Anomalous Coulomb Blockade in Nanoconstricted Quench-Condensed Bi Films

Sergey E. Kubatkin [1,2], Andrey V. Danilov [2], Håkan Olin, Tord Claeson

MINA, Chalmers University of Technology, S-41296, Göteborg, Sweden

Abstract

Nanobridges in thin (1 - 3) nm granular Bismuth Quench-Condensed films with lengths and widths of 10 nm have been formed on top of an electrostatic gate made of oxidized aluminum. Periodic gate modulation of the Coulomb Blockade type $I(V)$ curves of these nanoconstrictions has been observed in the temperature range (4.2 - 11) K, indicating that the charge of a single grain controlled the transport in the constriction. A reversible transition between two states with the same charging energy of 35 meV occurred at a temperature around 8 K, with up to 5 times enhanced conductivity at low temperatures.

Keywords: Coulomb blockade; single-electron tunneling; thin films

Experiments on semiconductor quantum dots with few electrons demonstrated an interplay between quantum mechanics and charging effects and resulted in observations of single electron states [1]. Similar results have been obtained for metallic dots, where due to high electron density the size of the dot had to be reduced to the scale of a few nanometers, to resolve single-electron levels in the grain [2]. Due to the small size of the island the experiments with metallic dots are technically difficult, but the higher energy scale makes experiments of this type attractive from fundamental and practical points of view. Here we report transport measurements through metallic clusters with sizes of a few nanometers and charging energies up to 100 mV.

Using a modified Dolan-Niemeyer bridge technique [3], we have produced 10×10 nm^2 nanobridges in thin quench-condenced (QC) Bi films [4,5].

Electrical measurements could be performed in situ during the fabrication and allowed to tune the width of the nanoconstriction formed by the electron-beam-defined shadow mask to 10 nm. A bridge of nanoparticles between self-aligned low resistive electrodes with a thicknesses of about 8 nm has been formed by depositing metal in the nanogap under angle (see Fig. 1). The nominal film thickness in the bridge D could be varied in the range (1-3) nm by in situ film depositions, changing the grain size and the configuration of the tunnelling paths until a single grain gains

[1] Corresponding author. Present address: MINA, Chalmers University of Technology, Fysikgränd 3, S-41296, Göteborg, Sweden. E-mail: kubatkin@fy.chalmers.se
[2] On leave from Kapitza Institute, 113117 Moscow, Russia

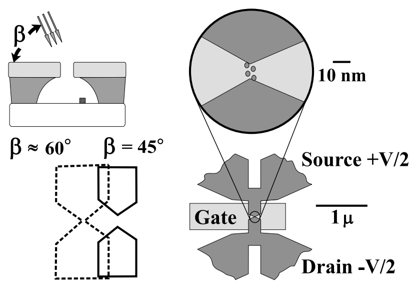

Fig. 1. Left - tuning a constriction size: starting from $\beta = 45°$, the tilt was incremented stepwise narrowing the gap by 10 nm in every step. After each step 2 nm of material were deposited and the sample conductivity was measured to check if the connection appeared. Right - resulting sample geometry. Substrate - oxidized Silicon, gate - oxidized Aluminium.

control of conductivity (see Fig. 2).

The observed regular gate modulation of the current (Fig. 2**c**) is in contrast to all reported properties of single electron devices based on random lateral structures, with reproducible, but irregular pattern of a modulation [6]. This is due to an exceptionally small size of the constriction leaving just one tunneling route available.

The reversible temperature dependence of the tunneling current revealed in our nanoconstrictions (Fig. 3) is very unusual. The transition temperature is close to the possible transition temperature of the leads (6.1 K). However, we do not see a direct relation between the observed effects and superconductivity in the leads. We believe

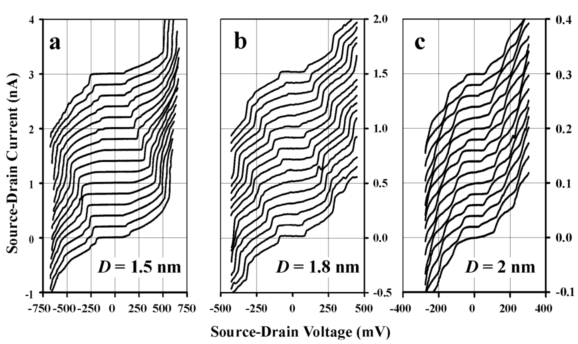

Fig. 2. Evolution of the sample properties caused by *in situ* film depositions. $I(V)$ curves are taken at equally spaced gate voltages and are shifted vertically for clarity. Sample **c** demonstrated a periodic gate dependence and well formed Coulomb diamonds.

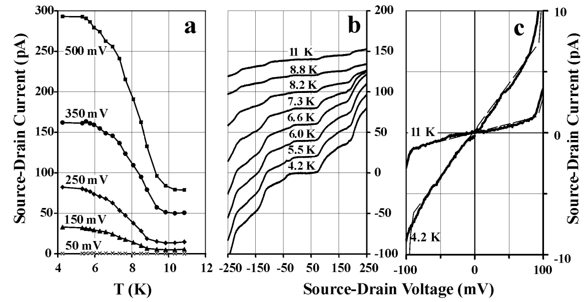

Fig. 3. The influence of the temperature on the sample presented in Fig. 2**c**. Closed state of the transistor at different temperatures: **a** - current at different biases and **b** - $I(V)$ curves. **c** - open state of the transistor.

that they need an explanation exploiting coherent electron transport in the constriction.

To summarize, single electron transistors based on metallic nanoclusters demonstrate clear deviations from an "orthodox" Coulomb blocade picture [7].

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