Related topics

Carbon film resistor, metallic film resistor, PTC, NTC, Z diode, avalanche effect, Zener effect, charge carrier generation, free path, Matthiessen's rule.

Principle

The temperature dependence of an electrical parameter (e.g. resistance, conducting-state voltage, blocking voltage) of different components is determined. To do this, the immersion probe set is immersed in a water bath and these parameters are measured at different well defined temperatures.

Equipment

1	Immersion probes f. determining ct	07163-00
1	Immersion thermostat Alpha A, 230V	08493-93
1	Bath for thermostat, Makrolon	08487-02
1	External circulation set f. thermostat Alpha A	08492-01
1	PEK carbon resistor 1 W 5% 2,2 kOhm	39104-23
1	Connection box	06030-23
1	Connecting cord, l = 500 mm, blue	07361-04
2	Connecting cord, l = 750 mm, red	07362-01
2	Connecting cord, l = 750 mm, blue	07362-04
1	Cobra4 Wireless Manager	12600-00
2	Cobra4 Wireless-Link	12601-00
1	Cobra4 Sensor-Unit Energy	12656-00
1	Digital Function Generator, USB, incl. Cobra4 Software	13654-99
1	Cobra4 Sensor-Unit Temperature, semiconductor -20...110 °C	12640-00
	Additionally required	
1	PC with USB interface, Windows XP or higher	

