TITLE: Resonant and Correlation Effects in the Tunnel Structures with Sequential 2D Electron Layers in a High Magnetic Field

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Resonant and correlation effects in the tunnel structures with sequential 2D electron layers in a high magnetic field

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Experiments concerning the high magnetic field suppression of the tunnelling current between 2DEG's [1, 2] have given rise to an intensive theoretical discussion [3] and a number of different models have been already proposed to explain the experimental findings. There is a general agreement that the observed suppression is related to Coulomb correlations between 2D electrons in a high magnetic field. The current understanding of the observed phenomena is far from the clarity and is the subject of intensive studies world-wide.

In this work we report the first results on the tunnelling between two 2DEGs in a high magnetic field parallel to the current which was realised on a GaAs/AlGaAs/GaAs heterostructure with a single doped barrier at liquid helium temperatures and in magnetic field up to 23 T. In this kind of structures two-dimensional electron accumulation layers with electron concentration $N_{2D} \sim (1.6 - 3.0) \times 10^{11}\,\mathrm{cm}^{-2}$ are formed on both sides of the barrier due to the 20 nm thick barrier doping and are separated from highly n-doped contact regions by lightly n-doped spacer layers 70 nm thick. The main difference between our and earlier experiments [1, 2] is the absence of a serial resistance along the 2DEGs. This would allow one to study the tunnelling conductivity in arbitrary magnetic fields including the case of integer filling factors when the current through the 2DEG is carried by edge states.

The current-voltage *IV* characteristic of this structure demonstrates negative differential conductance (NDC) (Fig. 1, curve "a", labelled by arrow A) at negative bias without magnetic field and some features at positive bias (arrow B on the same Figure). The capacitance does not show any dependence on voltage bias. This means that applied external voltage drops mainly across the barrier and gives us arguments to relate measured *IV* characteristics only with tunnelling between 2DEG's.

We argue that NDC is due to the resonance between ground states of 2DEG's (0-0 transition) and nonlinear increase in current at positive bias to the resonance between ground state of one 2DEG and first excited state of another one (0-1 transition). In this picture we presume that 2DEG's have different as grown electron concentration. Fitting of negative bias part of our *IV* data to simple theoretical expression [4] gives the difference of electron concentration in accumulation layers $\sim 1.2 \times 10^{11}\,\mathrm{cm}^{-2}$. At voltage bias only few mV we have observed SdH like oscillations with only one period corresponds to $N_{1,2D} \sim 3 \times 10^{11}\,\mathrm{cm}^{-2}$. We relate this fact to the different energy broadening Γ in electron layers and observation of oscillations from 2DEG with lower one. Estimation of energy broadening from magnetic field when SdH like oscillations in tunnelling current appear and from above fitting to theoretical expression for *IV*

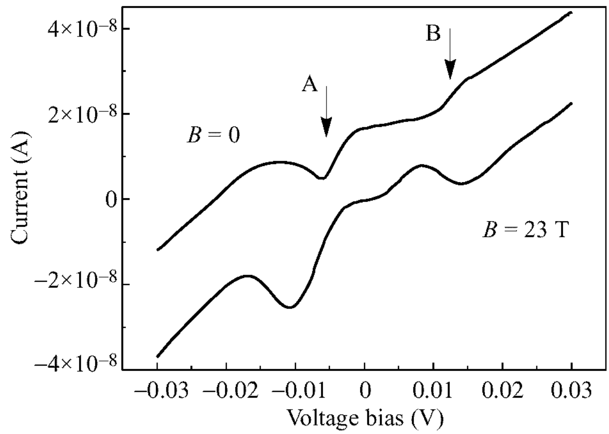

Fig 1. Current-voltage dependences without (a) and at magnetic field 23 T (b). Curves are shifted verticaly for clarity. Arrows indicate pecularities on *IV* curve without magnetic field (Details in the text).

