BAND GAP OF Ge

1 Objectives

- To measure the current and voltage across an undoped germanium test-piece as a function of temperature
- To obtain the electrical conductivity and plot it against the reciprocal of the temperature
- To determine the energy gap of germanium

2 Theoretical background

2.1 Semiconductors

The electronic properties of materials are related to the electrical conductivity σ. According to the behaviour of the electrical conductivity, materials can be classified into three large groups: insulators, semiconductors and conductors. A material can conduct electricity if there are free charge carriers that can move when an electric is applied. In the metal, the conduction band (CB) is partially filled ant the electrons can move to the unoccupied levels when an electric field is applied. In semiconductors the valence band (VB) is filled whereas the conduction band is empty. There is a region between the upper level of the VB and the lowest level of the CB in which there are not energy levels. This region is the forbidden band, and its width is the gap whose value is denoted as E_g. In semiconductor the value of the gap is of the order of the eV, so it is easy to excite electrons from the VB to the CB by the thermal agitation at temperatures not high above the room temperature. In the case of doped semiconductors, the impurities introduce energy levels in the gap, what make easier to the excite electrons to the conduction band (n-semiconductor) or excite holes from the valence band, increasing in this way the conductivity of the semiconductors. In insulator the energy gap is much greater than a few eV.

In short, according to the band structure:

- Conductors (metals) are those in which both energy bands overlap.
- Insulators are those in which the width of the gap is greater than or equal to 6 eV, which makes it impossible that at moderate temperatures ($E = k_BT$) electrons can jump from the VB to the CB, so there are no carriers free in the CB.
- Semiconductors (SC) are those in which the width of the gap is of the order of 1 eV. For example, in germanium it is 0.66 eV. In this case, the conductivity is highly dependent on temperature: at moderate temperatures ($T \sim 350K$) the carriers have enough energy to jump from the VB to the CB, thus increasing the concentration of free carriers in the CB, while at low temperatures they behave as perfect insulators.

If the level of impurities present in the semiconductor is considered, they can be classified as intrinsic, with negligible concentrations of impurities, and generally unwanted, and extrinsic, with high levels of impurities created intentionally in the manufacturing process. Depending on the type of impurity with which it is intentionally doped, a semiconductor can have extrinsic conductivity, by holes (p-type semiconductor) or by electrons (n-type semiconductor).

The dependence of the conductivity in an extrinsic semiconductor is shown in Fig. 1. In Fig. 1, three different regions can be distinguished: at low temperatures(R-I), the electrical conductivity is extrinsic, since on increasing the temperature, the impurities are ionized and their electrons pass to the conduction band (n-semiconductor). At moderate temperatures (R-II), almost all the impurities have already been ionized and an increase in temperature does not lead to an increase of the number of carriers in the CB. At elevated temperatures (R-III) the predominant conduction is intrinsic; the carriers that reach the BC come from the valence band. In the latter regime, the conductivity as a function of temperature can be expressed as:

$$\sigma = \sigma_0 \exp\left(-\frac{E_G}{2k_B T}\right) \quad (1)$$

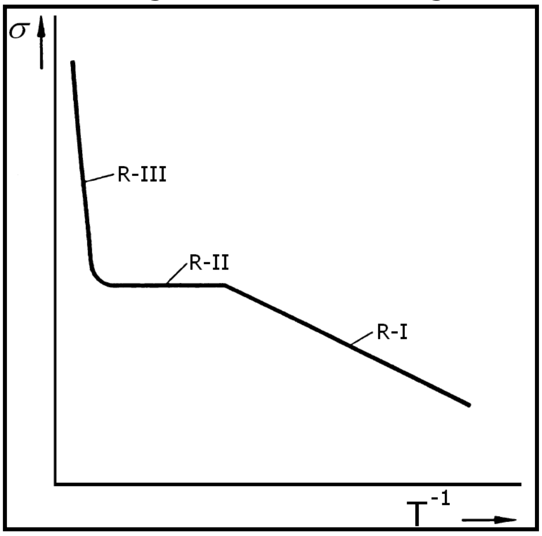

Figure 1. Evolution of the electrical conductivity with the inverse of the temperature in an extrinsic semiconductor.

Where E_G is the energy of the gap of the semiconductor, k_B=8.625·10^{-5} eV/K is the Boltzmann constant and T is the temperature in K degrees.

