Z43 - Electrical Conductivity of Nanowires

Physics Laboratory II – academic year 2017/2018
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Miniaturization of electronic devices has directed researcher attention toward nanoscale objects. In view of their low dimensionality exotic properties are often observed. As a result quantum effects influence significantly macroscopic properties of these objects. For instance, the electrical conductivity in quasi one-dimensional nanowires exhibits discrete spectrum. The experiment is focused on measurements of electrical conductivity of dynamically created gold nanowires. They are formed by periodic breaking of the junction between a sharp gold needle and a flat sample. In experiment sudden and stepped changes of wire resistance are observed allowing for determination of the electrical conductance quantum.

Preparatory questions

1. Drude model of electric al conduction. Ohm's law.
2. Density of states in one-, two- and three-dimensional systems. Density of states distribution.
3. Low dimensionality in nanoscale systems: density of states in quasi one- and two-dimensional objects. Indicate the difference between one(two)-dimensional systems and quasi-one(two)-dimensional. Transformation from discrete into continuum distribution. What are the subbands in electronic structure of low-dimensional systems? [1, 2, 3]
4. Electronic structure of crystals. Fermi energy, Fermi sphere. Fermi-dirca distribution. Pauli exclusion principle. [1, 2, 3]
5. Particle in a box: enegies, eigenfunctions. [1, 2, 3]
6. Bloch's theorem. Dispersion relation for electrons in crystals. Effective mass. [1, 2, 3]
7. Ballistic transport of electron in one dimensional junction. Electric al conductance quantum. [1, 2, 3]
8. Electric al conductance of a real quasi one-dimensional junction. Mean free path of electrons. What are the conditions that have to be fulfilled in order to suport conductance quantization observation? What is the limiting factor, which determines th number of open channels in the nanowire?
9. Experimental setup and measurement idea.

Computational assignments

1. Starting from the simple free electron model calculate the energy difference between the subband edges for a gold nanowire. Assume that the junction is quasi-one-dimensional and its cross section could be described as a $2nmx3nm$ rectangle. Calculate the numerical values! Effective mass equals $1,10$ electron mass.
2. Assuming the density of gold: $19,3\ g/cm^3$, the mass of gold atom: $197u$, effective mass of electron: $1,10$ electron mass, electrical resistivity: $2,2 \cdot 10^{-8}\ \Omega \cdot m$, calculate the mobility of electron and their relaxation time. In gold each atom provides on average one free electron. Calculate the Fermi energy for gold.
3. Assume that the average electron velocity is described by the formula: $v_T = \sqrt{\frac{8kT}{\pi m^*}}$. Using the relaxation time calculated in the previous exercise determine the maximum length of gold nanowires for which the electron transport could be ballistic at room temperature.
4. Starting from a simple model of the nanowire (as described in exc.1) as a cuboid calculate the transversal dimensions of the nanowire at which the 3rd and 2nd channel is closing, respectively. Assume that the cross section of the nanowire is rectangular and the ratio of its edges is constant.

Apparatus and materials

The scheme of the apparatus is shown on Fig.1.

Experiment

1. Adjust the micrometer screw and the sawtooth signal applied to the piezostack in order to observe periodic braking of the nanowire junction.
2. Adjust the frequency, amplitude and offset of the sawtooth signal to form stable nanowires with clearly observed stepped voltage readings.
3. Measure the resistance of the external resistor.

Data analysis

1. Analysis of the voltage values recorded during junction breaking, preparation of the histogram.

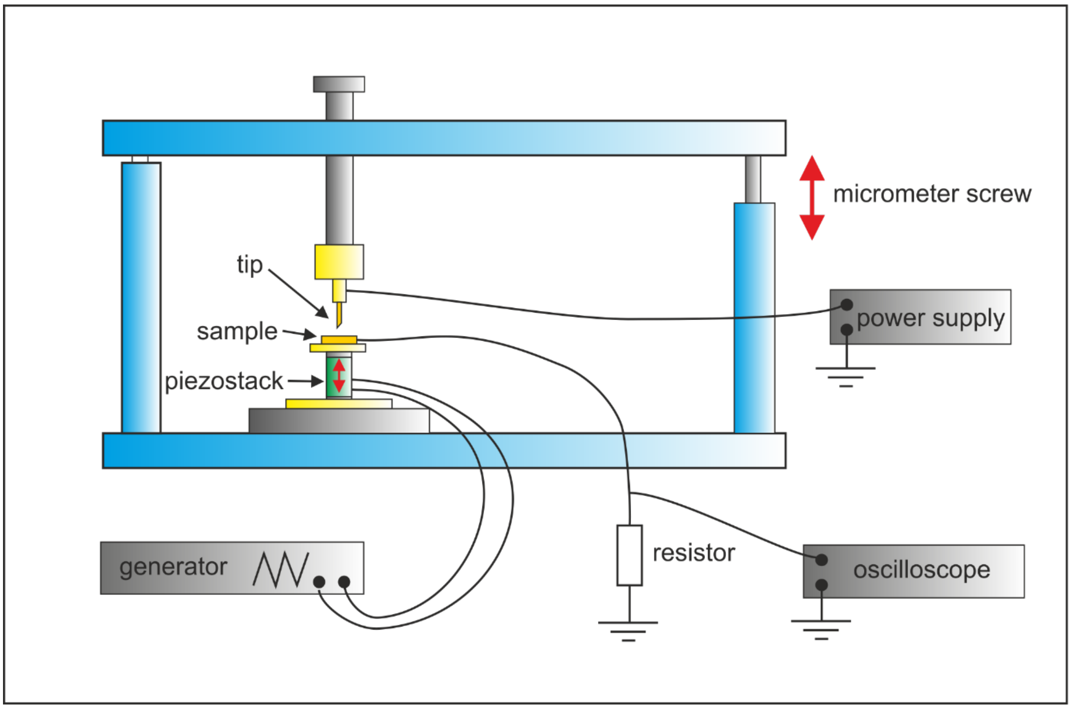

Figure 1: The scheme of the apparatus.

2. Preparation of the conductance value histogram, conductance quantum determination and comparison with expected value, discussion of deviations from literature data.

References

[1] N.W. Ashcroft, N.D. Mermin, *Solid State Physics*.

[2] C. Kittel, , *Introduction to solid State Physics*.

[3] Rainer Waser (Ed.), *Nanoelectronics and Information Technology*, 2003, WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim.