Resonant Tunneling Between Parallel 1D Quantum Wires and Adjoining 2D Electron Reservoirs

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Ever since the pioneering work of Esaki and Tsu resonant tunneling structures have attracted much attention due to their negative differential resistance (NDR). Following that trend we focus on basic tunneling processes between low-dimensional systems, for which we present our latest results.

We developed the resonant tunneling transistors shown in Fig. 1, in which we study lateral tunneling between large 2D electron reservoirs and one or more parallel 1D quantum wires. The basic *GaAs/AlGaAs* heterostructure that hosts the 2D system is a 750 nm long vertical transistor realized by means of the cleaved-edge overgrowth technique. In addition, the transistors are equipped with a varying number of 3 nm wide AlAs tunneling barriers with a distance of 12 nm, which confine the 1D states. By application of a gate voltage the 1D quantum wires and the adjacent 2D systems can be electrostatically induced and their carrier density continuously tuned.

We examine these devices by measuring the *I-V* output characteristic under gate voltage bias at 4.2 K with typical results introduced in Fig. 2. Although all curves are composed partially of gate leakage currents and pure transistor behavior, clear signatures related to resonant tunneling are found. The number of quantum wires involved in the tunneling process shows only small effect on the appearance and position of these signatures. The typical NDR region (*B*) and its replica ($\overline{B}$) at negative voltages are identified with tunneling from the 2D source through the 1D ground state. The weaker conductance change (*C*) is attributed to tunneling through the first excited 1D state. The differential conductance at zero bias (*A*) starts to increase above a threshold gate voltage, which corresponds to the onset of populating the 1D ground state in equilibrium. We also observe a shift of all features to larger absolute source-drain voltages with decreasing gate voltage. This can be explained qualitatively by treating the device as a series of two transistors and a tunnel junction. In particular the sole tunneling region is visible only in the limit of large gate voltages and small source-drain bias. For this part of the parameter space we then note: First, that the resonances are nearly independent of gate voltage. Second, that the resonance voltage marginally varies with the number of quantum wires. We propose that almost all source-drain voltage drops over the first barrier at the 2D-1D transition and only a small amount at the 1D-1D transitions. Based on this assumption we understand the observed behavior well from a simple 2D-1D tunneling model including energy and momentum conservation in the component transversal to the current direction. A NDR feature then occurs when the bottom of an 1D state drops below the conduction band edge of the 2D source. This condition is also independent of Fermi energy (or gate voltage, respectively).

The experimental results and schematics of the important tunneling conditions are summarized in Fig. 3 in case of one quantum wire between the reservoirs. This picture is also representative for devices including more parallel quantum wires, as all 1D states align in energy due to the small 1D-1D voltage drop proposed. We calculate the conductance from the *I-V* curves to highlight the tunneling resonances in the color coded plot for the whole source-drain/gate voltage space. The black lines mark the resonances (*B*) and (*C*) mentioned before. In addition line (A_3) appears, designating resonant filling of the 1D ground state from the 2D source in non-equilibrium. (A_1), (*D*) and (A_2) label equilibrium conditions with the 1D ground state above, directly at and below the 2D Fermi energy. This picture further includes all replica lines $(\overline{A}_3),(\overline{B})$ and $(\overline{C})$ at negative bias, which indicates the high symmetry in the resonant tunneling transistor structure. In conclusion, we presented a qualitative model explaining the characteristics of our resonant tunneling transistors.

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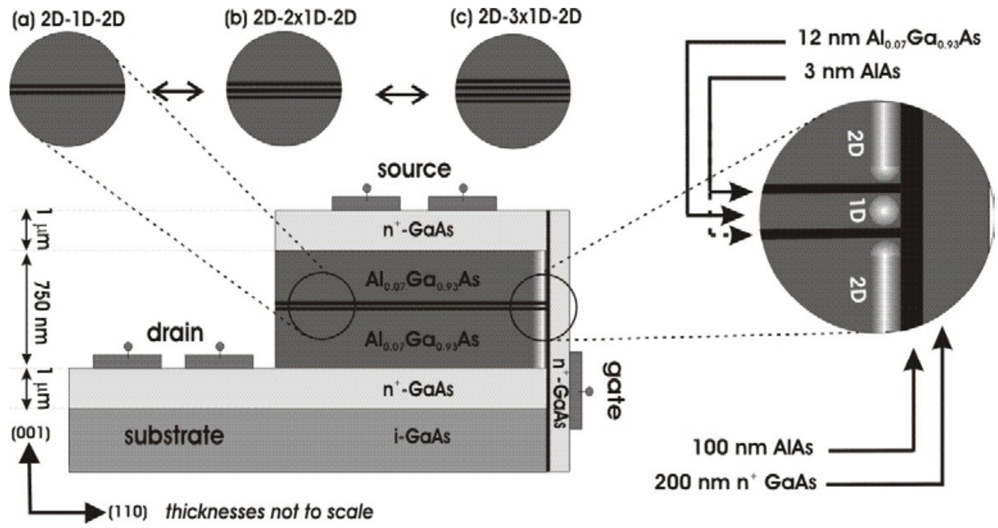

