Even-denominator Fractional Quantum Hall Effect at a Landau Level Crossing

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

Introduction

A strong perpendicular magnetic field *B* applied to a 2D electron system (2DES) quantizes the electron energies into discrete Landau levels (LLs). At very low temperatures, electron-electron interaction leads to new phenomena. An example is the fractional quantum Hall effect (FQHE), the condensation of 2D electrons into many-body incompressible states which are stable predominantly at odd-denominator fractional LL filling factors.

In our work, we discovered unexpected phenomena in 2DESs [1, 2], and also in 2D hole systems (2DHSs) [3, 4] confined to wide GaAs quantum wells (QWs). In particular, we observe an unusual crossing of the two lowest-energy LLs. This crossing leads to a weakening or disappearance of the commonly seen odd-denominator FQHE states in the filling range $1/3 \leq \nu \leq 2/3$. But, surprisingly, a new FQHE state at the even-denominator filling factor $\nu = 1/2$ comes to exist at the crossing. Our results attest to the rich many-body physics of the 2DHSs.

Experimental

Each of our samples consists of a Carbon doped GaAs QW bounded on its sides by undoped $Al_{0.24}Ga_{0.76}As$ spacer layers. The density (*p*) is controlled by carefully applying front- and back-gates, and keeping the charge distribution symmetric. The measurements were carried out in SCM1.

Results and Discussion

Figure 1 captures the highlights of our work. We show the longitudinal (R_{xx}) and Hall (R_{xy}) resistance traces for a 2DHS confined to a 30-nm-wide QW for several densities, ranging from p = 1.20 to 1.72, in units of 10^{11} cm^{-2}. At the lowest p (top trace), R_{xx} minima are observed at numerous odd-denominator fillings such as ν = 2/3, 2/5, 3/5, 3/7, 4/7, etc. As *p* increases, starting at $p \approx 1.32$, an R_{xx} minimum develops at $\nu = 1/2$, and quickly deepens and turns into a zero-resistance plateau centered at $\nu = 1/2$ for p = 1.47. Concomitantly, the R_{xy} trace exhibits a Hall plateau quantized at $2h/e^2$, signaling the formation of a strong FQHE state at $\nu = 1/2$. At a slightly higher density, p = 1.59, the $\nu = 1/2$ R_{xx} minimum becomes weak. The strong $\nu = 1/2$ minimum returns again at higher *p* and the $\nu = 1/2$ FQHE persists up to the highest achievable densities.

The behavior of R_{xx} near $\nu = 1/2$ (data not shown here), and in particular the strengths of the nearby FQHE states, provide clear demonstration of an unusual crossing of the two lowest-energy hole energy levels in a large perpendicular magnetic field. Surprisingly, the $\nu = 1/2$ FQHE is very strong at this crossing, and becomes weaker on either side of the crossing while all the odd-denominator FQHE states, are strong except at this crossing. We tentatively interpret this FQHE as a two-component Ψ_{331} state.

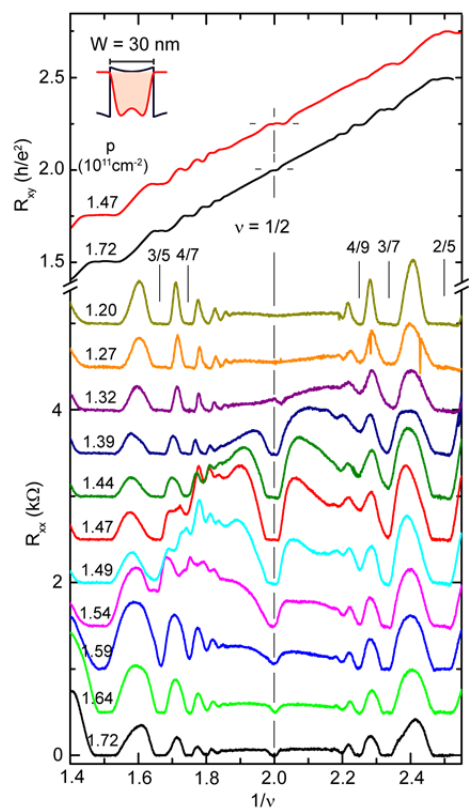

Fig. 1: Longitudinal and Hall resistances measured at $T \approx 30$ mK in a 30-nm-wide GaAs QW, at different 2D hole densities *p*.

Acknowledgements

A portion of this work was performed at the National High Magnetic Field Laboratory, which is supported by National Science Foundation Cooperative Agreement No. DMR-1157490, the State of Florida, and the U.S. Department of Energy.

We also acknowledge support through the NSF (DMR-1305691) and DOE BES (DE-FG02-00-ER45841) for measurements, and the Gordon and Betty Moore Foundation (Grant GBMF4420), Keck Foundation, the NSF MRSEC (DMR-0819860) for sample fabrication.

References

[1] Yang Liu *et al.*, Phys. Rev. B **90**, 085301 (2014).
[2] Yang Liu *et al.*, Phys. Rev. Lett. **113**, 246803 (2014).
[3] Yang Liu *et al.*, Phys. Rev. Lett. **112**, 046804 (2014).
[4] Yang Liu *et al.*, Phys. Rev. B **89**, 165313 (2014).