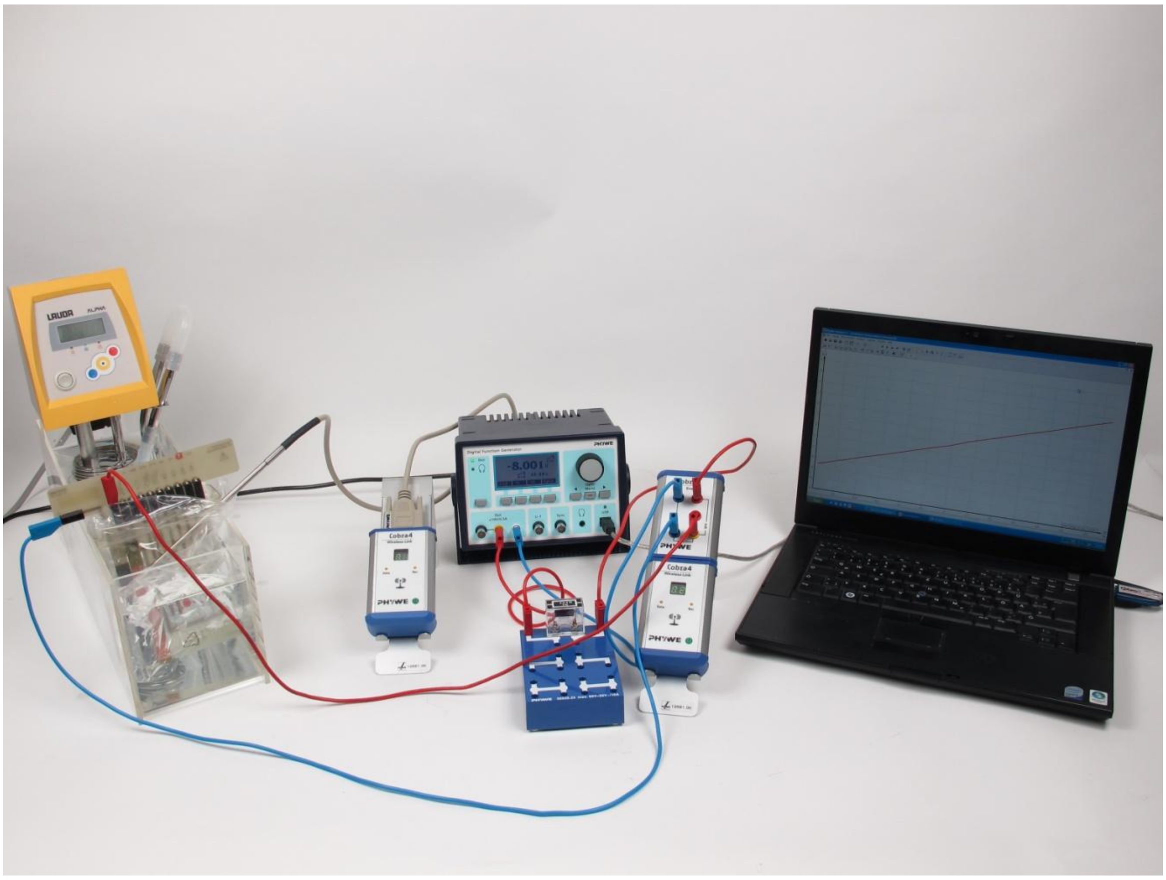

Fig.1: Photograph of the experimental setup.

Tasks

1. Measurement of the temperature dependence of the resistance of different electrical components.
2. Measurement of the temperature dependence of the conducting state voltage of semiconducting diodes.
3. Measurement of the temperature dependence of the voltage in the Zener diode and the avalanche effects.

Set-up and Procedure

Set up the equipment as seen in Fig. 1. The immersion probe set has to be put into a watertight plastic bag − be sure the immersion probe set does not get wet and there is no leakage − and put the temperature sensor right into that bag, too. Be careful not to destroy the coils by scratching etc. Be sure to connect the hose for the water coming from the circulation pump properly so that the water is led back into the bath before turning on the thermostat. Fill the bath with enough water that the probes are under the water surface. Set the temperature control on the thermostat to the reference temperature of 20°C and turn it on. Connect the Digital Function Generator and the wireless manager to a USB port. Connect the single socket of the immersion probe set to the blue socket of the Sensor-Unit Energy. Be sure to insert the 2.2 kOhm resistor in the circuit between the Sensor-Unit and the function generator. Connect the Cobra4 Wireless Manager to a USB port of the computer, plug the Cobra4 Sensor-Electricity on the Cobra4 Wireless-Link and connect the Digital Function Generator to another USB port.
Start the “measure” program on your computer and load the “Second order conductors” experiment. (Experiment > Open experiment). All pre-settings that are necessary for measured value recording are now carried out.

When the temperature of the water bath has become constant, plug the cable coming from the red socket of the SU-Energy in the first socket of the probe set and click on ● in the icon strip to start measurement. Go to the next socket and record a measurement again – one for each socket and the same temperature. Then raise the temperature of the water bath by 10 °C (or 15 °C for a faster performance). While the temperature is reaching the desired value, use "Measurement" > "Enter data manually" to note down the interesting values: Create a measurement with 10 channels (see Fig. 2) and enter there the resistance values in case of the carbon resistor, the metal film resistor, the PTC and NTC resistors, the copper and CuNi wires and the diodes. After typing the values, confirm them with "return". Evaluate the resistance with the "Regression" function in the measured curves: The resistance is the inverse slope. For the Si and Ge diodes take down the forward voltage where the current exceeds 1 mA and for the Zener diodes take down the breakthrouh voltage, where the current exceeds 1 mA, using the "Survey" function of "measure". Repeat the procedure for the next temperature steps until 85 °C taking all the data down into the same "Manually created measurement".

