Imaging Fractional Incompressible Stripes in Integer Quantum Hall Systems

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The non-interacting picture of the QH effect

Landau levels in a confined system

• Edge state picture: *current is carried by chiral 1D channels*

\[ G \equiv \frac{dI}{dV} = \nu \frac{e^2}{h} \]

Backscattering is suppressed due to the large spatial separation between counter-propagating channels
The non-interacting picture of the QH effect

Landau levels in a confined system

- Edge state picture:
  current is carried by chiral 1D channels

With a QPC we can intentionally induce backscattering, which provides us information about the edge properties

Roddaro et al.: PRL 90 (2003) 046805
Roddaro et al.: PRL 95 (2005) 156804
Roddaro, Paradiso et al.: PRL 103 (2009) 016802
Edge channel-based interferometers

The very large coherence length has been exploited to implement complex interferometers as the electronic Mach-Zehnder.

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Non-equilibrium edge-channel spectroscopy in the integer quantum Hall regime

C. Altimiars, H. Le Sueur, U. Gennser, A. Cavanna, D. Mailly and F. Pierre


Nat. Phys. 6, 34 (2010)
Edge channel-based interferometers

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**Puzzle**: internal structure of edge seems to play no role here

Roddaro *et al.*: experiments on QPCs revealed signatures of fractional components in “simple” integer channels


Need for **spatially** resolved measurements
Non-interacting VS interacting picture

• The self consistent potential due to e-e interactions modifies the edge structure

• For any realistic potential the density goes smoothly to zero.

• Alternating compressible and incompressible stripes arise at the sample edge

Incompressible stripes:
• The electron density is constant
• The potential has a jump

Compressible stripes:
• The electron density has a jump
• The potential is constant

**SGM technique:** we select individual channels from the edge of a quantized 2DEG, we send them to the constriction and make them backscatter with the biased SGM tip.

- Bulk filling factor $\nu=4$
- $B = 3.04 \, \text{T}$
- 2 spin-degenerate edge channels
- gate-region filling factors $g_1 = g_2 = 0$
**Edge channel tomography by SGM**

**SGM technique:** we select individual channels from the edge of a quantized 2DEG, we send them to the constriction and make them backscatter with the biased SGM tip.

- Bulk filling factor $v=4$
- $B = 3.04$ T
- 2 spin-degenerate edge channels
- gate-region filling factors $g_1 = g_2 = 0$

How we probe incompressible stripes

Self-consistent potential

Landau levels inside the constriction

$\hbar \omega_c$

Tip induced potential

Tip position

Conductance ($e^2/h$)

Tip position (nm)
How we probe incompressible stripes

conductance ($e^2/h$) vs. tip position (nm)
How we probe incompressible stripes

conductance ($e^2/h$) vs. tip position (nm)
How we probe incompressible stripes

Energy gap: $\hbar \omega = 5.7$ meV
Plateau width: 60 nm
Incompr. stripe width: $\approx 30$ nm
Histogram analysis

$n = 6$

300 nm

$v = 6$
Imaging fractional structures in integer channels ($\nu=1$)

Imaging fractional structures in integer channels ($\nu=1$)

$\delta_{IS} \sim 12 \text{ nm}$

Imaging fractional structures in integer channels ($\nu=1$)

Temperature dependence of 1/3 peak in histogram

Fractional edge reconstruction

The finite range in GT defines a stripe in the SGM map.

$\delta_{IS}$ determined from SGM measurements

$\frac{dn}{dr}$

$\delta_{IS}$ determined from Chklovskii’s formula

$$\delta_{IS}^2 = \frac{4A \mu_f \varepsilon}{\pi^2 e^2 \frac{dn}{dr} \mid_{r=r_f}}$$
Fractional edge reconstruction

The IS width values (colored dots) obtained from SGM images compare well with the reconstruction picture predictions (black lines).

Inner edge structure demonstrated and imaged

Quantitative test of the IS width dependence on the density slope
Can we exploit the non-trivial edge structure?

The picture of a QH device emerging from the experiments

A “bus” of fractional compressible and incompressible channels:

How do these channels interact?
N. Paradiso et al.
Summary

- Fractional incompressible stripes observed in integer edge channels
- Estimate width of these stripes
- Comparison with edge reconstruction theory
Appendix: the SGM @NEST lab in Pisa

Setup:

- AFM non-optical detection scheme (tuning fork)
- With vibration and noise isolation system
- $^3$He insert (cold finger base temp. :300 mK)
- 9 T cryomagnet

Tip at negative bias (moveable gate locally depletes the 2DEG)

SGM performed in constant height mode (10-50 nm above surface), no strain

Pioneering work by:

Appendix: tuning fork and sample holder

- Conductive tip glued on the TF
- Tip – sample geometry
- Top
- Bottom
- Z coarse posit.
- Tuning fork
- Thermometer
- XYZ scanner
- X,Y coarse positioners
- SGM Group
Appendix: SGM measurements on QPCs

The biased tip creates a depletion spot that we use to backscatter the electrons passing through the constriction.

The split gates define a constriction by depleting the 2DEG underneath.

source-drain current

2DEG
Appendix: SGM measurements on QPCs
Appendix: branched flow and interference fringes

- QPC conductance $G = 6 \, \text{e}^2/\hbar$ (3\textsuperscript{rd} plateau)
- Tip voltage $V\text{_{tip}} = -5 \, \text{V}$, height $h\text{_{tip}} = 10 \, \text{nm}$

Fringe periodicity: $\lambda_F/2 = 20 \, \text{nm}$
Appendix: Individual histograms

Histograms of the occurrence of each $G_T$ value for all the 9 different SGM scans performed at different $V_{\text{tip}}$ values. Fractional peaks are visible in each individual histogram.
Appendix: Determination of the IS width

The incompressible stripe width $\delta_{IS}$ is obtained starting from the FWHM of the corresponding peak in the histogram (left panel). This range of $G_T$ values defines a circular stripe in the SGM map (right panel). $\delta_{IS}$ is given by the average width of such a stripe.
A displacement $\delta r_t$ of the SGM tip toward the QPC center reduces the QPC width of the same amount. The corresponding reduction of the filling factor at the QPC center (which is measured as a reduction of $G_T = nG_0$) is approximately given by $\delta r_t/2$ times the filling factor slope.