Spin-resolved Edge-Current Injection into a Quantum Antidot

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We have used the extremely long equilibration length of quantum Hall edge states to achieve selective injection of spin-resolved edge current into a quantum antidot. This method allows us to investigate the tunnelling conductance spectrum of a quantum antidot in detail by separating the contributions by different spins.

The surface gate pattern of the sample is shown in Fig. 1. The injector and detector split gates reduce the filling factor in each constriction, reflecting edge states belonging to higher Landau levels. In the injector region, the chemical potential of the edge states is raised by a 5 μV AC excitation voltage at 77Hz. Some of these edge states are transmitted through the injector constriction, and run alongside the edge states from the grounded contact 1 that could not penetrate the injector constriction. Because of the difference in the spatial position of these edge states, the injected current is not immediately scattered into the other edge states, but travels adiabatically for a certain distance [1] that depends on conditions such as the magnetic field or the potential slope at the edge. Approximately 3.5 μm away along the edge from the injector is placed an antidot with a detector constriction further 3.5 μm. At high magnetic fields (> 3.5 T), this 7 μm path is well within the equilibration length of spin-split channels (injected spin-split edge states travel this distance with minimal scattering). At the detector constriction, the potential V_D of the edge states that were injected is measured. If those edge states are involved in the resonance through the antidot, V_D should be reduced from the injected potential V_I. Thus, by injecting and detecting various sets of edge states, the contribution of each to the resonance can be studied separately.

Figure 2A shows the two-terminal antidot conductance at 25 mK (measured by a separate circuit set up), showing so-called double-frequency Aharonov-Bohm oscillations [2]. Here, the filling factor in the antidot constrictions is 2 at B = 3.8 T, i.e. the two spins of the lowest Landau level form antidot bound states. A simple single-particle antidot model cannot explain such double-frequency oscillations, which seem to consist of two sets of single-frequency oscillations (with h/e period) with matched amplitudes and exactly π out of phase. This is because, if each set of single-frequency oscillations is due to the resonance through each spin state, there is no reason why their amplitudes should match and why they should be exactly in antiphase. A detailed study of conductance behaviour implied that the resonance is only through outer state (say, spin down) [3], however this has not been directly measured. A self-consistent model with two concentric compressible rings shows that , if the charging of the antidot [4] is taken into account, the resonance through the outer compressible region should have $h/2e$ periodicity in agreement with our data [3].

Figures 2B and 2C show the detector nonequilibrium conductance $G_D = I/V_D$, where I is the current through the injector constriction, with the filling factor in the injector and detector constrictions being 2 (B) or 1 (C). When the injected edge current is lost to other edge states, G_D increases from its non-equilibrium value ($2e^2/h$ in B, e^2/h in C). In Fig. 2B, G_D mirrors the shape of the conductance oscillations almost perfectly, whereas in Fig. 2C, G_D maintains the nonequilibrium value. This is direct proof that the spin-up edge state (the one closest to the edge) is not involved in the resonant process, as predicted by the double-frequency self-consistent model.

References

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[3] M. Kataoka *et al.*, Phys. Rev. B **62**, R4817 (2000).
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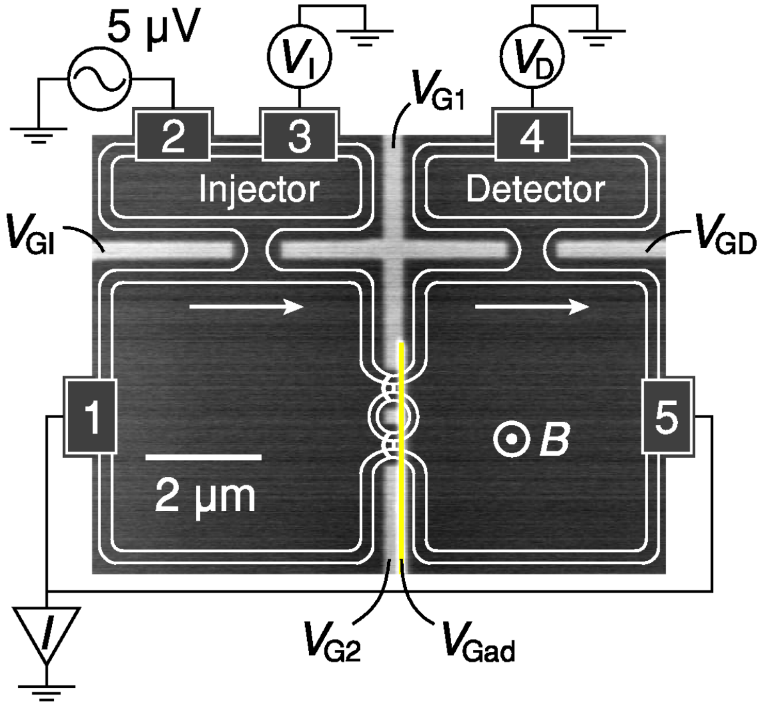

