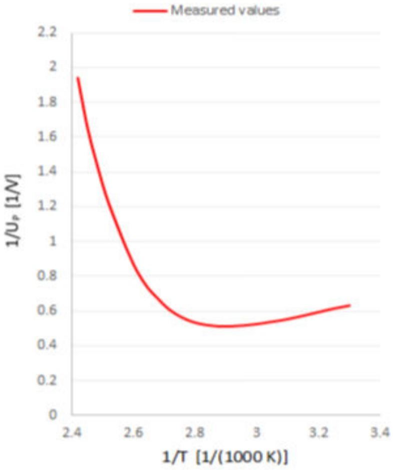
$E_g = b.2k = (0.05 \pm 0.04)eV$ for n-Germanium, and
$E_g = b.2k = (0.72 \pm 0.03)eV$ for p-Germanium.

Reciprocal sample voltage $1/U_p$ plotted as a function of reciprocal absolute temperature $1/T$ with $I_p = 30mA$ and no magnetic flux.

Evaluation (4/11)



n-Germanium

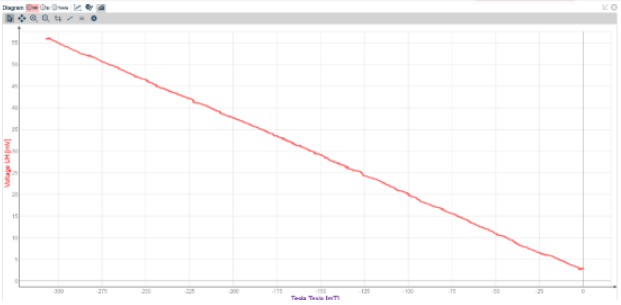


p - Germanium

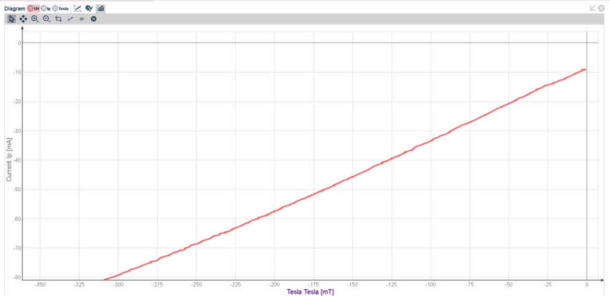
Evaluation (5/11)

Task 4:

Linear connections between Hall voltage U_H and magnetic field B for n and p - Germanium



n-Germanium



p-Germanium

Evaluation (6/11)

With the values used in the figures, the regression line with the formula $U_H = U_0 + b.B$ has a slope $b = 0.144\,VT^{-1}$ with a standard deviation $s_b \pm 0.004VT^{-1}$ for p-Germanium, and $b = 0.125\,VT^{-1}$ with a standard deviation $s_b \pm 0.004\,VT^{-1}$ for p-Germanium.

Since the sample thickness *d* = 1 mm and I = 0.030 A, the Hall constant R_H thus becomes

$R_H = 4.8.\,10^{-3}\,\frac{m^3}{As}$ with the standard deviation $s_{R_H} = 0.2.\,10^{-3}\,\frac{m^3}{As}$ for n-Germanium, and
$R_H = 4.17.\,10^{-3}\,\frac{m^3}{As}$ with the standard deviation $s_{R_H} = 0.08.\,10^{-3}\,\frac{m^3}{As}$ for p-Germanium.

With the measured values $l = 0.02\,m$, $R = 37.3\,\Omega$ for n-Ge, $R = 35.5\,\Omega$ for p-Ge, $A = 1.\,10^{-5}\,m^2$ we have

$\sigma_0 = 53.6\,\Omega^{-1}.\,m^{-1}$ for n-Germanium, and
$\sigma_0 = 57.14\,\Omega^{-1}.\,m^{-1}$ for p-Germanium.

Evaluation (7/11)

Hence

$\mu_H = 0.257 \pm 0.005\, m^2/Vs$ for n-Germanium, and
$\mu_H = 0.238 \pm 0.005\, m^2/Vs$ for p-Germanium.

Using the value of the elementary charge $e = 1.602.\,10^{-19}\; As$ we obtain

$p = 14.9.\,10^{20}\, m^{-3}$

The electron concentration *n* of n-doped specimen is given by $n = \frac{1}{e.R_H}$, hence

$n = 13.0.\,10^{20}\, m^{-3}$.

Evaluation (8/11)

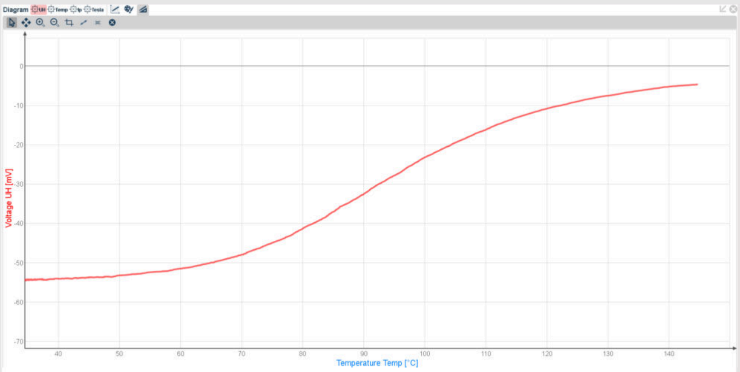
Task 5:

Hall voltage U_H is plotted as a function of the temperature *T* with $I_p = 300\, mA$ and $B = 300\, mT$. Graphs shows the Hall voltage decreases with increasing temperatue for both n- and p-Germanium.

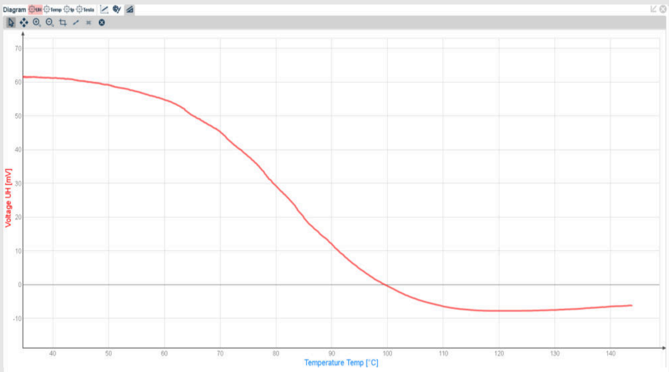
Since the experiment was performed with a constant current, it can be assumed that the increase of charge carriers (transition from extrinsic to intrinsic conduction) with the associated reduction of the drift velocity *v* is responsible for this. (The same current for a higher number of charge carriers means a lower drift velocity).

The drift velocity is in turn related to the Hall voltage by the Lorentz force.

Evaluation (9/11)



n-Germanium



p - Germanium

Evaluation (10/11)

Fill in the blank:

From the experiment, Hall voltage can be increased by _____ the current and _____. In the addition, it can be achieved by _____ the thickness of the sample plate, which means the plate with a _____ carrier capacity.

decreasing
magnetic field
lower
increasing

Check

Evaluation (11/11)

The Hall coefficient of a semiconductor enables the determination of:

- ○ Mobility of charge carriers
- ○ Type of conductivity and concentration of charge carriers
- ○ Thermal conductivity

Check

The Hall coefficient for a material is dependent of:

- ☐ Charge carriers density
- ☐ Temperature
- ☐ Type of charge carriers

Check

Slide	Score / Total
Slide 30: Hall voltage	**0/4**
Slide 31: Multiple tasks	**0/4**

Total Score **0/8**

Show solutions Retry