FINITE-SIZE EFFECTS IN THE ELECTRICAL RESISTANCE OF SINGLE BISMUTH NANOWIRES

T.W. Cornelius[1], M.E. Toimil-Molares[1], S. Karim[2], R. Neumann[1]
[1]Gesellschaft für Schwerionenforschung (GSI), Planckstr. 1, 64291 Darmstadt, Germany
[2]Fachbereich Chemie, Marburg University, Hans-Meerwein-Str., 35032 Marburg, Germany
th.cornelius@gsi.de

Objects whose size becomes comparable to intrinsic length scales, i.e., the electronic mean free path l_e and Fermi wavelength λ_F, classical and quantum size effects are expected [1]. In the semimetal bismuth both are large compared to conventional metals, making it an ideal material for studies on the nanoscale. In particular, the classical size effects cause an increase of the electrical resistivity originating from electron scattering processes from the wire surface [2] as well as from grain boundaries [3]. In order to separate both processes, it is necessary to fabricate a series of nanowires, their structure varying from poly- to single-crystallinity.

Bismuth nanowires are deposited electrochemically in ion track-etched polycarbonate membranes [4]. Single wires are prepared in single-pore membranes and subsequently contacted electrically while left embedded in the template [5]. The specific electrical resistivity ρ is affected by the fabrication conditions of the wire. The wires are constructed by smaller grains when deposited at lower temperatures T and higher potentials U. Due to the increased density of grain boundaries for such wires, ρ increases for wires created at lower T and higher U (Fig. 1). The wire resistance is a non-monotonic function of the temperature (Fig. 2). It rises, passes through a maximum, and declines when cooling from room temperature down to 20 K. The resistance maximum shifts to higher T for diminishing diameter and the maximum becomes the higher the smaller the mean grain size is. The non-monotonic $R(T)$ behaviour originates from the saturation of l_e caused by finite-size effects, in contrast to bulk bismuth where it increases from 100 nm to 400 µm when cooling down from 300 to 4 K [6].

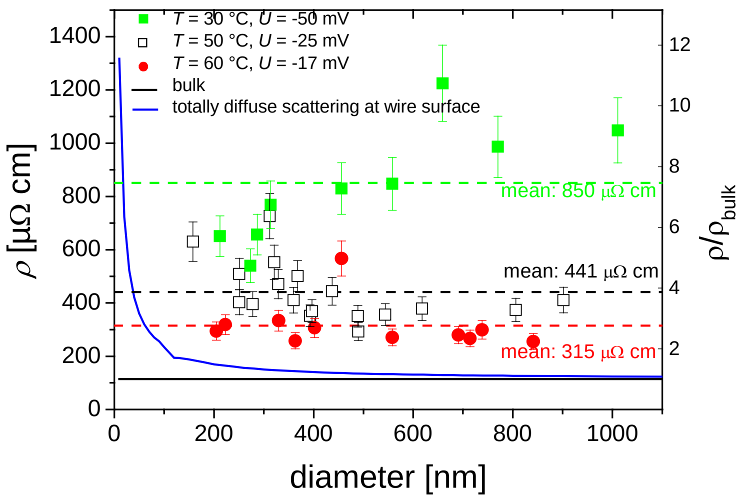

Fig. 1: Specific electrical resistivity as a function of diameter of single bismuth nanowires prepared under three different conditions.

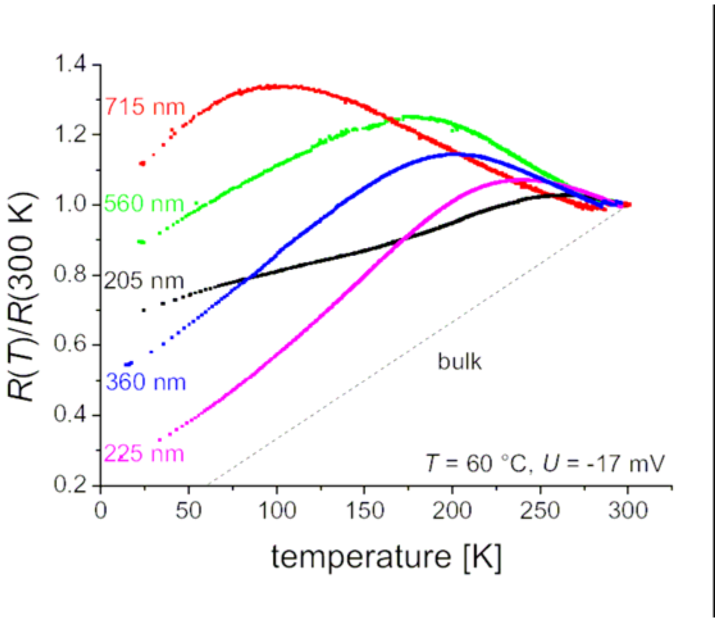

Fig. 2: Electrical resistance of single bismuth nanowires with different diameters as a function of temperature.

References

[1] V.B. Sandormirskiĭ, Sov. Phys. JETP **25** (1967) 101

[2] R.B. Dingle, Proc. R. Soc. London A **201** (1950) 545

[3] A.F. Mayadas, M. Shatzkes, Phys. Rev. B **1** (1970) 1382

[4] T.W. Cornelius, J. Brötz, N. Chtanko, D. Dobrev, G. Miehe, R. Neumann, M.E. Toimil-Molares, Nanotechnology **16** (2005) S246

[5] M.E. Toimil-Molares, N. Chtanko, T.W. Cornelius, D. Dobrev, I. Enculescu, R.H. Blick, R. Neumann, Nanotechnology **15** (2004) S201

[6] S.B. Cronin, Y.-M. Lin, O. Rabin, M.R. Black, J.Y. Ying, M.S. Dresselhaus, P.L. Gai, J.-P. Minet, J.-P. Issi, Nanotechnology **13** (2002) 653