Pis'ma v ZhETF

Supplemental Material to Temperature dependence of the the conductance and thermopower anomalous features in quantum point contacts

O. A. Tkachenko[1)], V. A. Tkachenko

A.V. Rzhanov Institute of Semiconductor Physics SB RAS, 630090 Novosibirsk, Russia

Submitted 29 October 2012

PACS:

In this Material we consider the following questions: applying of the Landauer formulas for thermopower and conductance to experiments; a comparison of thermopower data to our model; the correspondence of the widths of the anomalous plateaux between experiment and model; temperature behavior of the one-dimensional electron density and conductance. Figures provided in this Material are referred to as Fig. 1 sup–Fig. 4 sup, while the publication numbers, formulas (1)–(5) and Fig. 1–6 refer to the main paper.

We tested the validity of Landauer formulas by the following way. Combining formulas (1) with approximation (2) it is easy to write $S = -[(1-G)\ln(1-G) + G\ln G]/G$, where thermopower S and conductance G are measured in units of $-k_B/e$ and $2e^2/h$, respectively. Thus we can find thermopower from conductance data and compare it to the measured thermopower. We know about only one paper, which reports anomalous plateaux for conductance and thermopower simultaneously [13]. We extracted S from $G(V_g)$ and ploted the reconstructed and measured points $S(V_g)$ (scaled to common unit $-k_B/e$). The values corresponding to the first subband almost coincided (Fig. 1 sup). Above the first subband the thermopower behave in accordance with the Mott law and with the calculations of the peak height between zero plateaux [7]. Thus we show that the spin degeneracy Landauer approach is valid up to temperature 1K, including anomalous plateaux.

One can see that the height of the anomalous conductance plateau equals 0.7, and the corresponding height of the thermopower plateau is the same for two samples and agrees closely with model values $S = 0.8 \div 0.9$. For one of the samples these plateaux are as pronounced as in the model computations for largest T shown in figures 5 and 6. However, in constrast to figure 6 the gradual widening of anomaluos features with increase of temperature has not been reported yet for joint conductance and thermopower measurements.

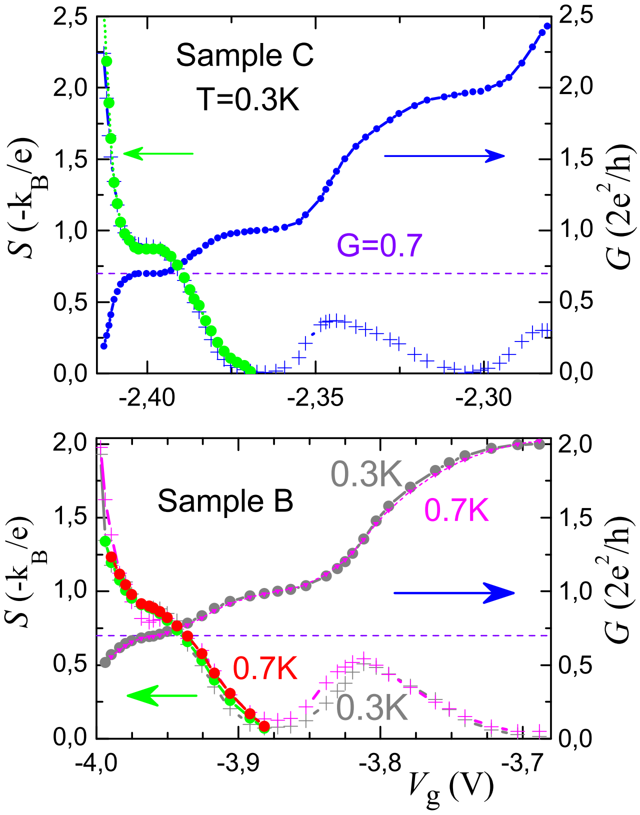

Fig. 1 sup. Data processing of the gate voltage dependences of conductance and thermopower from the paper [13] for two samples with the same geometry of metal gates and two temperatures. Seebeck coefficient obtained from conductance is shown by green and red circles; measured S-values are denoted by crosses.

A question of correspondence of calculated and measured plateaux reduces to determination of gate capacitance C_g of the quantum point contact (QPC). The capacitance depends on device geometry and the distance between the surface and the two dimensional electron gas. We performed self-consistent calculations of three-dimensional electrostatic potential and electron density for usual configuration of split gate and heterostructure from [5]. We took into

[1)] oatkach@gmail.com

account quantization of transverse motion and exchange-correlation correction in the local approximation, determined by the volume electron density [19]. Fig. 2 sup shows calculated gate voltage dependences of the first subband bottom $V_0 - E_F$ and 1D-electron density n_c at the narrowest place of the QPC ($V_0 = E_1(x = 0)$). One can see that

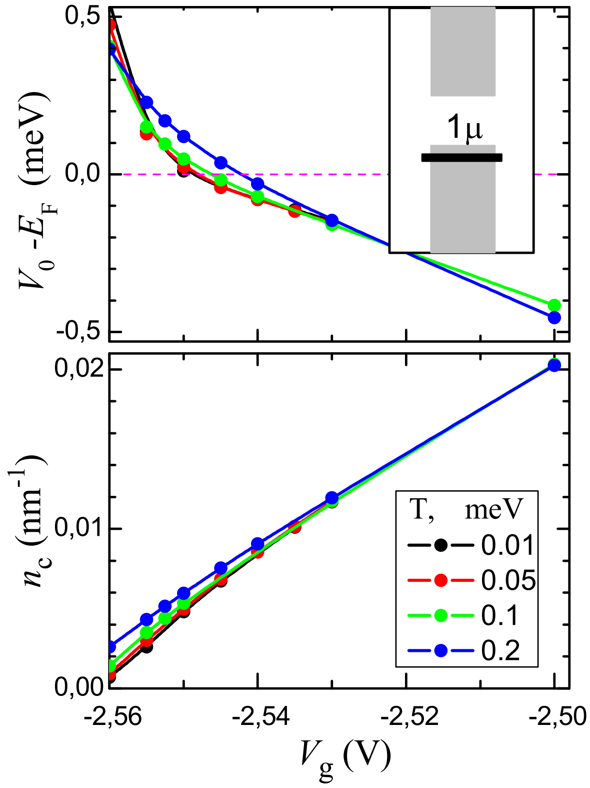

Fig. 2 sup. Dependences $V_0(V_g) - E_F$ and $n_c(V_g)$ obtained from the solution of 3D-electrostatics of the QPC.

