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# Conductance quantization in an array of ballistic constrictions

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Abstract We have investigated the transport properties of a two-dimensional array of ballistic constrictions and found that the conductivity as a function of gate voltage increases in approximately equally spaced steps. Surprisingly, the height of the observed steps is not an integer multiple of $2e^2/h$, but roughly one third of this fundamental unit. Numerical simulations strongly suggest that this increase in resistance is due to coupling between parallel channels in our superlattice.

## 1 Introduction

Since advances in nanofabrication have made it possible to access the ballistic transport regime, many interesting results associated with electronic transport through quantum point contacts (QPC's, i. e. short and narrow constrictions that are much smaller than the electron mean free path), have been obtained. Single [1] and double QPC's both in serial [2] and in parallel [3] configuration have been investigated. In most cases, the conductance of these systems is found to be quantized in units of $2e^2/h$.

Here, we report on transport experiments on a large two-dimensional array of such ballistic constrictions and show that we have realized a *material with a quantized conductance*.

## 2 Fabrication

The device was fabricated from a GaAs/AlGaAs-heterostructure with a shallow two-dimensional electron gas with typical carrier density of $6 \times 10^{11}\,\mathrm{cm}^{-2}$ and mobility of $8 \times 10^5\,\mathrm{cm}^2/\mathrm{Vs}$. High-resolution electron beam lithography and wet chemical etching techniques have been used to define a lateral superlattice of $55 \times 96$ quantum point contacts, i.e. parallel rows of narrow constrictions that are linked every 700 nm (see right inset of Fig. 2). A thin NiCr-gate, covering the entire structure allows us to vary the electron density and thus the number of occupied one-dimensional subbands in the constrictions.

## 3 Experiment

Fig. 1 shows the gate voltage dependence of the longitudinal conductivity $\sigma_{xx}$[1] at two different temperatures. As the measurements have been carried out in different cooling cycles, the two curves are slightly offset. Sweeping the gate voltage at sufficiently low temperature (250

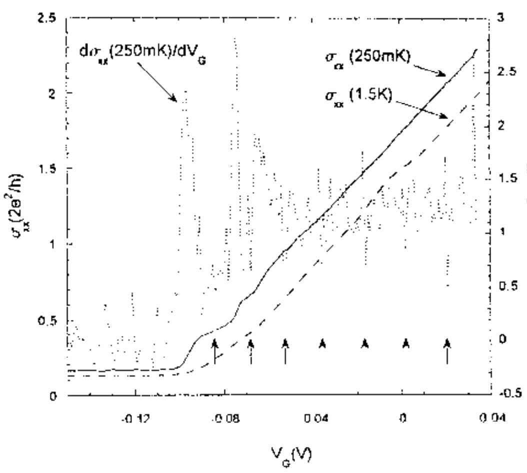


**Fig. 1** Longitudinal conductivity $\sigma_{xx}$ at 250 mK (solid line), 1.5 K (dashed line) and derivative $d\sigma_{xx}(250\mathrm{mK})/dV_G \propto dI/dV_G$ (dotted line) vs. gate voltage of a lateral superlattice of quantum point contacts. Minima in the differential transconductance, corresponding to plateaus in the conductivity, are indicated by arrows.

mK), both in two-terminal (shown here) and in four-terminal measurements $\sigma_{xx}$ reveals a step-like structure of equally spaced plateaus. Up to seven oscillations can be identified in the differential transconductance $dI/dV_G$ (dotted line in Fig. 1). As the ocurrence of these steps is qualitatively independent of the actual geometry, our device can be regarded as the realization of a material with a quantized conductance.

The height of the observed conductivity steps is $\approx 0.3\,\frac{2e^2}{h}$, and thus not an integer multiple of the fundamental unit of conduction. Previous results show that the conductance of parallel QPC's is practically additive [3], i.e. $G_{total} = (\frac{2e^2}{h})\sum_i n_i$, where $n_i$ is the number of modes propagating in contact $i$. The resistance of two series point contacts however is not simply additive [2]. In this case, the conductance can vary between $G_i/2$ and $G_i$, if $G_i$ is the conductance of an individual contact. Thus, our experimental data is neither consistent with the simple model of a mesh of Ohmic resistors, each of the value $\frac{h}{2ne^2}$, which would lead to a conductivity quantized in units of $2e^2/h$, nor with the picture of coherent