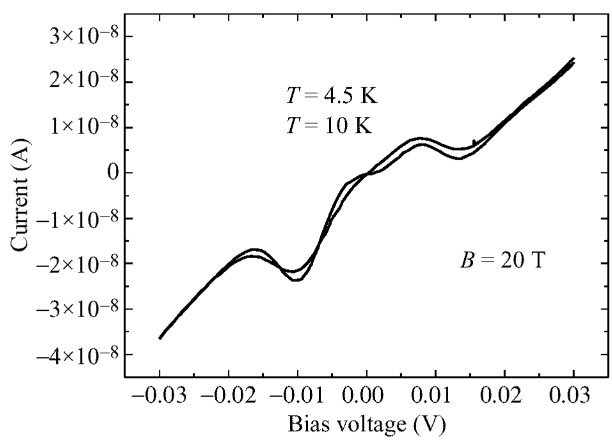

Fig 2. Current-voltage dependences at magnetic field 20 T for different temperatures.

characteristic around resonance gives $\Gamma_1 = 0.6$ meV and $\Gamma_2 = 2.1$ meV. It should be noted here that energy broadening in our samples is much higher than in samples used before in work [1] and higher, but of the same order, than used in work [2].

In magnetic field parallel to the current higher than 15 T ($\nu < 1$) the *IV* characteristic are drastically changed (Fig. 1, curve "b"). We note that any spin splitting have not been observed in our structures. Now NDC appears at both voltage polarities. We assign this behaviour to the magnetic field induced resonance at zero voltage . Indeed, when only one Landau level is occupied in both electron layers the Fermi level in contact regions pinned Landau levels and both 2DEG's, in spite of the different electron concentration, are brought to the tunnelling resonance. The *IV* characteristics in a magnetic field are similar to ones observed in references [1, 2] but more asymmetrical. The tunnelling current is suppressed near zero bias. It can be seen from Fig. 2 where *IV* curves are

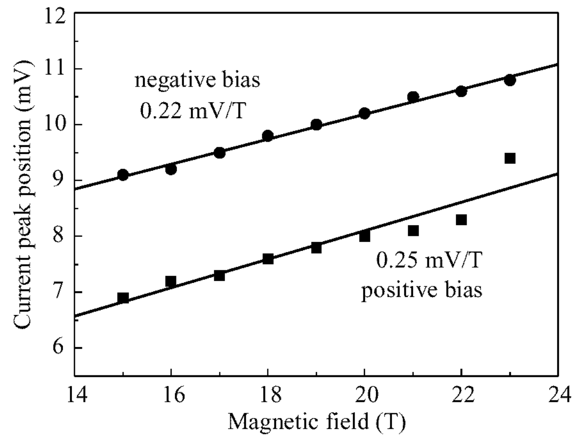

Fig 3. Dependences of the current peaks position as a function of magnetic field. Straigt lines are shown only as the guide for the eye.

shown for 4.2 K and 10 K. We assign this behaviour to the manifestation of the electron Coulomb correlation tunnelling gap introduced by the magnetic field [3]. Dependence of the current peaks position on magnetic field show linear dependence (Fig. 3) in agreement with previous observation [2], but in contrast to the current theories [3] predicted $B^{1/2}$ dependence.

At first sight it seems that asymmetry of *IV* curves in high magnetic field is related to slight off-resonance of the system. Nevertheless we compare our results with *IV* characteristic functional form which expected for tunnelling gap and was well established in previous experiments [2]. This form should be $I = I_0 \exp -\frac{\Delta}{V}$, where Δ is the gap parameter. To our surprise we determined different $\Delta_p = 3$ meV and $\Delta_n = 5$ meV for positive and negative bias correspondingly. These can not be explained by slight off-resonance conditions and give some indications that tunnelling gap is determined by Coulomb interaction only in one 2DEG. An analysis of our data show that most likely the magnitude of the tunnelling gap which is of the order of Coulomb interaction correlates with emitter electron concentration, but additional analysis is necessary to prove this assertion.

The suppression of tunnelling current by magnetic field have been observed when one of the 2DEG's is under exact $\nu = 2$ condition. An analysis of experimental data to understand the physical reason for this suppression are in progress now.

Thus we have investigated the tunnelling between 2DEG's in a high magnetic field in the structure with pure vertical transport for the first time. High magnetic field induced resonant tunnelling between 2DEG's with different electron concentration due to the pinning of the last Landau levels by Fermi level in contact regions. This gave us opportunity to investigate and compare our research of the tunnelling current suppression in a high magnetic field near zero bias with previous ones.

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