Reentrant Integer Quantum Hall Effect in the Lowest Landau Level

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Introduction

It has been well established for over 20 years that an insulating phase, reentrant around the filling factor ν = 1/5, is present in very high-quality 2D electron systems (2DESs). This phase is widely believed to be a manifestation of an electron Wigner crystal (WC) state, pinned by the disorder potential. Based on particle-hole symmetry, one would expect the appearance of similar insulating phases near filling factors ν = 1±1/5 but, surprisingly, such phases have not been observed until now. We report here the first observation of reentrant integer quantum Hall effect (RIQHE) states in the lowest Landau level near ν = 4/5 and 6/5 in very clean 2DESs confined to relatively wide GaAs quantum wells.

Experimental

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

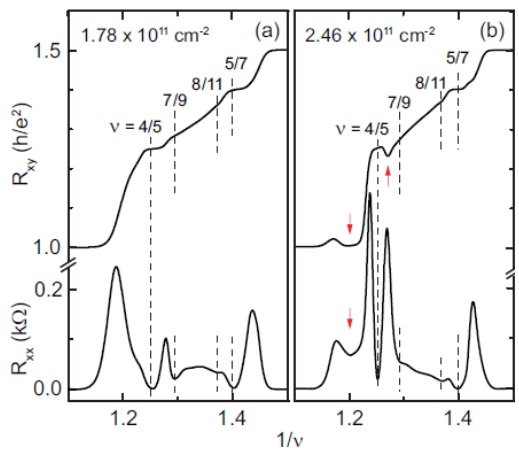

Figure 1: Rxx and Rxy vs. 1/ ν traces at T = 30 mK for a 42-nm-wide GaAs quantum well at two densities: (a) n = 1.78, and (b) 2.46 × 10^{11} cm^{-2}. In (b) the RIQHE phases observed on two sides of ν = 4/5 are marked by arrows.

Results and Discussion

Figure 1 highlights our main findings. A sharp contrast is seen in the data taken at two different densities in a 42-nm-wide GaAs quantum well. At the lower density, the R_{xx} and R_{xy} traces show what is normally seen in very clean 2DESs: strong QHE states at ν = 1 and 2/3 and, between these fillings, several fractional QHE states at ν = 4/5, 7/9, 8/11, and 5/7. At the higher density, however, a RIQHE (marked by down arrows) is observed near 1/ν = 1.20, as evidenced by an R_{xx} minimum and an R_{xy} quantized at h/e^2. Also evident is a developing RIQHE state between ν = 4/5 and 7/9, evinced by a dip in R_{xy} (up arrow in Fig. 1(b)), which becomes deeper at higher densities and R_{xy} approaches h/e^2.

We observe these RIQHE states only above a critical density (n_c) which is larger for narrower quantum wells. The RIQHE states can be interpreted as electron-hole counterparts of WC formed near ν = 1/5. In the present case, electrons at ν = 1±ν* can be considered as a filled Landau level, which is inert, plus excess electrons/holes with filling factor ν* which could conduct. At sufficiently small values of ν* and at very low temperatures, these excess electrons/holes crystallize into a WC phase which is pinned by disorder and does not participate in transport. Thus the magnetotransport coefficients R_{xx} and R_{xy} approach those of the ν = 1 integer QHE.

Conclusions

The RIQHE states in all samples are triggered by a sharp disappearance and reappearance of the ν = 4/5 FQH state near a critical density n_c, which is smaller in wider QWs. The ratio between the well width *W* and the magnetic length l_B is around 5~6 in all QWs. We believe it is the thick wavefunction in the z-direction that softens the short-range interaction and favors the formation of WC in our samples.

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References

[1] Y. Liu, C.G. Pappas, M. Shayegan, L.N. Pfeiffer, K.W. West, K.W. Baldwin, Phys. Rev. Lett. **109**, 036801 (2012).