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Transport in an Electron Interferometer and an Artificial One-Dimensional Crystal

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We have studied the electron transport in a one-dimensional electron interferometer. It consists of a quantum dot, defined in a two-dimensional electron gas, to which quantum point contacts are attached. Discrete electronic states are formed due to the constructive interference of electron waves which travel along the circumference of the dot in one-dimensional magnetic edge channels. An artificial one-dimensional crystal has been fabricated, which consists of a sequence of 15 quantum dots, coupled by point contacts. The conductance of this device reveals the formation of a band structure, including the gaps between adjacent bands and the discrete electronic states from which the bands are constructed.

Due to the wave-like nature of the electron transport, interference plays an important role at low temperatures. In disordered conductors interference is the origin of quantum phenomena like (weak) localization and universal conductance fluctuations. In ballistic conductors, where impurity scattering is absent, it is possible to study the interference in a highly controlled way. Although it is technologically feasible to construct a solid-state electron interferometer starting from a one-dimensional conductor formed by the lateral confinement of the electrons (1,2), we have taken an alternative approach. It has been shown that the transport though a two-dimensional electron gas in a high perpendicular magnetic field can be described in terms of edge channels (3,4). These edge channels consist of the current carrying states of each Landau level and are located at the boundaries of the 2DEG. It has also been shown that the scattering between adjacent edge channels is suppressed in high magnetic fields (5,6), and they can therefore be used as (almost) ideal one-dimensional channels.

The device lay-out is shown in fig. 1. Two gate pairs A and B are fabricated on top of a $GaAs/Al_xGa_{1-x}As$ hetero junction, with an elastic mean free path l_e=9μm and electron density 2.3 $10^{15}/m^2$). They define two individually controllable point contacts A and B. The figure illustrates the electron flow in edge channels for the case of two occupied single spin Landau levels. Edge channels belonging to different Landau levels flow along different equipotential lines. This makes it possible to control the number of edge channels transmitted through each point contact, by controlling the height of the potential barriers with the gate voltages. The

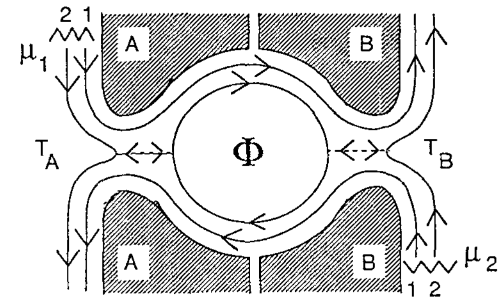

Fig. 1 Schematic lay-out of the device, showing the electron flow in edge channels

two-terminal conductance of a point contact can be written as (6) G= e^2/h (N+T), which illustrates that the N fully transmitted edge channel contribute Ne^2/h to the conductance and the transmission T of the upper edge channel can be tuned between 0 and 1. The conductance of the complete device is now given by $G_D=e^2/h\ (N+T_D)$, with T_D given by (7):

$$T_D = \frac{T_A T_B}{1-2\sqrt{(1-T_A)(1-T_B)}\cos(\phi)+(1-T_A)(1-T_B)} \quad (1)$$

In this expression ϕ denotes the phase acquired by the electron wave in one revolution around the loop. Due to the Aharonov-Bohm effect it is related to the flux Φ enclosed by the edge channel: $\phi=2\pi\Phi e/h$. Eq.(1) shows that G_D is quantized whenever G_A and G_D are quantized. When G_A and G_B are not quantized, and the electrons in the upper edge channels are partially transmitted and reflected at both point contacts, eq.(1) predicts regular oscillations, corresponding to successive constructive and destructive interference of the electron waves in the quantum dot .

Experimental results (8) obtained at 20mK are shown in fig. 2. Figure 2(a) shows the magnetic field interval where the transmission of the third edge channel drops from 1 to 0. Large oscillations are visible in this interval, with amplitude up to 40% of e^2/h. In 2(b) they are shown on an enlarged scale, which shows that they are extremely regular. This extreme regularity, together with the fact that G_D does not rise above $3e^2/h$, nor drop below $2e^2/h$, shows that the conductance of only a single channel is modulated, and demonstrates that a one-dimensional solid state electron interferometer has been realized.

The properties of a single quantum dot being understood, we have investigated the transport through a sequence of quantum dots (9). In this way a one-dimensional crystal, or superlattice (10), can be formed. The device lay-out is shown in the inset of fig. 3. A narrow channel is formed by depleting the electrons underneath the gate 2, and the corrugated gate 1. This forms a narrow channel with 16 barriers, together with 15 dots.

Calculations (11) show that when N quantum dots are coupled in series, each of the discrete electronic states of the dots develops into a group of N states. When N is large, these states form a band. These bands are separated from each other by gaps, energy intervals in which there are no states. When the Fermi energy is swept, the conductance approaches unity when the Fermi energy is located in a band (the calculations show that due to the small number of dots, the N individual states which make up each band give rise to N oscillations when the Fermi energy is swept through a band). When the Fermi energy is located in a gap the conductance should vanish.

The experiments performed at 10mK, show that there is no sign of a band structure in the absence of a magnetic field. This may be explained by the fact that the theoretical model assumes that scattering takes place exclusively at the barriers formed by the point contacts, which is probably not the case in zero magnetic field (No quantized plateaux at multiples of $2e^2/h$ were observed either). Fig. 3 shows the conductance of the device measured as a function of the gate voltage in the presence of a magnetic field. The conductance of the device now shows a sequence of 15 oscillations, in between a pair of deep dips. The deeper dips are associated with the gaps between consecutive bands, whereas the oscillations are associated with the individual states which make up a band.

Clearly the band structure is far from perfect. For instance, the conductance in the gaps is only slightly less than in the bands. A further improvement of the band structure therefore presents a big technological challenge.

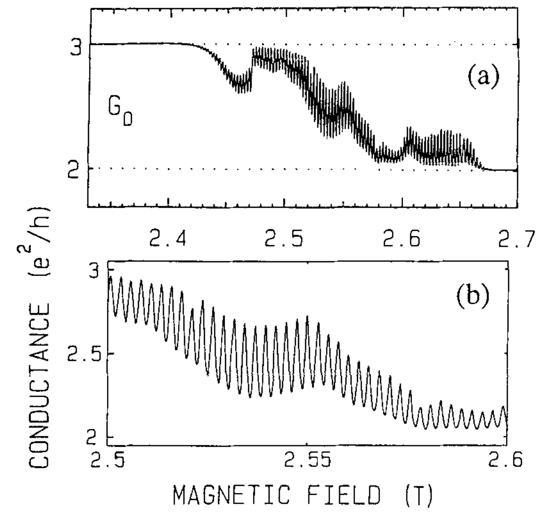

Fig. 2. Measured conductance of the device. (see text).

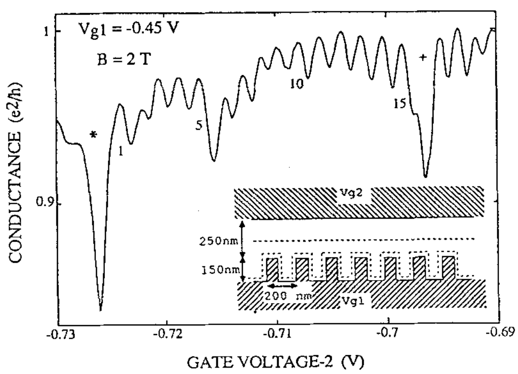

Fig. 3. Measured conductance of a one-dimensional crystal (see text).

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