wire width of 3500 Å. Clear conductance steps were observed at even higher temperatures up to 120 K. However, the conductance values at steps at those higher temperatures above 100 K do not agree with multiples of $(2e^2/h)$. This is probably due to the parasitic MESFET which turns on very weakly at high temperatures.

This is to our knowledge the first demonstration of 1 D quantized conductance and quantized currents at 80 K in any semiconductor devices. Our results clearly show the potential application of InAs quantum-effect devices which can operate at realistic temperatures.

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VB-4 A Novel Quantum Effect FET with Resonantly Modulated Transfer Characteristics

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A novel quantum effect field-effect transistor (FET) has been realized in which drain current I_{DS} is resonantly modulated with gate-source voltage by using the mobility-modulation effect [1], [2] in a double quantum well (DQW) structure. Such characteristics are achieved by the gate-controlled resonant coupling, which leads to a large positive-negative-positive transconductance. It may provide a new functional device feasible by rather simple FET compatible processes.

The FET consists of a modulation-doped DQW channel, an Al Schottky gate deposited on the channel, and a pair of source- and drain-contacts to the DQW channel containing a 150 Å GaAs QW (bottom QW) and a 100 Å GaAs QW (top QW) separated by a 25 Å AlGaAs central barrier. The top QW is δ-doped with Si of 2×10^{11} cm^{-2} so as to enhance the wavefunction-dependent scattering [3]. In this geometry, gate voltage Vg changes the electron wavefunctions between localized and delocalized states as well as the electron density in the DQW channel. Consequently the interaction between Si donors in the top QW and electrons originated from the bottom QW with rather high mobility is drastically increased around the resonance gate voltage. It leads to resonantly modulated channel conductance G as follows; when Vg increases from the threshold, G increases monotonously, and reaches its peak value where the electron density in the bottom QW gets saturated. Further increase of Vg induces electrons in the δ-doped top QW, while the energy levels in the two QWs get close to each other and tunneling of electrons is enhanced. Increasing interaction of electrons in the bottom QW with impurities in the top QW leads to the decrease of the effective mobility of DQW's, resulting in the decrease of G. The bottom of the valley in the G-V_g curve corresponds to the resonance of energy levels. When V_g is further increased, G recovers because wavefunctions are decoupled and localized in each QW again. One should note here that this resonance feature in G does not originate from the effect of carrier transfer from one well to the other but from the quantum mechanical change in electron wavefunctions.

The channel conductance G versus Vg characteristics measured under a low drain-source field at 4.2 K shows in fact a prominent valley structure with a peak-to-valley (P/V) ratio of 3. This resonance feature was observed also at 77 K although the P/V ratio is degraded to 1.5. This is due to the decrease of higher electron mobility in the bottom QW since the optical phonon scattering degrades the electron mobility in the bottom QW at higher temperature.

At higher V_{DS} than the pinch-off, I_{DS} is mostly determined by the total number of electrons in the DQW channel, resulting in the usual FET characteristics. As V_{DS} decreases and the gate electric field becomes uniform along the channel, the resonant structure in the transfer characteristics gets clearly visible. As long as V_{DS} is well below the pinch-off point, non-linear feature mentioned above was clearly observed also in the input-output characteristics of resistor-loaded circuits. Hence, as long as the bias and the load are appropriately set, this FET can offer novel functionalities such as frequency multiplier action. Digital logic applications will be also possible.

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VB-5 1D to 1D Tunneling in a Dual Electron Waveguide Device

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We report the first unambiguous observation of controlled electron tunneling between two closely spaced one-dimensional (1D) electron waveguides. This represents a significant step forward towards the realization of a quantum field-effect electron directional coupler (QFED) [1].

An electron waveguide is essentially a one-dimensional (1D) electronic channel through which electrons travel without scattering. Discrete quantum-mechanical modes which correspond to the 1D subbands arise due to the lateral confining potential. Recent experimental work has unmistakenly proven the existence of electron waveguiding through the observation of quantized conductance [2], [3] and tunneling oscillations [4] in short 1D devices.

