Poster

QUANTUM-SIZE AND FINITE-SIZE EFFECTS IN THE ELECTRICAL TRANSPORT PROPERTIES OF SINGLE BISMUTH NANOWIRES

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In recent years, bismuth nanowires were intensively studied both because of their unique electronic properties and possible future application in thermoelectric devices. When the size of an object becomes comparable to the electron mean free path l_e and Fermi wavelength λ_F, finite-size and quantum-size effects are expected, respectively [1]. Since these parameters are large in bismuth (l_e ~ 100 nm and λ_F ~ 40 nm at room temperature), such effects are anticipated for wires of comparatively large diameter, making bismuth an ideal material for studies on the nanoscale. Finite-size effects include additional electron scattering from inner grain boundaries and from the wire surface for which Mayadas et. al [2] and Dingle [3] developed a model, respectively. Quantum-size effects lead to a subband splitting which involves a diameter dependent oscillation of both charge carrier density and mobility. Consequently, the transport properties are modulated as a function of the wire diameter [4].
Single bismuth nanowires with diameters ranging from 70 nm to 1 µm were grown electrochemically in ion track-etched polycarbonate membranes [5]. The crystallinity was controlled by the fabrication conditions, in particular the choice of overpotential and temperature. The depositions were continued until caps were formed on top of the wires. In order to contact the wires electrically, while they were left embedded in the template, the cap was coated by an additional gold layer.
The specific electrical resistivity was found to be strongly influenced by the mean grain size D and increases with decreasing D which is attributed to additional electron scattering from grain boundaries. For wires with diameters d < 150 nm the resistivity rises with diminishing d being assigned to additional scattering from the surface (Fig. 1). Further, a non-monotonic resistance versus temperature behaviour was found. While the carrier mobility for bulk Bi increases by three to four orders of magnitude when cooling down from room temperature to 4 K, it saturates at a few ten Kelvin for nanowires because of finite-size effects [6] (Fig. 2). The saturation value diminishes with decreasing D. For the first time, the specific electrical conductivity shows evidence for oscillations as a function of d which can be attributed to quantum size effects.

References:

[1] V.B. Sandormirskii, Sov. Phys. JETP **25** (1967) 101.
[2] A.F. Mayadas, M. Shatzkes, Phys. Rev. B **1** (1970) 1382
[3] R.B. Dingle, Proc. R. Soc. London A **201** (1950) 545
[4] S. Farhangfar, Phys. Rev. B **74** (2006) 205318.
[5] T.W. Cornelius, J. Brötz, N. Chtanko, D. Dobrev, G. Miehe, R. Neumann, M.E. Toimil-Molares, Nanotechnology **16** (2005) S246.
[6] T.W. Cornelius, M.E. Toimil-Molares, R. Neumann, S. Karim, J. Appl. Phys. **100** (2006) 114307.

Figures:

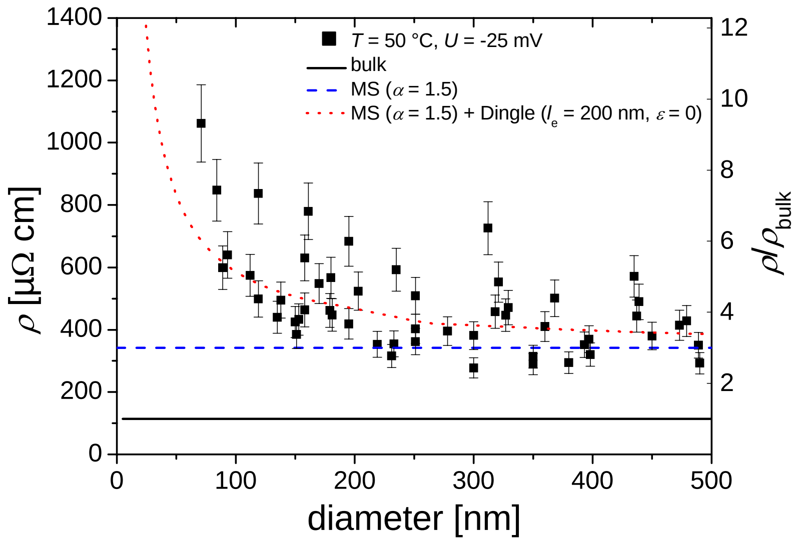

Fig. 1: Specific electrical resistivity of single bismuth nanowires. The solid line represents the specific electrical resistivity of bulk Bi. The dashed line considers electron scattering from grain boundaries, while the dotted curve takes into account also completely diffuse scattering from the wire surface.

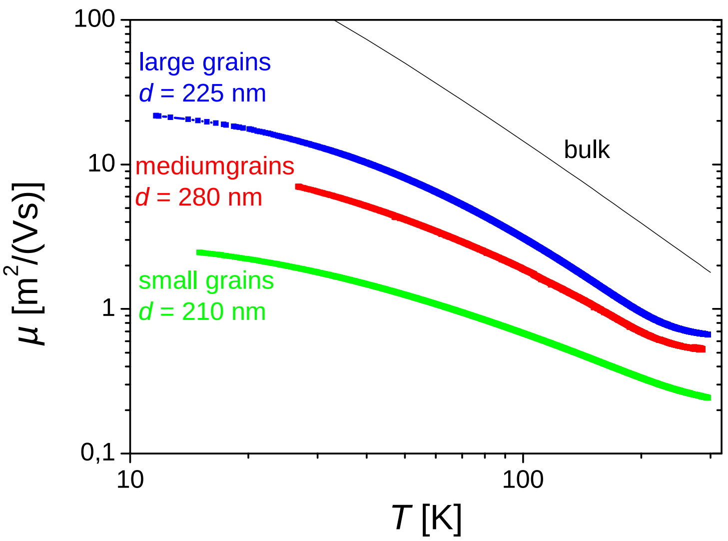

Fig. 2: Mobility of charge carriers for single bismuth nanowires as a function of temperature and mean grain size.