Remarks:
If a potential difference V is established between the end of a material of length L and cross-section A, (Figure 2) the electric current flowing through the material is:

$$RI = V \quad (2)$$

The electrical resistance is related to the resistivity by the expression

$$R = \frac{\rho L}{A} \quad (3)$$

So:

$$\rho = \frac{VA}{IL} \quad (4)$$

Since the electrical conductivity and the resistivity are related by the expression

$$\sigma = \frac{1}{\rho} \quad (5)$$

It implies that

$$\sigma = \frac{IL}{VA} \quad (6)$$

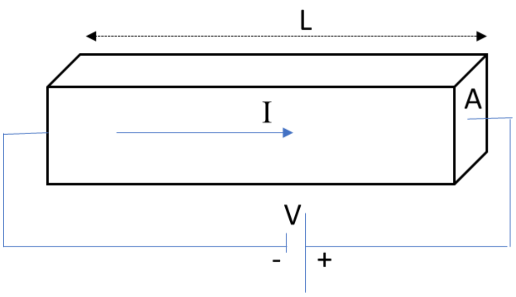

Figure 2. Rod-shape semiconductor with a potential difference between the ends.

3 Para saber más...

- **Charles Kittel, "Introduction to Solid staet Physics", Chapter 8, pp. 186. 8th Edition, John Wiley & Sons, Inc, 2005.**

- **L. Solymar, D. Walsh, "Electrical properties of materials", Chapter 8, pp. 120, Oxford Universitary Press. 2010.**

En internet

https://ecee.colorado.edu/~bart/book/book/chapter2/ch2_3.htm
https://www.pveducation.org/pvcdrom/pn-junctions/band-gap

Equipment

1. Power supply
2. PHYWE Hall-effect unit HU 2
3. Intrinsic Ge, carrier board (L = 20 mm; h = 10 mm, d= 1 mm)
4. Digital multimeter

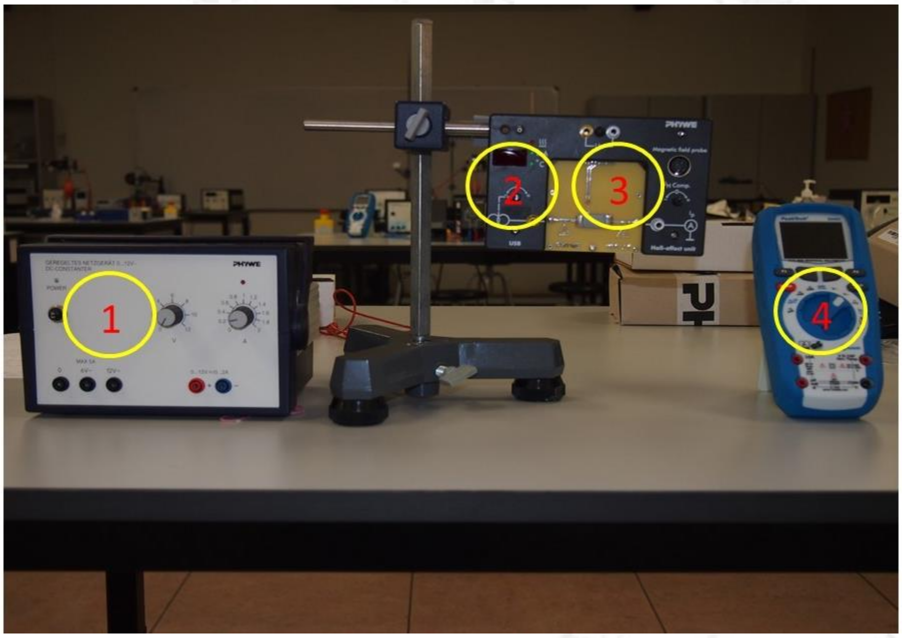

Figure 3. Equipment of the practice.

5 Equipment description

5.1 Power supply

The power supply can be used both for direct current (DC) and alternate current (AC). In this case it will be used only as a AC power supply. The control 1 corresponds to the AC power supply and the controls 2, 3 and 4 to the DC power supply. In this practice only the control 1 will be used. It is used to power the PHYWE Hall-effect unit and the carrier board. It can supply 6 Volts or 12 Volts. In this practice the PHYWE Hall-effect unit will be powered with 12 V in AC.