the function $n_c(V_g)$ is almost linear and weakly depends on temperature: $C_g \approx 1/3\,\mathrm{V}^{-1}\mathrm{nm}^{-1}$. Typical width of 0.7-feature in our model $\Delta n_c \approx 0.007\,\mathrm{nm}^{-1}$ (Fig. 5) corresponds $\Delta V_g \approx 0.02$ V. Notice that strongly pronounced 0.7-plateaux have the width ΔV_g: 0.01 V for sample C (Fig. 1 and Fig. 1 sup) and 0.02 V for sample B (Fig. 1 sup). Wider plateaux 0.04 V ($T = 6.5$ K) were observed in [9]. It is clear that the width spread of 0.7 feature is determined by discrepancy of the gate capacitance for different structures. Thus, we can conclude that our simple model correctly describes experiments.

Lastly, consider temperature behavior of electron density and conductance. Fig. 3 sup shows coordinate distribution of 1D electron density computed with formula (4). One can see that the density strongly changes with increasing temperature in the transition from the tunnel regime to the open one. At the lowest temperature there are Friedel oscillations (FOs) in the tunnel regime, while in the open regime they are suppressed. Calculated correction $\Delta n(x, T)$ is a wide perturbation of density across the whole barrier. At $V_0 > E_F$ one can see thermally activated increase $n(x, T)$ at the barrier top; this temperature behavior inverts in the open regime $V_0 < E_F$.

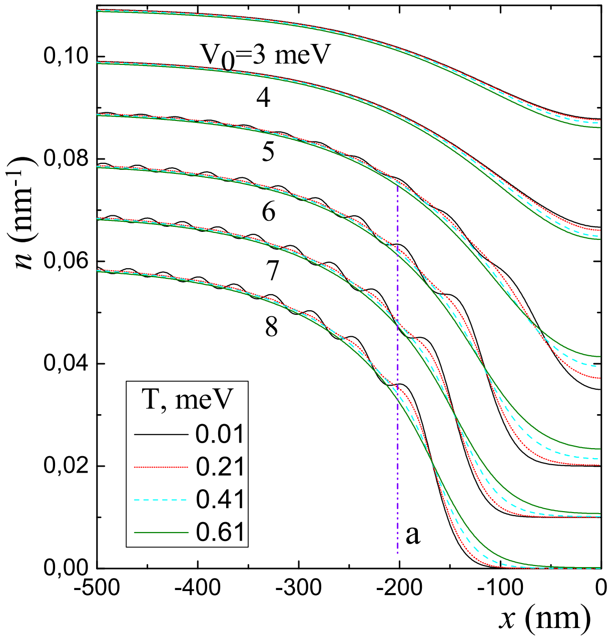

Fig. 3 sup. 1D-electron density calculated with formula (4) at $E_F = 5$ meV for potential $U_0(x) = V_0/\cosh^2(x/a)$, where the half-width a is fixed $a = 200$ nm and the height V_0 is varied $V_0 = 3, 4, 5, 6, 7, 8$ meV. Curves for different V_0 are offset by 0.01 nm^{-1} for clarity.

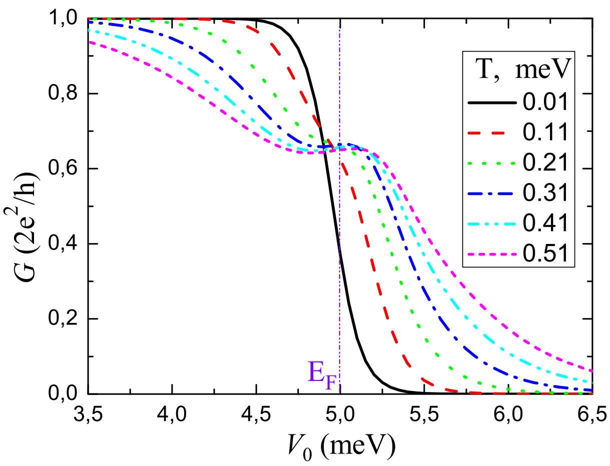

Fig. 4 sup. Conductance $G(V_0, T)$ calculated for corrected potential $U(x) = U_0(x) + \delta U(x)$ with $U_0(x) = V_0/\cosh^2(x/a)$, $a = 200$ nm, $E_F = 5$ meV, and interaction parameter $\alpha = 0.2$.

Conductance as a function of the barrier height V_0 was calculated with the aid of formulas (1), (4), (5). The result is shown in Fig. 4 sup. There is an usual conductance step with unit height at $T = 0.01$ meV. However with increasing temperature additional 0.6–0.7-plateau is developed at $V_0 = E_F$. The width of these plateaux well corresponds to temperature. Notice that the height of corrected barrier is almost not changed at the lowest temperatures and only the distant FOs can have influence on transmission. Indeed, similar to [17], scattering off FOs leads to a small decrease in transmission coefficient at low but finite temperatures and a shift of the conductance step to the lower values of V_0.