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# Transport across the incompressible strip in the fractional quantum Hall effect regime

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## Abstract

We experimentally investigate transport across a single incompressible strip at the sample edge in the fractional quantum Hall regime under high-imbalance conditions. We show that the *I–V* dependence exhibits a power-law behavior, which is the characteristic feature of a Luttinger-type tunnel density of states. The obtained results give the strong evidence for the existence of the so-called neutral collective modes at the sample edge. We observe the influence of the collective modes on the equilibration process across a single incompressible strip in the fractional quantum Hall regime.



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## 1. Introduction

In the integer and fractional quantum Hall effect (QHE) regimes, the edge of the two-dimensional electron system undergoes a reconstruction into strips of compressible and incompressible electron liquid [1]. Using a novel quasi-Corbino sample geometry [2], it becomes possible to study transport across a single incompressible strip. The additional advantage of this geometry is the possibility to investigate transport at high imbalances, exceeding the spectral gaps at the edge. It was shown before Ref. [2] that in the integer QHE regime these investigations are suitable to determine the energetic structure of the reconstructed sample edge. In the fractional QHE, where interaction effects become important, the transport across the incompressible strip is supposed to be sensitive to the structure of the collective excitations at the sample edge [3]. Namely, common collective excitations at the two strip edges can be expected [3], resembling neutral collective modes [4], with charge oscillation across the edge.

Here we experimentally investigate transport across a single incompressible strip at the sample edge in the fractional QHE regime under high-imbalance conditions. We show that the *I–V* dependence exhibits a power-law behavior, which is the characteristic feature of a Luttinger-type tunnel density of states. The obtained results give the strong evidence for the existence of the so-called neutral collective modes at the sample edge [3]. We observe the influence of the collective modes on the equilibration process across a single incompressible strip in the fractional QHE regime.

## 2. Samples and technique

Our samples are fabricated from molecular beam epitaxial-grown GaAs/AlGaAs heterostructure. They contain a 2DEG located 150 nm below the surface. The mobility at 4 K is $1.83 \times 10^6\,\mathrm{cm}^2/\mathrm{Vs}$ and the carrier density $8.49 \times 10^{10}\,\mathrm{cm}^{-2}$. Samples are patterned in the quasi-Corbino sample geometry [2], see Fig. 1, which has the following advantages: (i) split-gate with well-defined strip structure allows to separately contact strips in the gate-gap; (ii) Corbino topology provides direct measurements of the

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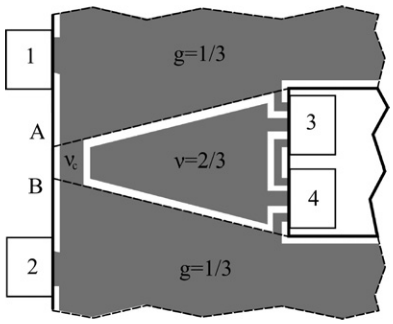


Fig. 1. Schematic diagram of the sample working area. The etched mesa edges are shown by solid lines, the dashed lines represent the split-gate edges. The gate-gap region at the outer mesa edge is denoted as AB. Light gray areas are the incompressible regions at filling factors $\nu$ (in the bulk) and $g = \nu_c$, $g < \nu$ (under the gate and the incompressible strips at the mesa edges). Compressible regions (white) are at the electrochemical potentials of the corresponding ohmic contacts, denoted by bars with numbers.

electron transport across the incompressible strips at any imbalances $V$, also exceeding the spectral gaps $V \gg \Delta$.

We study $I$–$V$ curves in 4-point configuration, by applying dc current between a pair of inner and outer contacts and measuring dc voltage between another pair of inner and outer contacts, for different contact configurations. The measured voltage $V$ is determined by the electrochemical imbalance across the incompressible strip at local filling factor $\nu_c = g$ in the gate-gap [2], see Fig. 1.

