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Planar Field-Effect Coupled Quantum Wires

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Using a planar split-gate scheme, we have fabricated two quantum wires in close proximity to each other. The field-effect action of a thin middle gate separating the wires allows controlled coupling between the wires. Our experiments show that this coupled quantum wire scheme leads to interesting new device possibilities based on novel regimes of electron interaction.

A split-gate scheme can be used to create a one-dimensional (1D) electron channel at the interface of an AlGaAs/GaAs MODFET structure. A negative gate voltage depletes the 2D electron gas (2DEG) underneath the gates but leaves a narrow conducting channel in between. The channel width can also be controlled by the gate bias through the fringing fields of the gate. For short enough devices and low temperatures, electrons can travel ballistically through the quantum wire, giving rise to characteristic quantized conductance steps [1-3].

In a logical next step, we have fabricated two quantum wires very close to each other and allow them to interact. We have used a split-gate scheme to create two quantum wires that share a common, very narrow confining electrode. In this manner we not only get the two wires to be in close proximity to each other, but we can control the degree of interaction or coupling between them through the field-effect action of the middle gate electrode. Two side gates are used to define the outer boundaries of the wires. The three gates can be individually accessed, thereby the width of the individual wires can be controlled with the side gates (determining the number of allowed modes in each wire) and the coupling or interaction between the wires can be controlled with the middle gate. This approach leads to new device possibilities based on electron interaction such as a quantum field-effect directional coupler (QFED) [5] and a quantized 1D source-drain FET.

We have fabricated a variety of planar coupled quantum wires with different lengths and widths using electron-beam lithography on a AlGaAs/GaAs MODFET structure ($N_s = 7 \times 10^{11}\ cm^{-2}$ and $\mu = 170{,}000\ \frac{cm^2}{V-sec}$ at 4 K). The key feature in these devices is the 30 nm wide middle gate fabricated using a single-pass e-beam lithography technique. The middle gate is widened outside of the coupled region to prevent interaction in the extrinsic device. Device processing consists of mesa isolation, ohmic contact formation to allow individual access to the input and output of each wire, and a combination of uv and e-beam lithography for gate formation.

The coupled quantum wires have been characterized at 300 K and 4 K. By monitoring the current through the various terminals, we have identified the regime in which two quantum wires are formed. Controlling the middle gate voltage, we can vary the level of interaction of the two wires, from complete isolation to merging into a very wide wire whose boundaries are the side gates. At low temperatures, we observed conductance steps in each wire separately at T=1.7 K, confirming quasi-ballistic 1D transport (L= 0.5 μm). We then biased the middle gate so as having the two quantum wires separated by a narrow tunneling barrier. Current from one wire to the other was studied in a configuration in which the device is essentially an FET with a quantized 1D source and drain. We observed strong oscillations in the current traversing the middle gate as a function of the drain wire. The oscillations disappeared at high V_{DS} ($\cong 1\ mV$), high temperatures ($\cong$ 10 K), and for very negative middle gate biases, indicating that this is a tunneling current whose features might derive from the 1D density of states structure of the drain.

In summary, we have fabricated for the first time two planar quantum wires, whose coupling can be controlled through the field-effect action of a gate. Our split-gate coupled wire scheme provides a new architecture to study electron interaction in low dimensionality systems. This work might lead to the conception of new electron devices with enhanced functionality.

[1] van Wees et al., *Phys. Rev. B* **60**, p. 848, 1988. [2] Wharam et al., *Journ. Phys. C* **21**, L209, 1988. [3] Eugster et al., *DRC 1990.* [4] del Alamo et al., *Appl. Phys. Lett.* **56**, p. 78, 1990.

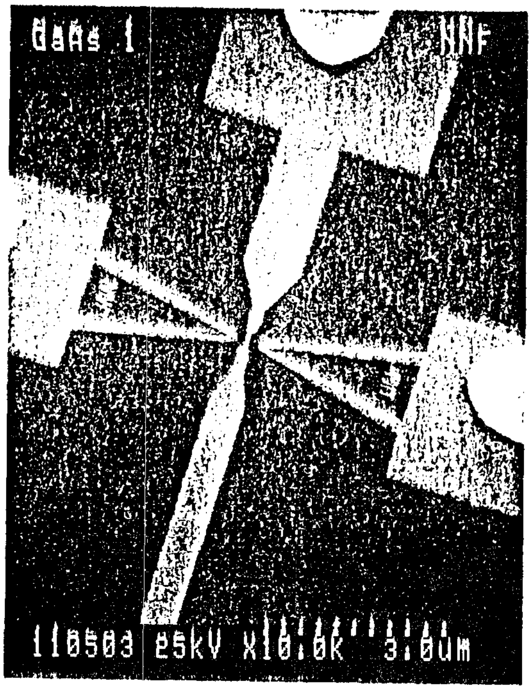

Figure 1. SEM micrograph of coupled quantum wires. The white areas are the Au/Pd gates. The side gates were not completely filled in to conserve electron-beam writing time.