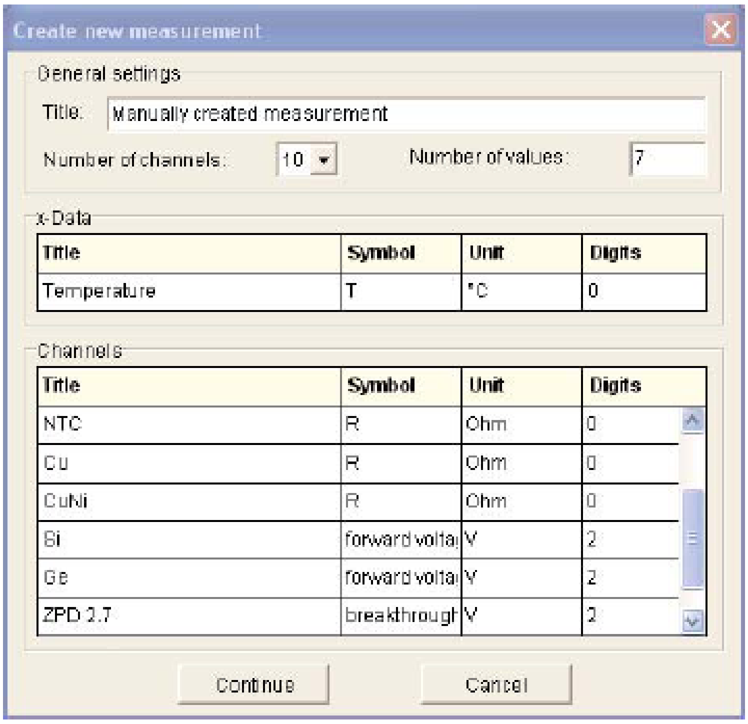

Fig. 2: Manually created measurement.

Theory and evaluation

In restricted temperature ranges the change in the resistance of the electrical components with temperature can be assumed to be linear. In these regions, a general formula for the dependence of the resistance on the temperature is valid:

$$R(T) = R_{ref} + R_{ref} \cdot \alpha \cdot (T - T_{ref})$$

where

$R(T)$ = Resistance at temperature T

R_{ref} = Resistance at T_{ref} (usually 20°C)

α = Temperature coefficient

T = Temperature at time of measurement

T_{ref} = Reference temperature (usually 20°C)

You may split the curves from your "Manually created measurement" up into several diagrams using "Measurement" > "Channel manager…". Figs. 3 to 6 show measurement results.

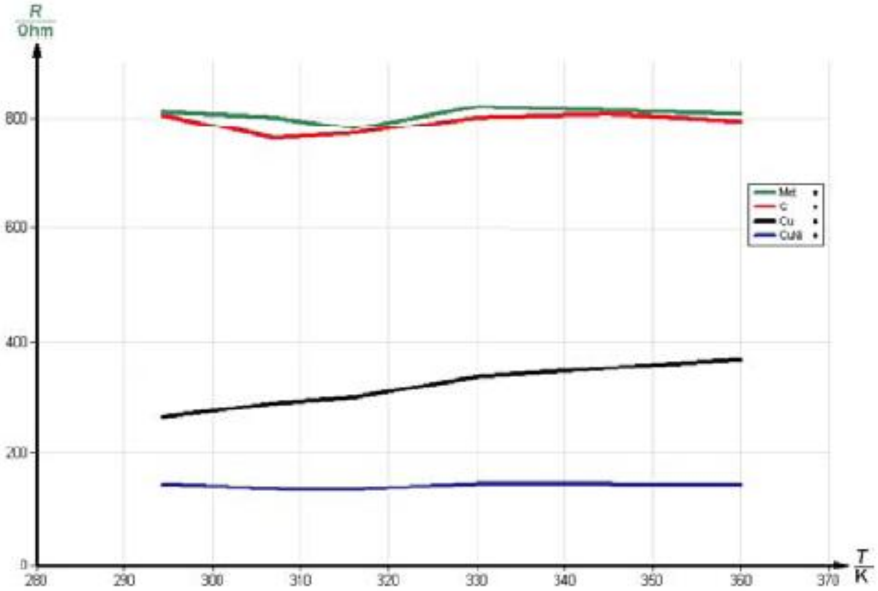

Fig. 3: Resistance of different materials vs. temperature.