## 3. Experimental results and discussion

Examples of $I$–$V$ curves at low (30 mK) temperature for fractional filling factors $\nu = \frac{2}{3}, g = \frac{1}{3}$ are shown in Fig. 2 for different gate-gap widths $L_{AB}$. $I$–$V$ curve is linear at highest $L_{AB}$ with the slope that can be calculated [2] from Buttiker [1,5] formulas for full equilibration in the gate-gap. $I$–$V$ becomes slightly non-linear at $L_{AB} = 10\,\mu m$, and goes above the full-equilibrating line, indicating a lack of full equilibration. $I$–$V$ curves are strongly non-linear at $L_{AB} = 0.5\,\mu m$, under high-imbalance conditions, see Fig. 2(b). There also qualitative differences from the integer QHE case [2]: (i) $I$–$V$ traces are practically symmetric; (ii) no threshold behavior can be observed; (iii) curves from different contact combinations are practically coincide (see Ref. [2] for technical details), while the equilibrium lines differ significantly, see Fig. 2(b). Thus, the physics of transport across a single incompressible strip at high imbalances differs significantly in integer and fractional QHE regimes.

The described behavior is characteristic for $I$–$V$ curves at all fractional filling factors at $L_{AB} = 10\,\mu m$, i.e. for the $\nu = \frac{2}{5}, g = \frac{1}{3}$ also. The evolution of the $I$–$V$ curve is different in the latter case, as shown in Fig. 3. The experimental curve for $L_{AB} = 10\,\mu m$ consists from two slightly non-linear branches and is situated above the equilibrium line ($R_{eq} = 18h/e^2$). It is similar to the shown in Fig. 2(a), but the central linear region is not developed at all. Increasing $L_{AB}$ leads to the $I$–$V$ curve, which is situated *below* the

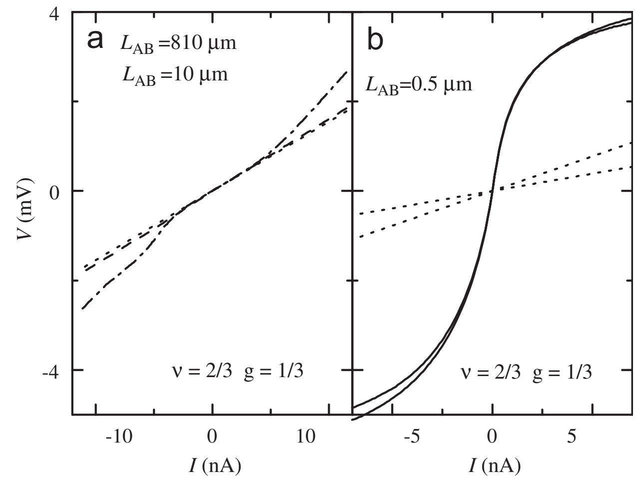


Fig. 2. $I$–$V$ curves for fractional filling factors $\nu = \frac{2}{3}, g = \frac{1}{3}$ at different gate-gap widths: $L_{AB} = 10\,\mu m$ (dash-dot) (panel (a)), $L_{AB} = 810\,\mu m$ (dash) (panel (a)), $L_{AB} = 0.5\,\mu m$ (solid) (panel (b) for two different contact configurations). Equilibrium lines (with $R_{eq} = 6; 3h/e^2$) are shown by dots, also for two different contact configurations in panel (b). Magnetic field $B$ equals to 5.18 T.

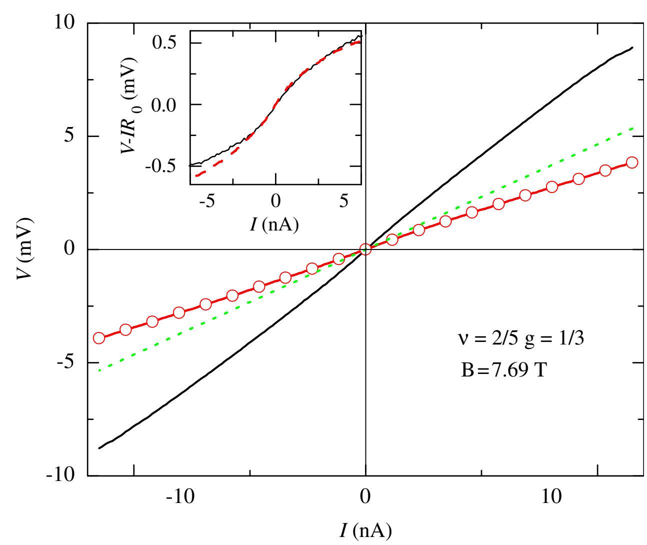


Fig. 3. (Color online) $I$–$V$ curves for fractional filling factors $\nu = \frac{2}{5}, g = \frac{1}{3}$ for narrow (10 μm, solid line) and wide (800 μm, line with open circles) interaction regions. Equilibrium curve (with $R_{eq} = 18h/e^2$) is shown by dots. Inset shows the wide-region curve (dash), scaled to the narrow-region one (solid) by dividing the current by factor $q = 2.35$. The linear dependence $IR_0$ with $R_0 = 28h/e^2$ is subtracted to highlight the non-linear behavior. Magnetic field $B$ equals to 7.69 T.