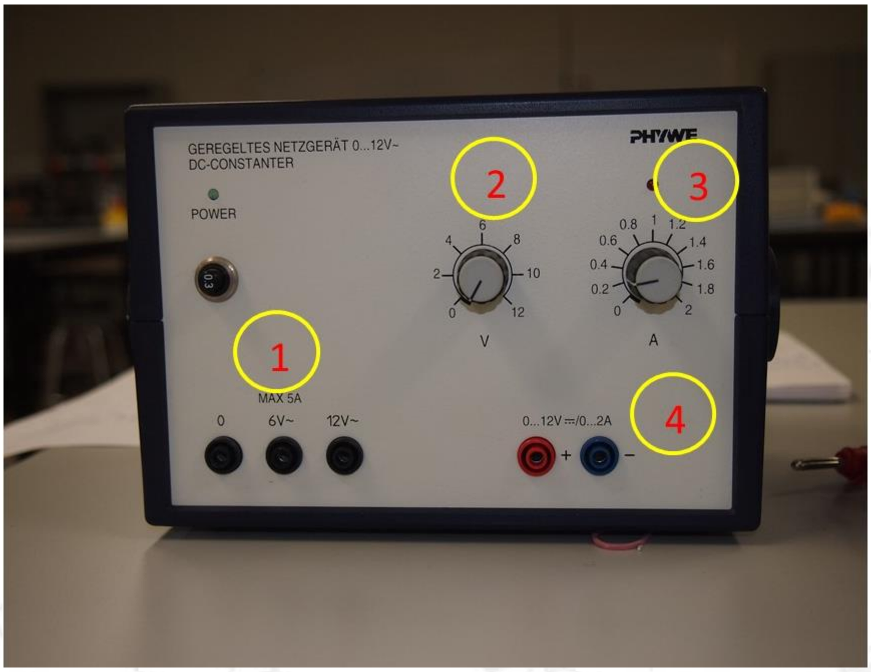

Figura 4. Power supply.

5.2 PHYWE Hall-effect unit and the GE Carrier board.

The control (1) is for connecting the power supply in AC mode. The 12 V connection is connected to the corresponding 12 V connection of the power supply and the other point is connected to the 0 point of the power supply. The control 3 allows to heat the germanium sample and increase its temperature. It is always in mode OFF; on pushing the mode ON, the system heats the Ge sample up to a maximum temperature of 140 ºC. It is not possible to control the temperature, t is just ON or OFF. On pushing ON, it takes around 1 minute in achieving 140 ºC. Therefore, push this button to the mode ON only when you are ready to start to do the measurements. In this case, wait more a less one minute, and once the maximum temperature, 140 ºC, has been achieved, start to take the data, as the Ge sample will start to cool due to the lower temperature of the environment.
The control (2) corresponds to the display, if it is in Ip, in the screen of the display, control (4), of the head part, the value of the current intensity will be shown. If it is in mode T_P, the temperature will be shown in the screen of the display.
The control (4) is the screen of the display, it is shown either the current intensity or the temperature, depending of the control (2).
The control (5) allows to vary the value of the current intensity flowing through the Ge sample. The value appears in the screen of the display. During the practice, the current intensity must be 5 mA.
The control (6) and (7) are connected to the input/output of the digital multimeter. Do the connections so that a positive value appears on the screen of the multimeter.
The controls (8) and (9) corresponds to the case that this unit is used for measuring the Hall-effect. In this practice, these controls are not used.

