APPLICATION NOTE M39

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Imaging fractional incompressible stripes in integer quantum Hall systems using the attoAFM III

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Introduction

Transport experiments provide conflicting evidence on the possible existence of fractional order within integer quantum Hall systems. In fact, integer edge states sometimes behave as monolithic objects with no inner structure, while other experiments clearly highlight the role of fractional substructures. Recently developed low-temperature scanning probe techniques offer today an opportunity for a deeper-than-ever investigation of spatial features of such edge systems. In our work we used the attocube attoAFM III in an attoLiquid3000 ^{3}He cryostat system to demonstrate that fractional features were unambiguously observed in *every* integer quantum Hall constriction studied [1]. We present also an experimental estimate of the width of the fractional incompressible stripes corresponding to filling factors 1/3, 2/5, 3/5, and 2/3. Our results compare well with predictions of the edge-reconstruction theory.

Setup Description

The attoLiquid3000 allows for AFM and transport measurements at low temperature and high magnetic field. The only customization that we made in our lab was to add a special sample holder, which now can receive a chip carrier with 20 contacts, allowing to combine LT-AFM operation with transport studies, i.e. AFM can be performed on a device in operation.

The ^{3}He part of the attoLiquid3000 cryostat is inserted in a liquid helium bath reservoir which is suspended by means of springs in a soundproof box, in order to damp vibrations induced by the lab floor and acoustical noise. The cryostat is a ^{3}He-closed cycle refrigerator that can reach a base temperature of 300 mK at the cold finger. The dewar is equipped with a superconducting coil which provides magnetic fields up to 9 T. The AFM head of our setup is constructed with a stack of actuators for both the coarse and fine control of the tip-sample position. The sample, mounted on a leadless chip carrier, is positioned on top of the piezo scanner, while the tip is glued to a tuning fork. The sample topography is obtained by controlling the oscillation amplitude damping of the tuning fork due to the tip-sample shear force (non-contact mode).

The scheme of our transport experiment is shown in Fig. 1a. Our samples (indicated as A and B) are obtained starting from AlGaAs-GaAs heterojunctions with an embedded two-dimensional electron gas (2DEG). The 2DEG depth, electron density, and mobility are $d = 80$ (80) nm, $n = 1.77$ (1.99) x 10^{11} cm^{-2}, $\mu = 4.2$ (4.5) x 10^6 cm^2/Vs, for the A (B) sample, respectively. By optical lithography we fabricated a Hall bar with source and drain contacts. A quantum point contact (QPC) was fabricated by thermal evaporation of Schottky split gates (10 nm Ti / 20 nm Au bilayer), defined by electron beam lithography. The gap between the split gates is 300 nm (400 nm).

At very low temperature and high magnetic field (the so-called *quantum Hall regime*) the bulk 2DEG is insulating whenever the chemical potential lies between two consecutive Landau levels. In such condition the electron transport between source and drain contacts is mediated by 1D edge channels. The number of edge channels equals the number of filled Landau levels (called filling factor, ν). Each edge channel has a counter-propagating partner on the opposite side of the Hall bar. Due to their macrosco-

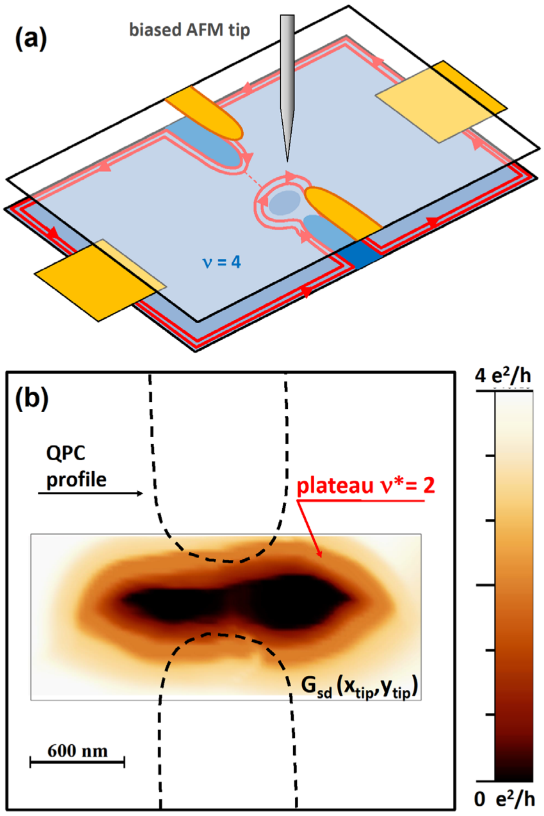

Figure 1: *(a) Sketch of the SGM operation mode. The AFM tip is used to perturb the edge confining potential and selectively bring the edges into interaction. (b) Map of G_{sd} as a function of the position of the tip (V_{tip}=-5 V) with respect to the split-gates (dashed line). The plateau ν*=2 corresponds to the backscattering of the inner edge channel.*

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pic spatial separation, the backscattering between them is suppressed. Therefore, since each channel carries e^2/h units of conductance, the source-drain conductance is $G_{sd}=\nu\, e^2/h$. At the QPC center, however, the separation between the counter-propagating edge channels is much smaller. It is therefore possible to intentionally induce backscattering using the electrostatic potential of the tip. This mode of operation of the AFM, in which the tip is used as a local gate, is called Scanning Gate Microscopy (SGM).

