PHASE DIAGRAM FOR PHASE TRANSITIONS IN WIDE QUANTUM WELLS DETERMINED BY MICROWAVE SPECTROSCOPY

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The fractional quantum Hall effect (FQHE) series terminates in an insulating phase (IP) for Landau filling factor $\nu < 1/5$ in a single-layer two dimensional electron system. In a wide quantum well (WQW), the charge distribution can separate into two layers with increasing density (n) resulting in an IP onset of $\nu < 1/2$ [1]. In both cases the IP is understood as an electron solid pinned by residual disorder. Microwave spectroscopy accesses the pinning mode resonance, due to pieces of the solid oscillating within the disorder potential.

Our microwave spectra reveal multiple phase transitions between different solids within the terminating IP [2]. Figure 1(a) shows measurements of the microwave conductivity, Re(σ_{xx}), in the frequency-filling factor (f,ν)-plane from an 80 nm WQW at $n = 1.26 \times 10^{11}$ cm^{-2}. For $\nu < 0.5$, we observe a resonance onset at $\nu \sim 0.44$, which occurs well above the single-layer state onset. We attribute this resonance to a bilayer electron solid. The resonance peak frequency, f_{pk}, vs ν exhibits a gradual increase interrupted by a series of jumps. Concurrent with these f_{pk} jumps are sharp reductions in the resonance intensity. We interpret these jumps as phase transitions, and plot them in a phase diagram in Fig. 1(b) in the (γ,ν)-plane, where γ is the ratio of the Coulomb energy to the subband separation. Plotted in this manner we observe *five* well defined phase transition boundaries within the bilayer IP. We interpret these transitions as due to structural changes of the bilayer electron solid. We have investigated the role of charge imbalance, well width, and in-plane magnetic field effects on these transitions.

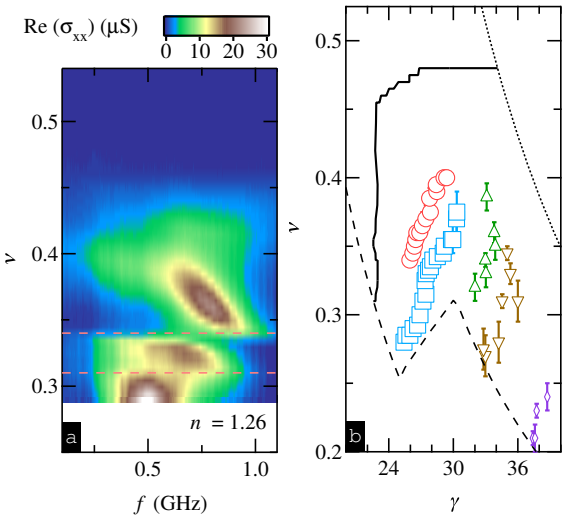

Fig. 1. (a) False color plot in the (f,ν)-plane. (b) Phase diagram in (γ,ν)-plane. The bilayer electron solid resonance area is bounded by the black line (resonance onset) and the dashed and dotted lines (density and magnetic field limitations). Symbols mark the *five* phase transition boundaries.

We will also address the ν region near 1/2 where we observe a second, additional resonance. Measurements of its sensitivity to growth-direction charge imbalance and analysis of its intensity are consistent with identification of this additional resonance as a pinning mode for a solid of quasihole excitations of the $\nu = 1/2$ FQHE.

[1] H. C. Manoharan, Y. W. Suen, M. B. Santos, and M. Shayegan, Phys. Rev. Lett. **77**, 1813 (1996).
[2] A. T. Hatke, Y. Liu, L. W. Engel, M. Shayegan, L. N. Pfeiffer, K. W. West, and K. W. Baldwin, Nat Commun. **6**, 7071 (2015).

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