Figure 1. SEM micrograph of the surface gates of a sample, and schematics of the measurement circuit and edge states. Metal gates directly on the GaAs surface appear in white, and the second metal layer (on top of the cross-linked PMMA resist) is shown in yellow.

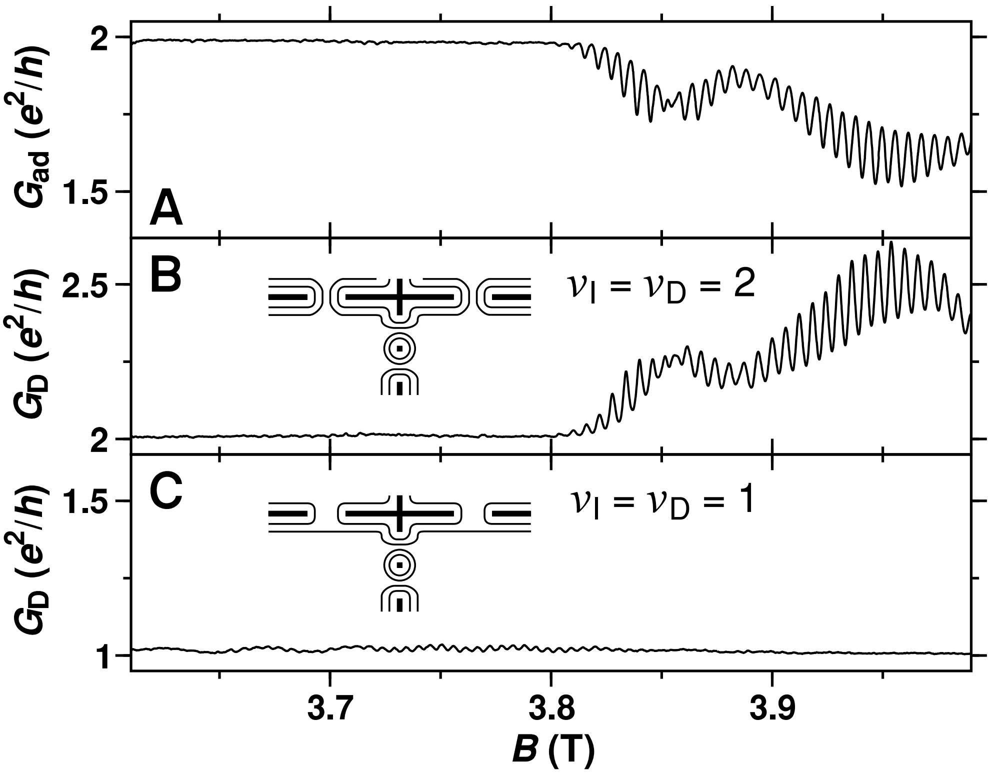

Figure 2. (A) G_{ad} in the double-frequency regime. (B) G_D with $\nu_I = \nu_D = 2$ and (C) with $\nu_I = \nu_D = 1$. The absence of oscillations in C implies that only the spin-down states are involved in the resonances.