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COULOMB BLOCKADE IN A 2D ELECTRON GAS

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Abstract. The 2D electron gas of a GaAlAS/GaAs heterojunction is confined to a small 2D granule by means of Schottky gates. Periodic conductance oscillations of tunneling via the 2D granule are observed as its average electron number is varied, a characteristic of Coulomb blockade. Adjustable tunnel barriers enable us to show that the minimum in conductance is limited by simultaneous co-tunneling of electrons through the input and output barriers.

Introduction.

The large energy $E_c = e^2/2C$ required to add a single electron to a metallic granule of small capacitance C can block tunneling [1]. This occurs for low temperatures $k_BT \ll E_c$ and for weak coupling to the contact leads by tunnel barriers of conductance$\sigma \ll \sigma_Q = e^2/h$. The Coulomb gap for tunneling, and so the total conductance, are periodic with the average electron number in the granule controlled by capacitive coupling. However, if the tunnel conductances are increased to $\lesssim \sigma_Q$, quantum charge fluctuations allow higher order co-tunneling transitions which limit the conductance blockade[2]. Observations in both conductance regions in a 2D Electron System (2DES) are reported [3].

The system.

Three Schottky gates are evaporated on the surface of a GaAlAs/GaAs heterojunction. By applying depleting voltages on the gates (Fig.1), a 2D granule is defined by lateral confinement. The Quantum Point Contacts (QPC) G1 and G2 provide adjustable tunnel barriers to the granule of conductance $\sigma_1$and σ_2 . The gate G0 controls its average number of electrons.The 2D granule(1.1×1.3μm) contains ≃1200 electrons so that effects arising from the discreteness of the energy level spacing(≈40mK) can be neglected.

Experimental observations.

Measurements are made by appyling a voltage V across the leads and measuring the current. When both QPC are in the tunneling regime ($\sigma_{Tot} \lesssim 0.5\sigma_Q$), the total zero bias conductance shows accurately periodic oscillations with the central gate voltage V_{G0}. Fig.3 shows a current–voltage characteristic(IVC) for a value of V_{G0} at a conductance minimum. The low conductance region around the origin is followed by an asymptotic linear variation typical of Coulomb blockade for single electron tunneling. From the asymptote offset, $V_{off} = e/C$, one obtains the total capacitance $C \cong .65fF$ and the charging energy $E_c = 1.5K$ which is compatible with the disappearance of the periodic oscillations at T$\gtrsim$1.2K. However, the thermally activated behaviour expected at a conductance minima for the single electron tunneling model of Coulomb blockade is not observed : instead, as shown on Fig.4 ,one finds a T^2variation at all the conductance minima of Fig.2.

Co-Tunneling effects.

When the conductance of the QPC are not very small compared to σ_Q ,higher order electron tunneling processes may occur. Averin&Nazarov have pointed out that second order quantum processes allow simultaneous tunneling of two electrons via excitation of a virtual state of energy $E_C$to give a finite leakage current in the blockaded regime[2] :

$$I(V) = (2h/3e^2)\sigma_1\sigma_2 V\left[(k_BT)^2 + (eV/2\pi)^2\right]/E_C^2 \qquad (1)$$

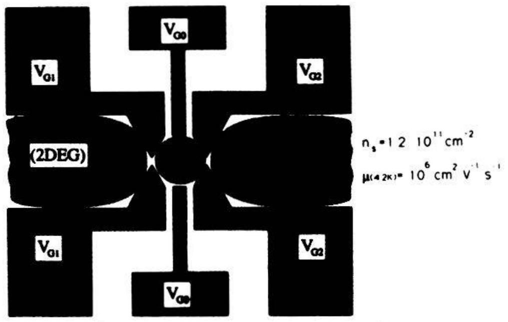

Fig.1 *Topview of the Schottky gates which define the 2D metallic granule by lateral confinement.*

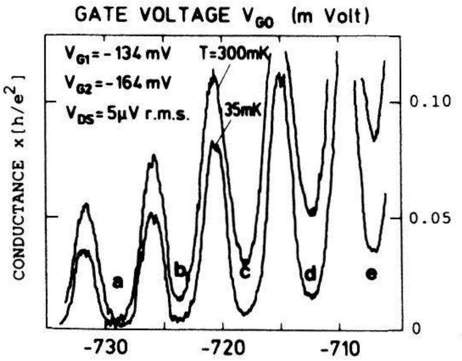

Fig.2 *Periodic zero bias conductance oscillations versus V_{G0} for two temperatures measured at $\sim 11\ Hz$*

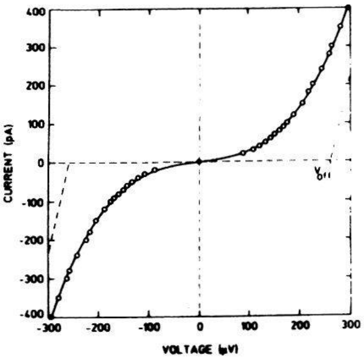

Fig.3 *IVC on a conductance minimum, the solid line is a $(AV + BV^3)$ fit to the experimental points (open circles)*

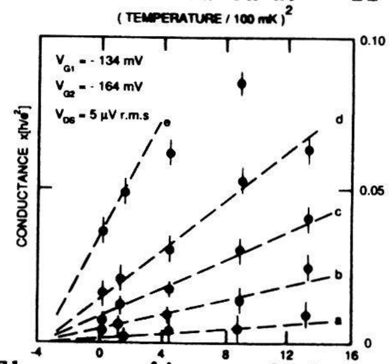

Fig.4 *The zero − bias conductance versus T^2 at the minima labelled a − e in Fig.2.*

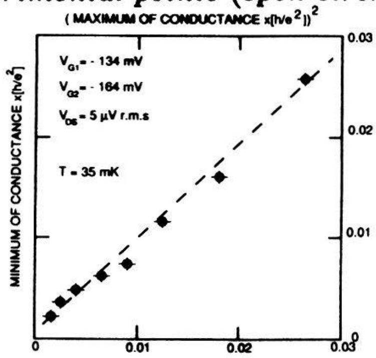

Fig.5 *Plot of the conductance minima versus the conductance maxima The experimental points correspond to different values of V_{G0}.*

Our observations show that, at the conductance minima, both the zero bias conductance $\sigma \alpha T^2$ (Fig.4) and the current $I = AV + BV^3$ at constant T (Fig.3). Fig.5 shows clearly that the zero bias conductances at the minima vary as the square of those at the maxima as the model predicts if we assume that σ_1 and σ_2 are changed identically by V_{G0}.

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