Fig. 1a shows the SGM configuration for measurements in the quantum Hall regime at bulk filling factor $\nu=4$ (sample A, magnetic field $B=3.04\,\mathrm{T}$, temperature $T=300\,\mathrm{mK}$). In these conditions the source drain current is carried by two pairs of spin degenerate edge channels at the sample edge, each carrying $2e^2/h$ units of conductance [2]. We apply a negative bias (-5 V) to the AFM tip and we scan it (in non-contact mode) over the QPC. SGM maps are obtained by plotting G_{sd} as a function of the tip position. As shown in Fig. 1b, when the tip is far from the QPC center there is no backscattering, i.e. the conductance takes the unperturbed value ($G_{sd}=4e^2/h$). As the tip is moved towards the center, the confinement potential is modified, so that the counter-propagating edges are put in interaction and backscattering occurs. Therefore the transmitted conductance decreases, until a complete pinch-off occurs when the tip is placed exactly at the QPC center (inner black area in Fig. 1b).

The attoLiquid3000 allows us to perform SGM measurements at the temperature and magnetic field conditions required to observe the *fractional* quantum Hall effect. Our goal is to image for the first time the presence of fractional incompressible stripes, i.e. the existence of an inner structure within the integer edge channel. We repeated the same measurements described above on the sample B at bulk filling factor $\nu=1$ ($B=8.23\,\mathrm{T}$, $T=300\,\mathrm{mK}$). The corresponding SGM map in the region close to the QPC center is depicted in Fig. 2a. Analogously to the $\nu=4$ case, we expect to find plateaus when the local electron phase is gapped, i.e. when the local filling factor ν^* equals a robust fraction. The scan profile depicted in Fig. 2b reveals a clear shoulder for $G_{sd}=e^2/3h$ (corresponding to points where $\nu^*=1/3$). A more careful analysis [1] allows to determine the occurrence of incompressible phases for $\nu^*=1/3$, 2/5, 2/3, and 3/5, i.e. the two most robust fractions and their hole-particle conjugates, respectively. The SGM maps allow us not only to *reveal* the fractional incompressible stripes, but also to *measure* their width and correlate it with the local electron density slope. With this data we were able to test directly the predictions of the reconstruction theory [3]. The agreement between the data and the reconstruction model is remarkable, especially in light of the uncertainty on the fractional-gap value, which is known to be rather sensitive to the details of disorder potential. Notably, data globally follow the expected dependence on the electron density gradient.

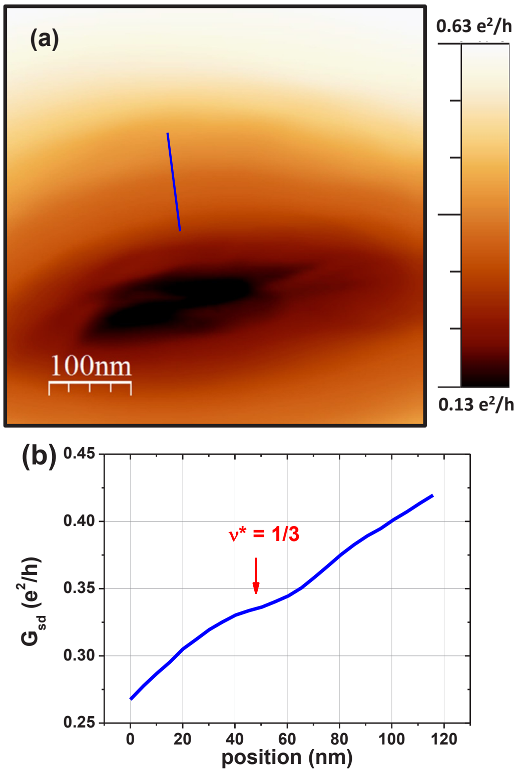

Figure 2: *(a) SGM scan at the center of a QPC in a $\nu=1$ QH system (V_{tip}=-6 V). The map shows the transmitted differential conductance G_{sd} as a function of the tip position. (b) Profile of G_{sd} along the light blue line in the top panel.*

Summary

In conclusion, we exploited the attocube attoLiquid3000 setup to perform a *spatially resolved* study of the edge structure. Our findings shed a new light on quantum Hall physics, and in particular on the complex phenomena recently reported in transport experiments [4]. In fact, the role of fractional phases in quantum interferometry is still not clear and this knowledge may open up exciting developments, as for instance the implementation of a Mach-Zehnder interferometer for fractional quasiparticles.

References

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