With the ultimate goal of implementing an electron directional coupler, we have been working for a few years on a dual electron waveguide device. In this device, two closely spaced 1D channels are electrostatically formed by negatively biasing three gates patterned in a split-gate fashion on top of an AlGaAs/GaAs modulation-doped heterostructure. In a split-gate scheme, the 2D electron gas (2DEG) is depleted underneath the gates leaving a narrow conducting channel in between. In our approach, the two side-gates are used to define the outer boundaries of the two waveguides and the middle-gate is used to establish the thin common barrier separating the waveguides. Independent access to the three gates allows control over the width and carrier concentration of the individual waveguides (which determines the number of occupied modes in each waveguide) as well as the proximity and interaction of the waveguides with each other.

We have fabricated a variety of dual electron waveguide devices with different lengths L and widths W on an AlGaAs/GaAs heterostructure ($N_s = 4 \times 10^{11}$ cm^{-2} and $\mu = 1.2 \times 10^6$ 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. Such a thin gate is required to achieve significant tunneling. The middle gate is widened outside of the coupled region to prevent interaction outside the waveguiding region. Device processing consists of mesa isolation, ohmic contact formation to allow individual access to the input and output of each waveguide, and a combination of UV and e-beam lithography for gate formation.

In our measurements, a middle-gate voltage V_{GM} is set to establish a thin tunneling barrier between the two waveguides. A drain-source voltage is fixed between the input of one waveguide and the output of the other waveguide. We modulate the width of only one of the waveguides using the appropriate side-gate voltage V_{GT} (V_{GB}) while the other waveguide is set at a certain width by the other side-gate voltage V_{GB} (V_{GT}). The tunneling current between the two halves of the device is measured. We report on the tunneling characteristics of an $L = 1.0$ μm, $W = 0.4$ μm dual electron waveguide device at $T = 1.6$ K.

There are three distinct regimes in the tunneling current dependence with V_{GT} and V_{GB}. A 1D to 2D regime exists when only one waveguide is implemented while the other waveguide is not yet formed (there is a 2D gas). In this regime, tunneling oscillation ridges characteristic of the subband structure in the waveguide are observed [4]. In a similar manner, a 2D to 1D regime, in which a waveguide is formed on the other half of the device, shows tunneling oscillation ridges characteristic of the subband structure in that waveguide. A 1D to 1D regime is established when two electron waveguides are implemented. The tunneling current should now be sensitive to the alignment of the subbands in the two electron waveguides. In this regime, we observe bumps in the tunneling current as a function of both side-gate voltages as the individual subbands line up between the two waveguides. This is unmistakable proof that 1D to 1D tunneling is taking place.

In summary, we have observed tunneling between two 1D electron waveguides. These results constitute the first observation of 1D to 1D tunneling in any electronic system.

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VB-6 A New Quantum Dot Transistor

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We propose and demonstrate a new quantum dot transistor (QDT) which consists of a nanoscale dot-gate inside the gap of a split-gate. Current switching due to Coulomb blockade of a single electron has been observed at much higher temperatures and larger biases than that in any other types of single electron transistors (SET's) [1], [2]. Furthermore, since the critical size of the QDT is about an order of magnitude smaller than that of other SETs, quantum size effects become important and interplay with classical coulomb effects to further increase the energy level spacing in the quantum dot.

The dot-gate consists of a 80 nm diameter metal dot in the middle of a 30 nm wide metal wire; when positively biased, the gate creates a quantum box connected by two one-dimensional wires beneath the gate. The negatively biased split-gate is used to change the Fermi level and therefore the electron concentration in the quantum box. The gates are fabricated on top of a δ-doped AlGaAs/GaAs heterostructure using electron-beam lithography followed by a lift-off of Ti/Au.

As the dot-gate voltage was scanned from 0 to 160 mV with the split-gate voltage fixed at -0.5 V, four distinct oscillation peaks appeared in drain current at $T = 0.5$ K. The average oscillation period is 17.2 mV, and the maximum ratio of "on" and "off" currents exceeds three orders of magnitude. The oscillation peaks were still quite distinct as temperature increased to 4.2 K. The effects of drain bias on the oscillations were studied. It was found that at about 5 mV the oscillation peaks smeared out into steps. The temperature and bias effects indicate that the separation between the neighboring energy levels is higher than 5 meV, which is consistent with the estimation from device size.

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