NMR reveals maximum spin polarization in the presence of Wigner crystal domains at $\nu \sim 3$

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We probe the spin signatures of a two-dimensional electron system (2DES), confined to a GaAs quantum well, around filling factor three ($\nu \sim 3$) using resistively detected nuclear magnetic resonance (RD-NMR) spectroscopy at millikelvin temperatures. Whereas the existence of spin textures, known as skyrmions, around $\nu \sim 1$ in the lowest Landau level (LL) is well established, an understanding of the spin degrees of freedom for its higher-LL counterparts remains elusive. Although activation gap measurements in tilted fields showed the lowest-energy charged excitation at $\nu = 3$ to be a single spin flip, i.e., not skyrmions [1], recent light scattering experiments performed in the millikelvin temperature regime on ultra-high-mobility samples reveal a rapid collapse of the spin wave for $\nu \leq 3$, suggesting a loss of full spin polarization [2]. We attempt to clarify the nature of spin properties at $\nu \sim 3$ using NMR, a direct probe of the electron spin polarization. Measurements of spin-lattice relaxation time, T_1, which is a sensitive probe of spin textures, find very long T_1 at $\nu \sim 3$, indicating the absence of skyrmions. This interpretation is corroborated by Knight shift measurements, which highlight the existence of maximum spin polarization away from $\nu = 3$. Surprisingly, NMR spectroscopy also reveals that quasiparticles (quasiholes) of the $\nu = 3$ quantum Hall ferromagnet form Wigner crystal (WC) domains at $\nu > 3$ ($\nu < 3$).

A simulation of NMR spectra [3], based on a uniform 2DES model, matches experimental spectra exceedingly well around $\nu = 2.7$, 3.0 and 3.3. However, the uniform 2DES model breaks down around $\nu = 3 \pm 0.1$, where striking anomalies in the RD-NMR spectral line shape emerge. The anomalies manifest from broadening of NMR spectra, suggesting inhomogeneity in the in-plane local electron density. Using a model that describes the periodic lattice of a WC [4], we can fabricate simulations which match anomalous spectra remarkably well. As a result, we interpret the anomalous NMR spectra around $\nu = 2.9$ and 3.1 as emerging from the presence of domains of WC phases. Our simulation allows us to extract a crystal domain size of ~ 2 μm, provide a measure of electron-electron correlations not explicitly included in the ansatz wave function [4] and to show that the 2DES remains at maximum spin polarization for $2.7 \leq \nu \leq 3.3$ in the presence of translational symmetry breaking.

[1] A. Schmeller, J. P. Eisenstein, L. N. Pfeiffer, and K. W. West, Phys. Rev. Lett. **75**, 4290 (1995).
[2] T. D. Rhone, et. al., Phys. Rev. Lett. **106**, 196805 (2011).
[3] L. Tiemann, G. Gamez, N. Kumada, and K. Muraki, Science **335**, 828 (2012).
[4] K. Maki and X. Zotos, Phys. Rev. B **28**, 4349 (1983).