Tunneling in Double Quantum Wire Devices

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Motivation—Interactions in nanoelectronic systems is a frontier area of basic science and possible novel application. One very good candidate for study is the system of coupled double quantum wires. Single one-dimensional (1D) wires are expected to have ground states that are strongly modified by Coulomb interactions. Coupled 1D wires have been used to probe many-body effects and have been suggested as a platform for quantum computation. In our experiments, we focus on the fundamental nature of the inter- and intra-wire interactions and examine the role of coherent tunneling of the electrons between the 1D wires.

Accomplishment—We have measured tunneling in a double quantum wire device and observed a narrow tunneling resonance that we attribute to 1D-1D tunneling. An image of the device is shown in Fig. 1a where the dark regions are the semiconductor and bright regions are metallic gates. A GaAs/AlGaAs electron bilayer with a 10 nm AlGaAs barrier between the two GaAs quantum wells is grown using molecular beam epitaxy (MBE). Electron beam lithography is used to pattern metallic gates above and below the electron layers. In the central region two pairs of split gates (only the two top gates are visible due to the high degree of alignment) form the top and bottom quantum wires. The gates on the left and right that span the image are used to establish independent contacts to the individual wires.

The conductance of both wires in parallel is shown in Fig. 1b. In the 1D regime, plateaus form as integer numbers of subbands in the quantum wires are occupied. The equally spaced white regions (I and III) are the well known quantized conductance steps of a single wire. In the center of the plot (region II), the structure of both wires overlap and form diamonds where two 1D wires coexist. One advantage of this device is our control of the number of occupied 1D subbands in each wire.

Tunneling measurements are presented in Fig. 2. In a tunneling measurement, electrons are transferred between the quantum wells conserving both energy and momentum. Fortunately, we have control over both energy (via a dc source-drain voltage between the layers) and momentum (using a parallel magnetic field to give the electrons a momentum “kick”). Due to limitation of lateral patterning, the active tunneling areas consist of two small 2D-2D coupled areas joined by the 1D-1D (diagram in Fig. 2), so both 2D-2D tunneling and 1D-1D tunneling signatures are expected. The tunneling conductance as a function of the voltage between the layers is shown in the main panel in Fig. 2 at three magnetic field values. The large peak at B=0 is easily identified as the 2D-2D contribution to the tunneling. The peak position, splitting with magnetic field and ultimate collapse at high field can be quantitatively understood through simple tunneling models. The side peak at $V_{source\text{-}drain}$ = -9 mV, however, is not expected from 2D-2D, and its position varies as the split-gate voltages are varied. The presence of this peak indicates 1D tunneling.

Significance—We have identified a 1D tunnel resonance in the vertically coupled 1D-1D device. Demonstration of the 1D resonance is the first step in future experiments on coherent tunneling oscillations. Coherent transport is one of the major advantages of nanoelectronics.

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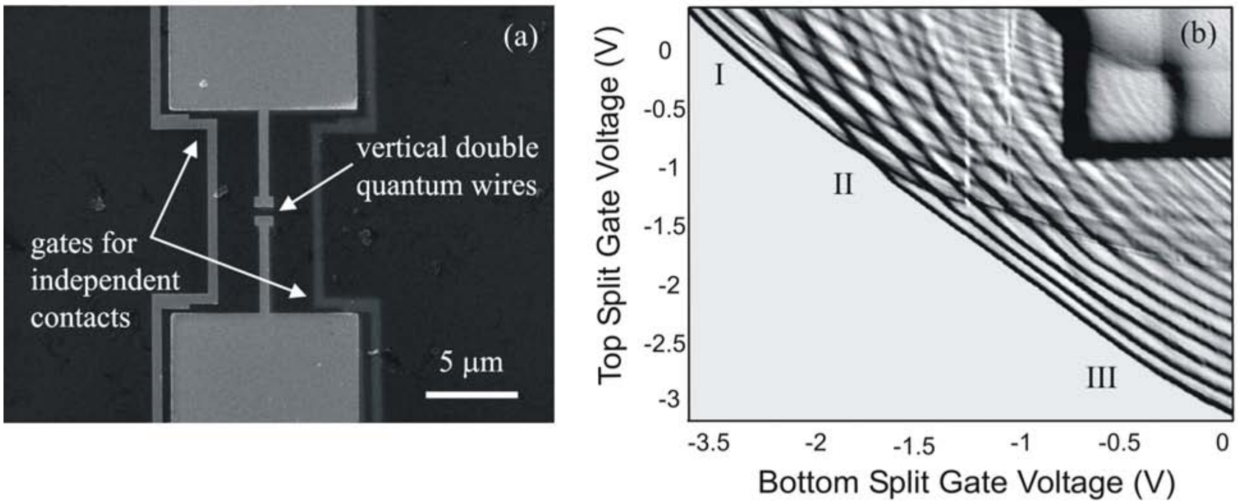

Figure 1. (a) Scanning electron microscope image of the double quantum wire device. (b) Parallel conductance of the double wire. White regions are dg/dV ~ 0 (plateaus) and dark regions are dg/dV > 0. Regions I and III are singly occupied 1D wires with evenly spaced quantized plateaus indicating high quality ballistic quantum wires. In region II, both wire are occupied, and the number of subbands can be controlled with the top and bottom split gate voltages.

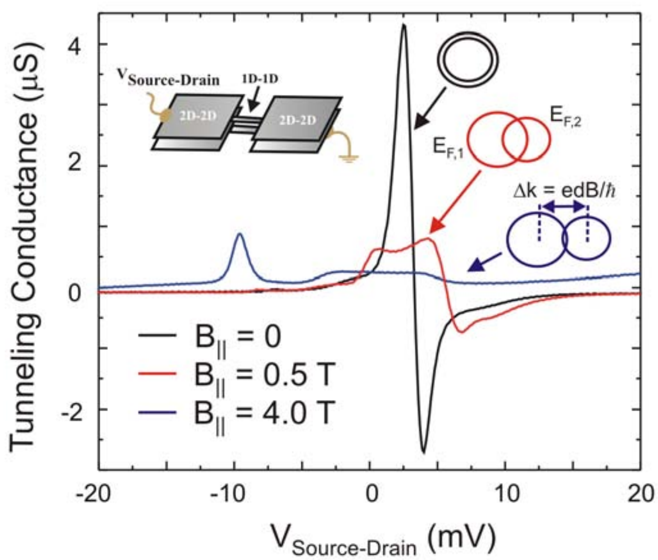

Figure 2. Tunneling conductance in the double quantum wire system. The diagram (upper left) indicates that both 2D-2D and 1D-1D tunneling can occur. The large peak at $V_{Source\text{-}Drain} = 2.5$ mV that splits with a parallel magnetic field is due to 2D-2D tunneling. The parallel field separates the Fermi circle in k-space; tunneling only occurs at the intersection of the Fermi circles. The onset of a second peak at high field is due to 1D tunneling.