Evidence for a ν = 5/2 Fractional Quantum Hall Nematic State in Parallel Magnetic Fields

Y. Liu, S. Hasdemir, M. Shayegan, L.N. Pfeiffer, K.W. West, K.W. Baldwin (Princeton U., Dept. of Electrical Engineering)

Introduction

We report magneto-transport measurements for the fractional quantum Hall (FQH) state at filling factor ν = 5/2 as a function of applied parallel magnetic field ($B_{||}$). As $B_{||}$ is increased, the ν = 5/2 FQH state becomes increasingly anisotropic. The anisotropy ratio remains constant over a relatively large temperature range, yielding an energy gap which is the same for both directions. Our results are qualitatively consistent with an FQH nematic phase.

Experiments

Our sample consists of a 30-nm-wide GaAs quantum well bounded on both sides by undoped $Al_{0.24}Ga_{0.76}As$ spacer layers. The two-dimensional electron system (2DES) has a density of $n = 3.0 \times 10^{15}$ m^{-2} and a very high mobility, $\mu \simeq 2500$ m^2 / (V·s). It exhibits a very strong ν = 5/2 FQH state, with an energy gap of $\Delta \simeq 0.4$ K at $B_{||} = 0$. We measured the sample in SCM1, and rotated the sample normal direction by an angle θ from the field direction to induce the parallel field component $B_{||}$ along the x-direction (the $[1\bar{1}0]$ crystal direction). We denote the longitudinal resistivities measured along and perpendicular to the direction of $B_{||}$ as ρ_{xx} and ρ_{yy}, respectively.

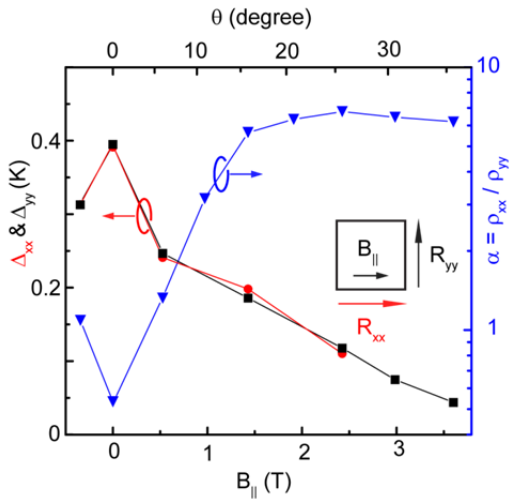

FIG. 1: Measured ν = 5/2 FQH state energy gaps, Δ_{xx} (red circles) and Δ_{yy} (black squares), are shown as a function of the in-plane magnetic field $B_{||}$. Also plotted (blue triangles) is the anisotropy ratio α.

Results and Discussion

The transport energy gaps at ν = 5/2 measured as a function of $B_{||}$ up to $\simeq 3.6$ T are summarized in Fig. 1. We denote the energy gaps deduced from the temperature-dependence of ρ_{xx} and ρ_{yy} by Δ_{xx} and Δ_{yy}, respectively. We also plot the transport anisotropy ratio $\alpha = \rho_{xx} / \rho_{yy}$. It is clear in Fig. 1 that, despite the large anisotropy ratio ($\alpha \simeq 6$ when $B_{||} \gtrsim 1.5$ T), Δ_{xx} and Δ_{yy} remain the same. As a function of $B_{||}$, the ratio α grows very quickly, approximately exponentially up to $B_{||} \simeq 1$ T, and then saturates at higher $B_{||}$. The energy gaps, Δ_{xx} and Δ_{yy}, however, exhibit a very steep drop at small $B_{||}$, followed by a more gradual and monotonic decrease at higher $B_{||}$.

The data provide clear evidence for a strong ν = 5/2 FQH state whose transport is anisotropic at finite temperatures. A possible interpretation is that we are observing a FQH nematic phase. In this interpretation, the ground-state is a FQH state but the longitudinal resistivity at finite temperatures is anisotropic as it reflects the anisotropic property of the thermally excited quasiparticles. In a 2DES with finite layer thickness, it is known that $B_{||}$ couples the electrons' in- and out-of-plane motion and causes anisotropy of their Fermi contours at zero perpendicular fields. It is reasonable to expect that $B_{||}$ also breaks the rotational symmetry in the N = 1 Landau level and induces a FQH nematic phase at ν = 5/2.

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References

[1] Y. Liu, S. Hasdemir, M. Shayegan, L.N. Pfeiffer, K.W. West, K.W. Baldwin Phys. Rev. B **88**, 035307 (2013).