Separately Contacted Edge States in the Fractional Quantum Hall Regime

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The edge state picture developed by Büttiker, Chklovskii and others is one of the most successful models for the description of the integer quantum Hall effect. In the fractional quantum Hall effect, on the other hand, more emphasis is put on bulk models, like the composite fermion picture. Edge states, however, also play an important role in the understanding of transport in two-dimensional electron gases (2DEG) at fractional filling factors.

We have developed a sample geometry that allows us to separately contact edge states in the integer and fractional quantum Hall effect. The sample layout consists of a quasi-Corbino geometry combined with a cross gate, that separates inner and outer edge states (see Fig. 1). Thus, the edge states are brought into close proximity for a controllable length (interaction length L). The sample geometry allows for true 4-probe measurements of the transport properties between separately contacted edge states. This enables us to study edge state transport at high imbalance without the need for high currents that would lead to spurious (heating) effects. As shown in Ref. [1], the energy barriers between edge states give rise to pronounced steps in the IV-characteristics that directly reflect the size of the spin- or Landau-gap.

Here, we use our novel spectroscopic technique to study the edge state structure in the fractional quantum Hall effect. As shown in Fig. 2, the IV-curves for filling factors $\nu = 1$ and $g = 1/3$ exhibit different slopes, depending on the different 4-probe combinations. This is in agreement with our findings for the integer quantum Hall effect, where all 4-probe resistances can readily be explained using the Landauer-Büttiker formula and assuming full equilibration between the different edge states in the interaction region [1]. Surprisingly, the same approach can be used for the present case (as well as for $\nu = 1$ and $g = 2/3$), when edge states of fractional charge are assumed. This is demonstrated by the solid lines in Fig. 2, which give the resistances calculated from the Landauer-Büttiker-formula for separately contacted edge states of charge 1/3 (see inset).

The assumption of separately contacted fractional edge states gives rise to the question whether an energy gap between the fractional quantum Hall states can be identified by non-linear IV-spectroscopy. Indeed, for the lowest temperatures (30 mK) and the smallest interaction length (0.5 μm) a small step in the IV-trace is discernible (see Fig. 3). In analogy to the steps observed for the spin- and Landau-gaps in the integer quantum Hall effect [1], this feature can be attributed to a gap of approximately 40 μeV between adjacent fractional edge states. Temperature dependent measurements support this picture, since they show that both the step structure and the agreement with the Landauer-Büttiker-formula disappear at temperatures around 100 mK.

[1] A. Würtz, et al.: *Separately Contacted Edge States: A Spectroscopic Tool for the Investigation of the Quantum Hall Effect*, Phys. Rev. B **65**, 075303 (2002).

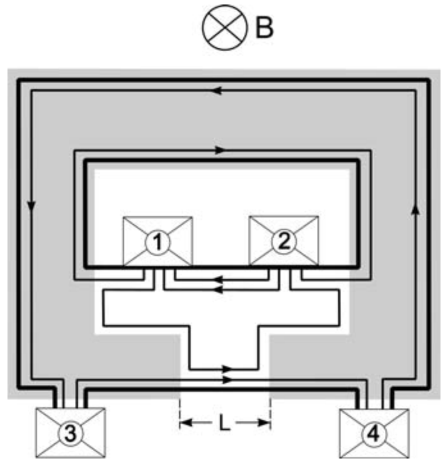
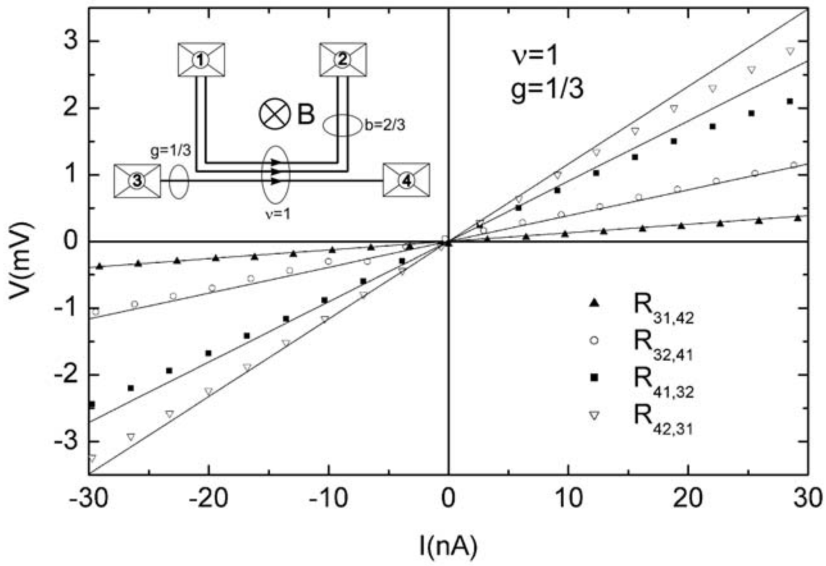


Figure 1:
Schematic diagram of the sample geometry. The ring-shaped mesa is indicated by the thick outline and the shaded area is covered by the gate electrode. Contacts are positioned along the edges of the 2DEG. Arrows indicate the direction of electron drift in the edge channels. The filling factor in the ungated regions is adjusted to ν=2. One edge channel (g=1) is transmitted under the gate while the other is reflected by the gate potential. L is the geometrically defined interaction length, where separately contacted edge states are in close proximity.

Figure 2:
IV-characteristics for the filling factors ν=1 and g=1/3 obtained for an interaction length L = 5µm. The experimental four-point resistances $R_{ab,cd}$ are obtained by using contacts a and b as current injectors and contacts c and d as voltage probes. Solid lines show the calculated resistances according to the Landauer-Büttiker formalism for fully equilibrated transport among edge channels of fractional charge 1/3. The inset sketches the interaction region.



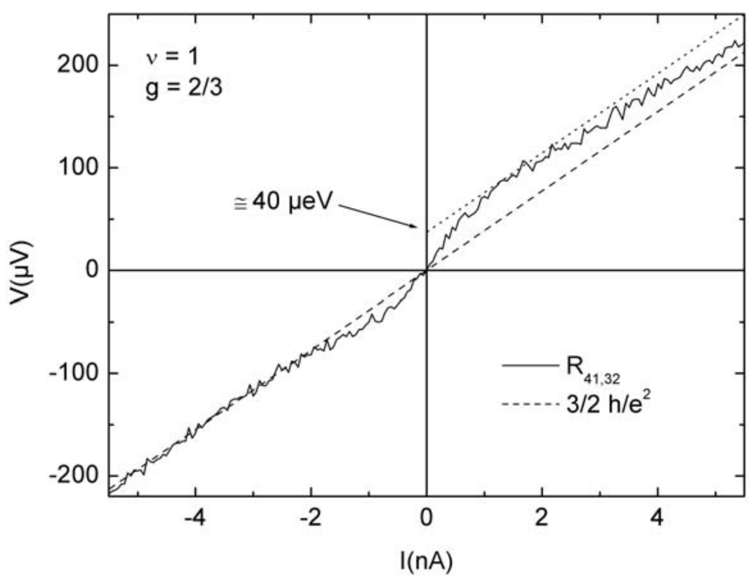


Figure 3:
Four-point resistance (solid line), for a sample with L = 0.5 µm, and calculated fully equilibrated resistance (dashed line). In analogy to measurements at integer filling factor combinations the observed step at small positive biases can be attributed to an energy gap between fractionally charged edge states.