The measurement yields a temperature coefficient for copper of

$$\alpha_{Cu} = 5.6\ 10^{-3}\ K.$$

The other temperature coefficients are not to be discriminated from zero with the here achieved level of precision. In copper wire the free path of the electrons in the electron vapour, which contribute to charge transport, becomes shorter with increasing temperature. The change in resistance can be seen: the resistance increases. The result is a positive temperature coefficient. The liteature value (Giancoli, Douglas C., Physics, 4th Ed., Prentice Hall, 1995) for copper is

$$\alpha_{Cu} = 6.8 \cdot 10^{-3}\ /K.$$

The two NTC and PTC resistors consist of alloys. Depending on their compositions, great changes in resistance can be realised in a small temperature range. The curves that are recorded in this experiment can not be considered linear. They serve to illustrate the behaviour of NTC and PTC resistors.

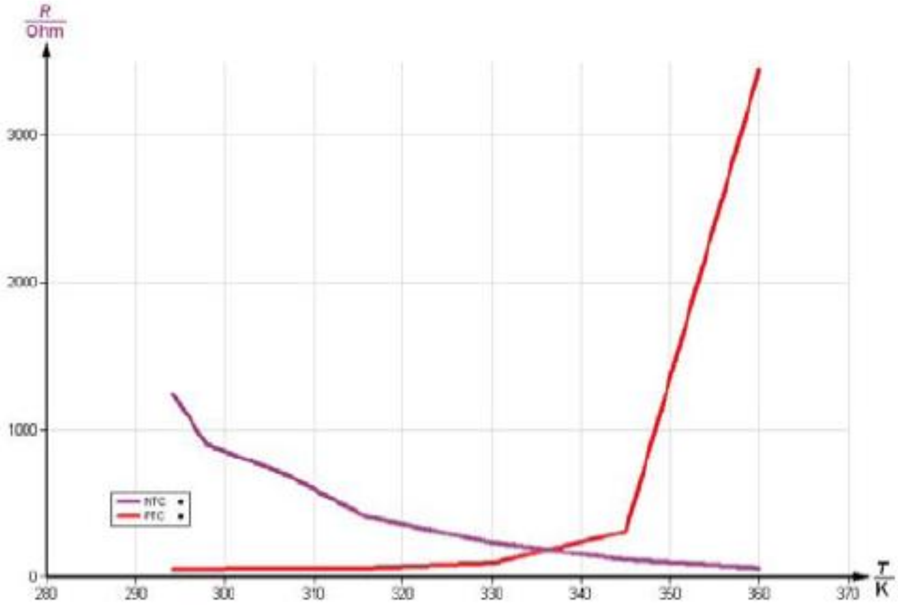

Fig. 4: Resistance of NTC and PTC elements vs. temperature.

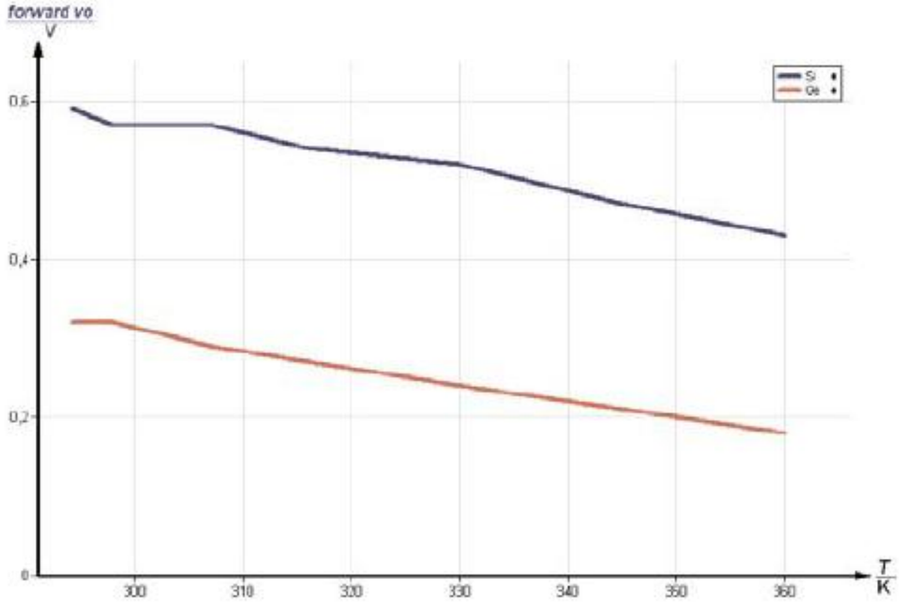

Fig. 5: Forward voltage of diodes in dependence on temperature.