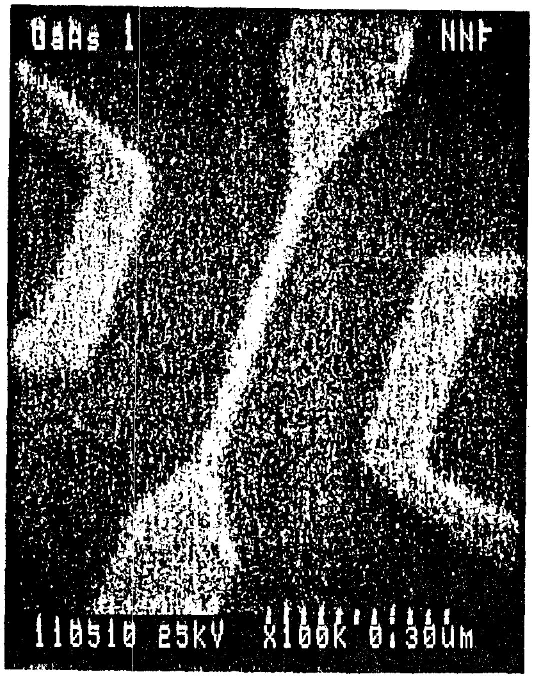

Figure 2. SEM close-up of the coupled quantum wire region. The linewidth of the middle gate is 30 *nm*.

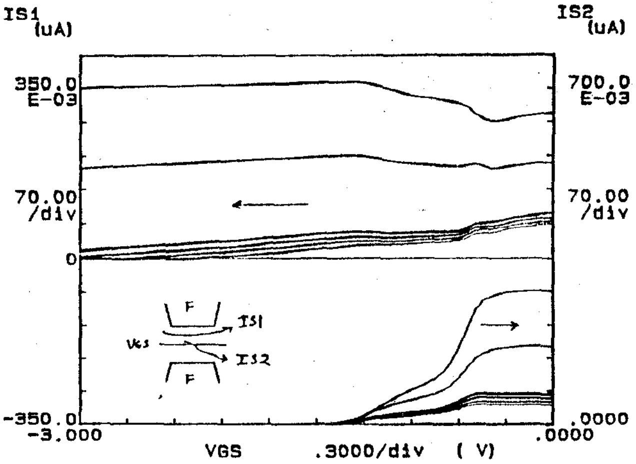

Figure 3. A voltage, $V_{DS} = 100\ \mu V$, is applied between the input of the top wire and the outputs of both wires. The current is independently measured at the output of the top wire, I_{S1}, and the output of the bottom wire, I_{S2}, as a function of the middle gate voltage, V_{GS} for various gate biases, F, on the side gates.

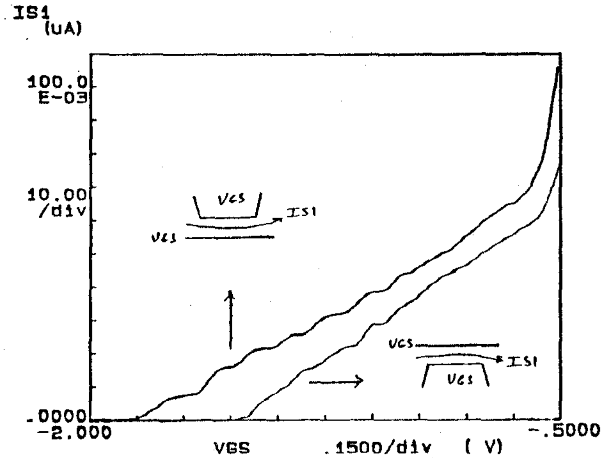

Figure 4. Confirmation of quasi-ballistic transport at T=1.7 K in each wire individually. The steps in the current correspond to the 1D subbands in the wires. $V_{DS} = 100\ \mu V$.

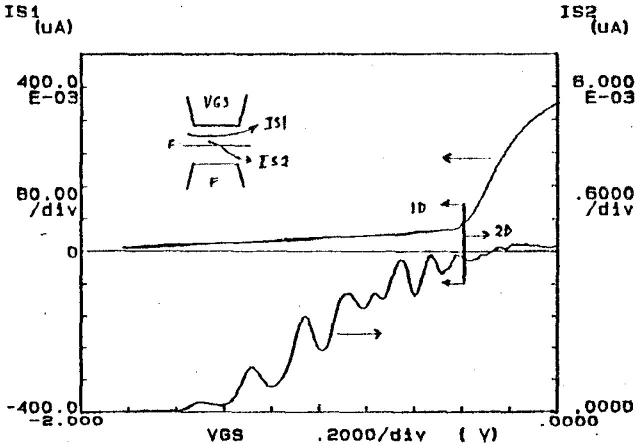

Figure 5. Oscillations at T=1.7 K in the cross-current, I_{S2}, as a function of the top gate bias, V_{GS}. The middle gate bias, F, was fixed such that there was a tunneling barrier between the two wires. The bottom gate bias was fixed at a voltage more negative than the 2D threshold. Note that the oscillations occur only when the top wire is in the 1D regime as seen by I_{S1}.