Fig. 1: *Cross section of the resonant tunneling transistor containing (a) 1, (b) 2 or (c) 3 quantum wires.*

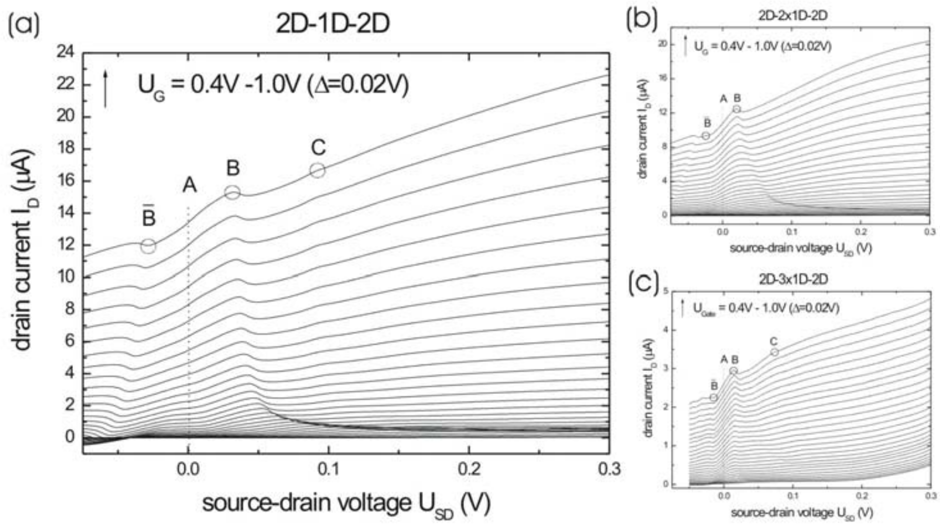

Fig. 2: *I-V traces for several gate voltages in case of (a) 1, (b) 2 or (c) 3 parallel quantum wires.*

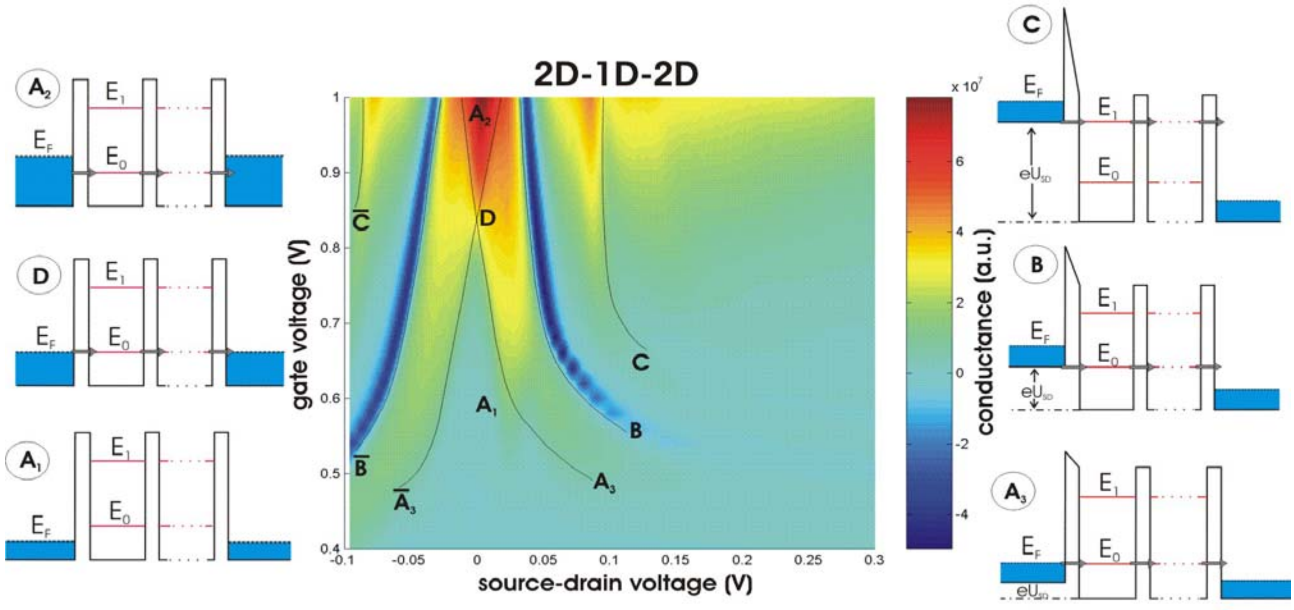

Fig. 3: Color coded conductance plot of the source-drain/gate voltage space in case of one quantum wire. The black lines are guides to the eyes of all characteristic tunnelling signatures with their energy schematics shown to the left and right hand side.