In semiconductors (Fig. 10) the number of charge carriers and the charge carrier density increases with temperature (charge carrier generation, electron-hole pair formation). From the law

$$\sigma = e \cdot n \cdot \mu$$

where

σ = Intrinsic conductivity

e = Elementary charge

n = Charge carrier density

μ = Mobility

one can see that the intrinsic conductivity of the semiconductor thus increases. The mobility indeed decreases with increasing temperature, but the increase in the charge carrier densityovercompensates for this effect.

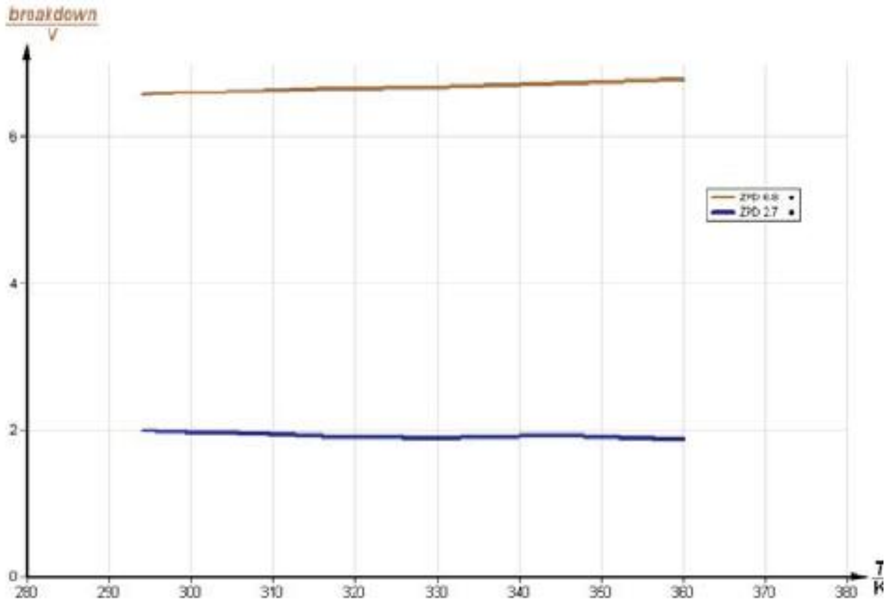

Fig. 6: Breakdown voltage vs. temperature.

At low voltages, around 3 V, a Zener breakdown occurs in Z diodes. As a result of the strong electric field, electron-hole pairs are spontaneously generated in the inner electron shells in the barrier-layer zone. Under the influence of the field, they cross the barrier layer. A higher temperature increases the energy of the bound charge carriers. As a consequence, the Zener effect can occur at lower voltages. In the avalanche effect, the charge carriers are accelerated by the electric field to such a great degree that they in turn ionize other atoms on their way producing more carriers, that can be accelerated. The higher temperature shortens the free path, so that for releasing the same amount of charge carriers, the voltage must increase with the temperature.

The following values are read from Fig. 11:

$\alpha_{ZPD\ 2.7} = -7.9 \cdot 10^{-4}$ /K

$\alpha_{ZPD\ 6.8} = +4.4 \cdot 10^{-4}$ /K

Literature values:

$\alpha_{ZPD\ 2.7} = -9 \cdots -4 \cdot 10^{-4}$ /K

$\alpha_{ZPD\ 6.8} = +2 \cdots +7 \cdot 10^{-4}$ /K

with α the relative temperature coefficient.

Room for notes: