1.1. Effect of temperature on resistance

1.1.1. Theoretical background

Electrical resistance of an object is a measure of its opposition to the flow of electric current. Resistance R of an object is defined as the ratio of voltage U across it to current I through it.

$$\mathrm{R}\ [\Omega] = \frac{\mathrm{U}}{\mathrm{I}}\ [\frac{\mathrm{V}}{\mathrm{A}}] \quad (1)$$

Band theory is one of main ways of explaining differences in conduction. Electrons orbit nucleus of an atom within permitted levels of energy. Energy levels are organized into two bands – valence band and conduction band. Energy gap exists between bands where electrons can't exist. When conduction occurs, then electrons move and for it to happen there must be space and energy for them available.

Resistances vary depending on material and we look for three different categories – conductors, semiconductors, and insulators.

Electrical resistance of insulator

Insulator has large gap between conduction and valence bands, it is hard to break the bond. Electrons cannot move into conduction band so material cannot conduct and can be used as an insulator to prevent flow of current or heat. [34]

Electrical resistance of metals

Conductor has easy flow of an electrons from one atom to another atom because there are no band gaps between valence and conduction bands. Movement of electrons is influenced by electric field induced by electric field inside conductor. Induced electric field develops an electric potential across conductor that initiates movement of electrons towards opposite terminal. Electrons start colliding with each other and generate heat. The temperature rise creates additional collisions among the moving electrons which in total reduces net movement of electrons which reduces the current. Therefore, resistance increases with temperature.

For metal, relationship between resistance and temperature can be approximated using following formula

$$\mathrm{R} = \mathrm{R}_0(1 + \alpha(\mathrm{T} - \mathrm{T}_0)) \qquad (2)$$

where R_0 is original resistance, T_0 is original temperature and α is empirical parameter fitted from measurement data and it will vary depending on material.

From formula (2) can derive temperature coefficient for α:

$$\alpha = \frac{R - R_0}{R_0(T - T_0)}$$

Electrical resistance of semiconductors

Semiconductor has gap between valence and conduction bands, but it is not small enough to facilitate movement of electrons at room temperature to enable conduction. A rise in temperature increases conductivity because more electrons will have enough energy to move into conduction band.

Concentration of free electrons and electron holes in semiconductor can be calculated using:

$$p = n = Ne^{\frac{-\Delta W}{2kT}}, (3)$$

where p is concentration of holes, n – concentration of electrons, N – concentration of atoms, T – absolute temperature, k – Boltzmann constant ($k = 1.38 \cdot 10^{-23}\,\frac{J}{K}$ and $\frac{\Delta W}{2}$ – energy to free one charge carrier, because need to spend ΔW amount of energy to free electron and hole.

From formula (3) we can see that with increase in temperature, amount of charge carriers increases exponentially.

For semiconductor, the temperature dependence on resistance can be calculated [35]

$$R = R_\infty e^{\frac{\Delta W}{2kT}} \quad (4)$$

From formula (4) can derive

$$\ln R = \ln R_\infty + \frac{\Delta W}{2kT}$$

Here we see linear relationship between ln R and $\frac{1}{T}$ and after plotting it, we can derive slope $\frac{\Delta W}{2k}$.

The activation energy of the semiconductor material can be easily found from:

$$\Delta W = k \cdot \beta$$

ΔW [J] – activation energy
K – Boltzmann constant [J/K]

1.1.2. Laboratory instrumentation

Equipment used: electronic device containing 5 sample materials (3 metals and 2 semi-conductors) with heater and ventilator for cooling. Device can be connected via USB to computer, commands for heating/cooling can be given and temperature can be read for visualizing on a website. Simplified diagram of laboratory structure is described on Figure 1 - Hardware components for resistance lab.

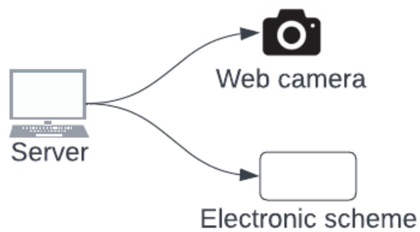

Figure 1 - Hardware components for resistance laboratory

1.1.3. How to use laboratory

Steps to use laboratory:

- Start lab
- Select unknown material for heating and start measurement.
- Device starts heating sample material, measuring its resistance and sends result back to website where temperature and resistance are plotted on graph.
- At 70 C degrees heating is automatically turned off, ventilator starts working to cool sample material.
- When temperature is reached back at 25 C degrees, then ventilator stops, collecting results stops and website is notified about finishing measurement.
- Save measurement results.
- There are 5 different sample materials to test, can repeat procedure for other labs too.
- Save measurement results and leave lab.
- Plot results and determine which sample materials were metals and which were semiconductors. Calculate temperature coefficients and activation energy.