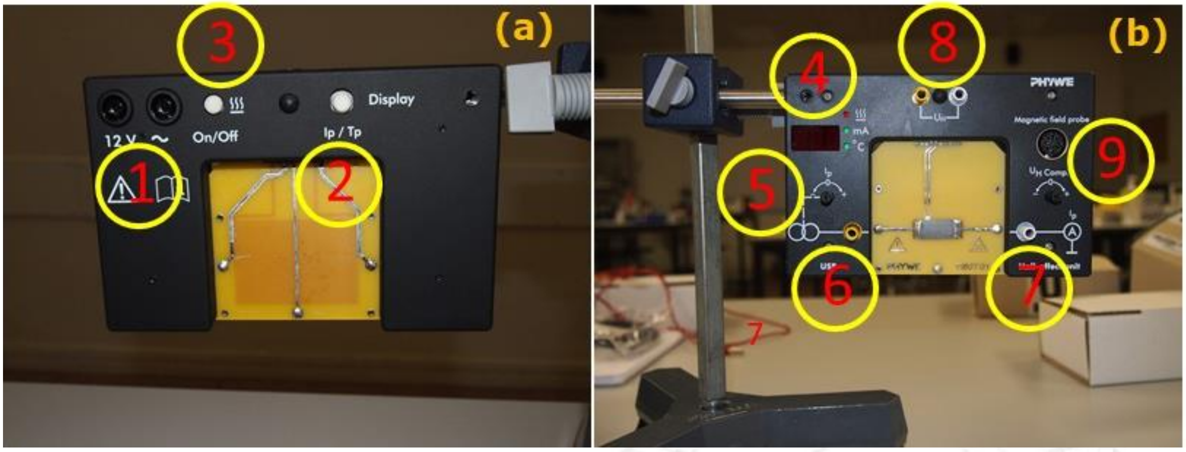

Figura 5. PHYWE Hall-effect unit and the Ge carrierd board. (a) Back part. (b) Head part.

5.3 Digital multimeter.

The digital multimeter Will be used for measuring the potential difference between the end of the Ge sample. It is possible to change the scale, that will depend from the values of the voltages that it will be measured. This task must be done by hand by the operator. In this practice, you should chose the 20 V scale

Figura 6. Digital multimeter.