[1] $\sigma_{xx} = \frac{I}{V}\frac{96}{55}$ in the present case

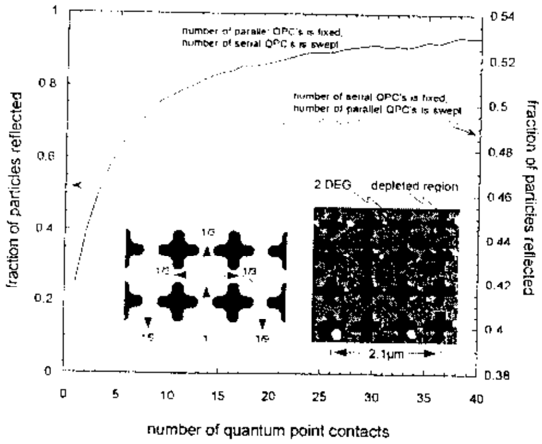


Fig. 2 Fraction of particles reflected in the numerical simulation when sweeping the number of series (solid line, left scale) and the number of parallel (dotted line, right scale) point contacts. Right inset: AFM micrograph of a section of the fabricated superlattice. Arrows represent electron trajectories that are backscattered by the concave boundaries. Left inset: Illustration of the model used in the simulation.

transport through a series of quantum point contacts, which would result in even larger conductance steps.

## 4 Numerical simulation

As schematically indicated in the right inset of Fig. 2, a mechanism that could explain our observations is backscattering from the boundaries of the coupled quantum dots formed between the constrictions. Due to the fact that parallel rows of point contacts are linked every 700 nm, coherent backscattering of electrons should become possible in this system (see left inset of Fig. 2).

In order to find out, how the characteristics of an individual point contact are modified in a large array, we employ a simple model, simulating electronic transport in our structure. As a first approximation, we assume that an electron entering a dot will leave it through either of the "exits" with equal probability (see left inset of Fig. 2). Thus, coupling of the rows is introduced by a finite probability for leaving the dot to the sides. If we now inject particles from one side of the structure, we can trace their trajectories through the lattice and determine the fraction $R$ of those that do not manage to get to the other side. Fig. 2 shows the results of this Landauer-Büttiker-type description for two different situations. When the number $n_p$ of parallel QPC's is kept at a fixed value (in this case $n_p = 2$) and the number $n_s$ of series QPC's is swept, we obtain the solid curve. Keeping $n_s$ constant (here $n_s = 2$ again) and sweeping $n_p$, we obtain the dotted curve. Obviously, the $n_s$-dependence of $R$ is much more distinct than the dependence on $n_p$. However, the important result is that a growth of the lattice in either of the two directions leads to an increase of $R$.

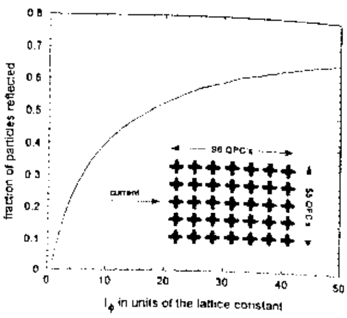


Fig. 3 Fraction of particles reflected in the numerical simulation when sweeping the phase coherence length. Inset: Sketch of the superlattice geometry used for this calculation.

To get a more realistic model of the device, in a second step we introduce a finite phase coherence length $l_\phi$. The number of electrons that, after having travelled a distance $l$ through the lattice, can still be reflected in a coherent way decays like $e^{-l/l_\phi}$. Fig. 3 shows the result for the special geometry of our sample, i.e. an array of $55 \times 96$ quantum point contacts. It can be seen that the fraction of coherently reflected particles strongly depends on the phase coherence length. However, even at small values of $l_\phi$ the reduction of transmission, compared to an array of totally uncoupled QPC's, is maintained.

Of course, this simple model is not suitable for making quantitative statements. However, it illustrates that in a superlattice of our size the coupling of adjacent contacts in connection with a sufficiently large phase coherence length can significantly reduce electronic transport through the system. It therefore offers an explanation for the fact that the height of the experimentally observed conductivity plateaus is smaller than the fundamental unit. Magnetotransport experiments on the same structure in the classsical regime ($T = 4.2\,\mathrm{K}$) show that the concave shape of the dot boundaries strongly influences the transport properties of the device [4]. The conductance measurements discussed here suggest a similar mechanism.

## 5 Acknowledgments

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