Vertical-mode dependence of coupling between an electron waveguide and reservoirs with two occupied subbands

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For a ballistic one-dimensional (1D) electron system like a quantum point contact (QPC) the quantized conductance steps are broadened mainly due to the finite temperature and to tunneling processes. In this work we study the conductance contributions of transport modes belonging to different subband series, characterized by the quantum numbers *(s,n)* for the vertical (*s*) and lateral (*n*) confinement. Remarkable larger broadening of the conductance steps arising from the second vertical mode ($s = 2$) compared to those of the ground mode ($s = 1$) indicates a mode-dependent scattering in coupling the 1D states to the two-dimensional (2D) electron system of the reservoirs.

The QPCs are fabricated by atomic force microscope (AFM) lithography and subsequent wet chemical etching [1]. The constriction of 30-140 nm width is formed by two 75-85 nm deep grooves which are laterally displaced (see insert of figure 1), and is controlled by a top gate electrode. The 2D electron system is located in a 30 nm wide quantum well, which is modulation doped on both sides. Shubnikov-de Haas measurements prove the onset of the second 2D subband population at a gate voltage $V_G \sim 0.02$ V.

In the transport characteristics of the QPCs we distinguish two series of signals, each series arising from one vertical mode. Conductance characteristics measured at 4.2 K show quantization with distinct plateaux (figure 1). Deviations from the regular increase in $2e^2/h$ multiples, such as missing or ill-defined steps, are noticed. A missing step appears at the coincidence of two 1D-subbands belonging to different vertical modes, while an ill-defined step is caused by their close proximity. The confining potential of a QPC can be changed by applying a forward bias voltage to the gate electrode during sample cooling from room temperature to 4.2 K [2]. This effect corresponds to the persistent partial neutralization of the donors in the supply layer. A change of the confining potential results in a shift of the different 1D subband series ($s = 1, 2$) relative to each other. This enables us to identify the transconductance maxima with the corresponding 1D modes *(s,n)* as shown in figure 2. The amplitudes of these maxima show striking differences between the $s = 1$ and $s = 2$ modes, while the corresponding conductance contribution is close to $2e^2/h$ for both series. Obviously, the broadening of the conductance steps depends on the vertical mode *s*, which we attribute to an enhanced scattering rate in coupling the excited mode $s = 2$ to the second subband in the 2D reservoir.

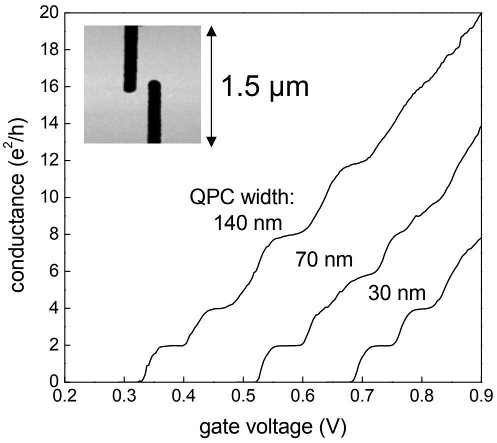

Figure 1. Conductance characteristics of three QPCs of different width. Note the missing step at $6e^2/h$ for the 140 nm wide QPC and the ill-defined at step $4e^2/h$ for the 70 nm wide QPC. Series resistances between 400 Ω and 650 Ω have been subtracted. The insert presents an AFM image of the groove pattern defining the constriction.

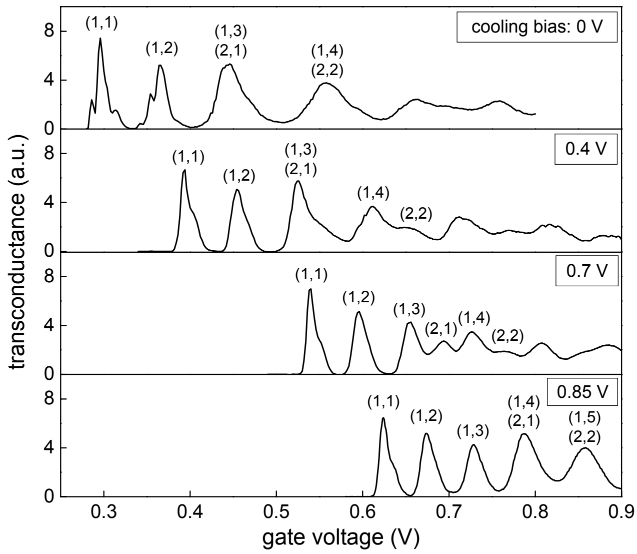

Figure 2. Transconductance of a 140 nm wide QPC at 4.2 K measured after cooling the sample from room temperature under different gate voltages. The index *(s,n)* associates each maximum in transconductance to a 1D-subband. *s* describes the quantization in the growth direction (vertical modes) while *n* describes the lateral confinement (transversal modes).

References

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