equilibrium one, see Fig. 3, with 28% lower resistance. This curve is still non-linear and can be scaled to one for the $L_{AB} = 10\,\mu m$ case, see inset to Fig. 3.

To analyze $I$–$V$ curves at $L_{AB} = 10\,\mu m$, we should mention that for fractional filling factors, in the regime of high imbalance, the form of the curve is determined by the tunnel density of states [6,7] $I \sim \int D\,dV$. In Fig. 4 $D$ is shown as a function of the voltage imbalance $V$ (a) and the temperature $T$ (b) for different fractional filling factors in logarithmic scales, as calculated from the $I$–$V$ curves.

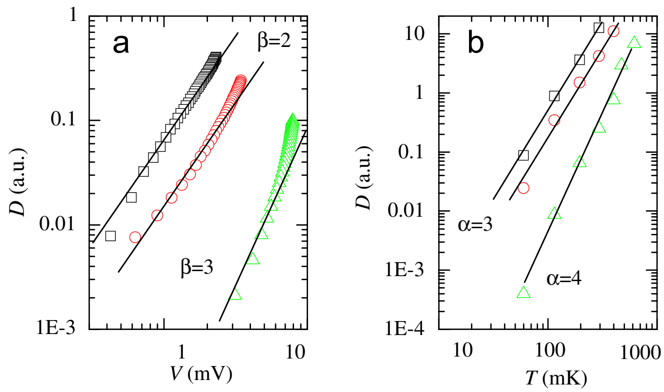


Fig. 4. (Color online) $D$ is shown as a function of the voltage imbalance at $T = 30\,\mathrm{mK}$ (a) and as a function of the temperature at $V = 1.6\,\mathrm{mV}$ (b) in logarithmic scales. The filling factors are $\nu = \frac{2}{3}, g = \frac{1}{3}$ (squares and circles, corresponding to different spin polarization of the $\frac{2}{3}$ ground state, [7]); $\nu = \frac{2}{5}, g = \frac{1}{3}$ (triangles).

The dependencies are of a power-law behavior: $D \sim V^{\beta}$, $\beta = 2$ for $\nu = \frac{2}{3}, g = \frac{1}{3}$ and $\beta = 3$ for $\nu = \frac{2}{5}, g = \frac{1}{3}$; $D(T) \sim T^{\alpha}$, $\alpha = 3$ for $\nu = \frac{2}{3}, g = \frac{1}{3}$ and $\alpha = 4$ for $\nu = \frac{2}{5}, g = \frac{1}{3}$. (The fact, that the temperature behavior is not activated one was also checked by plotting $D(T)$ in the Arrhenius scales.) They are the power-law dependencies with $\beta = \alpha - 1$ that were predicted for tunnel density of states $D$, determined by the edge collective excitations [3]. Thus, neutral excitation modes [3] do exist at the edges of the incompressible strip and determine transport across it at high imbalances in the FQHE regime.

The edge of the $\nu = \frac{2}{5}$ bulk incompressible state is extremely close to $\nu_c = \frac{1}{3}$ strip in this case, because of $\nu - \nu_c \ll \nu$. Thus, we can expect some influence in $D$ also from the edge excitations of $\nu = \frac{2}{5}$ bulk incompressible state, affecting the exponents in power-low $D(V, T)$. Thus, the structure of the collective excitations is more complicated at $\nu = \frac{2}{5}$, despite we study transport across the same $\nu_c = \frac{1}{3}$ incompressible strip.

It is a surprise that collective modes affect the equilibration process also in this case, see Fig. 3. This influence was still predicted [8] for very simplified model. The exact calculations are the problem of future theoretical efforts.

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