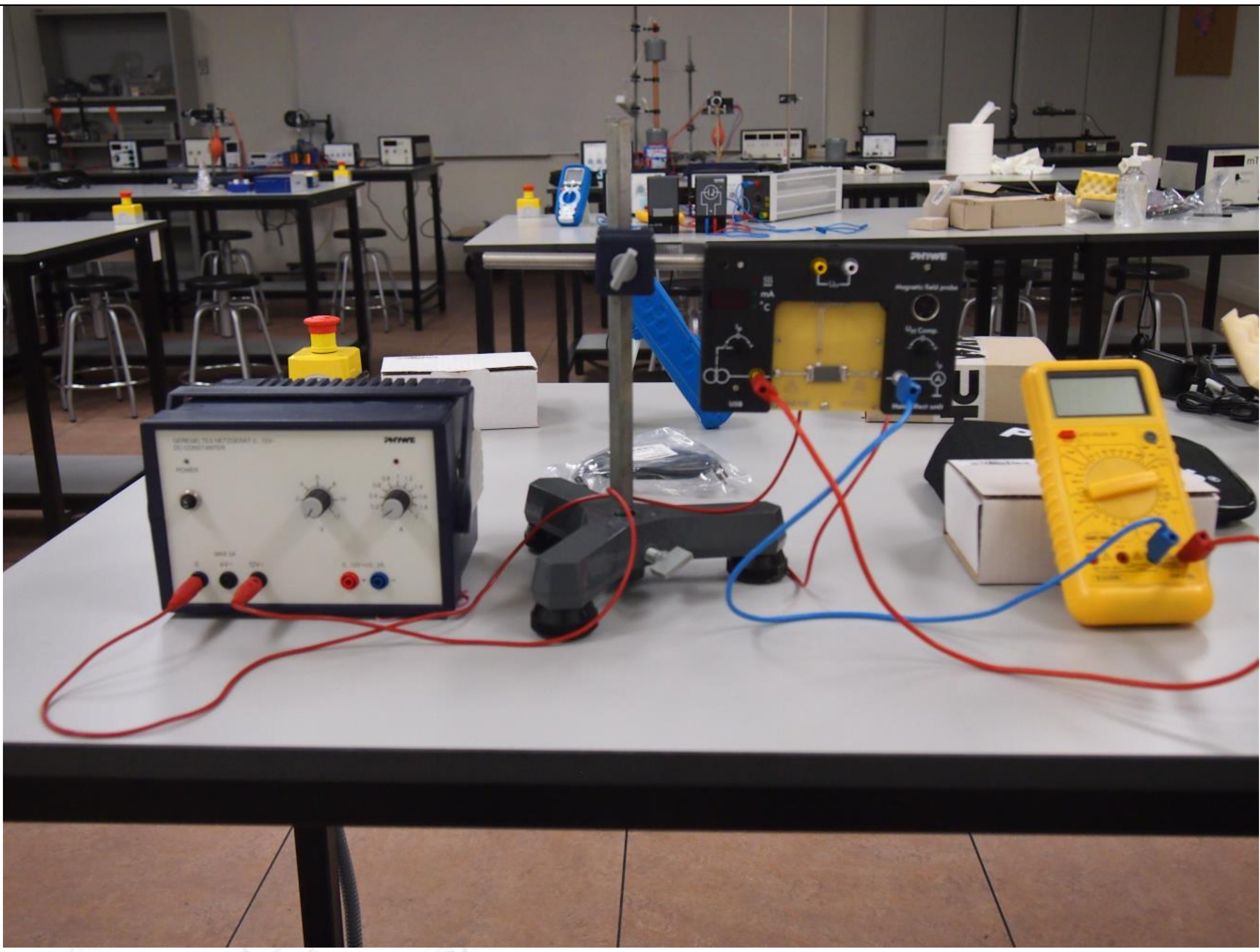

Figure 7. Experimental set-up for the determination of the band gap of Germanium .

6 PROCEDURE

6.1 Check that all the connections are properly performed (see Fig. 7)
6.2 Switch on the power supply
6.3 Switch on the digital multimeter
6.3 Push the control (2) of the PHYWE Hall-effect unit to display the initial temperature. Subsequently, push the control (2) of the PHYWE Hall-effect unit to display the current intensity. With the control (5) changes the intensity of current up to obtaining a value of 5 mA in the screen of the display.
6.4 Measure the value of the temperature and the value of the voltage given in the screen of the digital multimeter. In case this value is negative, change the polarity (Exchange the connection of the cables)

6.5 Now you are ready to start to the experiment. Before star the experiment, READ CAREFULLY THESE REMARKS:
-On pushing the control (3) of the PHYWE Hall-effect unit, the system will heat the semiconductor sample and its temperature will go up very quickly. In one minute time, more or less, the temperature of the sample will be 140 ºC.
-On reaching the maximum temperature, 140 ºC, the heating system will be off, and the temperature of the sample will start to decrease. At the beginning it will be very rapid. In the experiment you must read the value of the temperature in the screen of the PHYWE Hall-effect unit (control 4) and the corresponding value of the voltage in the screen of the multimeter. Both measurements must be noted in your classnotes at the same time
-Take a measure every 5 degrees from the maximum temperature up to room temperature. Therefore, before starting the measurements prepare a table with the values of the temperature at which you will take the values of the voltage.
-Chose a scale of 20 mV in the digital multimeter, since in this case the stability of the multimeter is better.

HAVE YOU RED AND UNDERSTOOD THE ABOVE REMARKS ? IF it is Yes, you can start to to the measurements.

START THE EXPERIMENT

6.6 Verify that the current intensity flowing through the Ge sample is 5 mA (change to I_P in control (2) of the control (2) of the PHYWE Hall-effect unit)
6.7 Change to T_P in control (2) of the PHYWE Hall-effect unit, and take the initial temperature and the corresponding value of the voltage ion the multimeter
6.7 Push the control (3) of the PHYWE Hall-effect unit. The temperature of the Ge sample will rapidly increase. It will take about a minute for reaching the maximum value. On achieving this value, the heating system will automatically be off. Then, after a few seconds, the temperature of the sample will start to decrease
6.8 Start to measure the temperature in the screen of the display (control (4) and the corresponding value of the voltage in the screen of the multimeter. Take data every 5 degrees from 140 ºC up to room temperature, around 27 ºC.

The same experiment must be repeated three times.

ANALYSIS OF THE RESULTS

-Plot the experimental results on a curve, Voltage versus the temperature. The temperature in Kelvin degrees
-Determine the value of the electrical conductivity σ. For it, use the expression given in the Theoretical background
-Plot in graphic the Lnσ versus the inverse of the temperature (the temperature must be expressed in K degrees)
-Perform a fit of the straight line by using the least square method. From the parameters of the fitting obtain the band gap E_G and σ_0.
-Compare the results obtained in the three experiments and compare them with the band gap of Germanium.
-Perform a discussion about the results of the experiment.s