# Observation of 2 electron bubble crystal about $\nu = 4 + 1/4$ and $4 + 3/4$ in clean 2D electron systems

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In the vicinity of filling factor $\nu = 9/2$, clean two–dimensional electron systems (2DES) show anisotropic conductivity when the temperature is below 100 mK [1]. In addition, at $\nu = 4 + 1/4$ and $4 + 3/4$, extra minima appear in the magnetoconductance which show quantized plateaus with $\sigma_{xy}$ equal to the value of the adjacent integer plateau—dubbed the reentrant integer quantum Hall effect (RIQHE). Both the anisotropy and the RIQHE are conjectured to be caused by charge density waves (CDW) known respectively as stripe and bubble phases[2]. Measurements of the real diagonal microwave conductivity, Re[$\sigma_{xx}$], are one means of probing CDW's[3]. We have measured Re[$\sigma_{xx}$] systematically for $\nu = 4 \rightarrow 5$ and present data showing a resonance in Re[$\sigma_{xx}$] at a frequency, $f \sim 300$ MHz about $\nu = 4{+}1/4$ and $4{+}3/4$ where the RIQHE occurs. Furthermore, we find a *second* resonance at $f \sim 1.5$ GHz for $\nu$ between 4.06 and 4.2, or approximately where the integer quantum Hall effect plateau is observed. Because the two resonances have different characteristic frequencies, we interpret the resonance closer to integer $\nu$ as the pinning mode of an electron crystal with one electron per lattice site and the resonance about $\nu = 4 + 1/4$ as the pinning mode of a bubble crystal with *2 electrons* per lattice site[4].

In Figure 1, we show 63 Re[$\sigma_{xx}$] spectra for frequencies, $f$, from 80 MHz to 1 GHz at $\nu$ between 4.15 and 4.77 (marked on the right) taken at $T \sim 50$ mK. The sample used is a GaAs/AlGaAs quantum well of mobility $\mu = 2.4 \times 10^7 \mathrm{cm}^2/\mathrm{Vs}$ and density n=$3.0{\times}10^{11}\mathrm{cm}^{-2}$. A weak resonance first appears at $\nu = 4.21$ with a peak frequency $f_{pk} \approx 500$ MHz. The strength of the resonance in terms of peak conductivity and $Q$, is greatest at about $\nu = 4.3$ where $f_{pk} = 330$ MHz and $Q = 2.5$. We are able to observe a resonance out to $\nu = 4.38$ where $f_{pk} \approx 130$ MHz but then it disappears as the center of the Landau level is approached. Above $\nu = 4.5$, the resonance reappears at $\nu = 4.62$ and reaches its' maximum at about $\nu = 4.7$. It continues to be visible until the lower edge of the figure at $\nu = 4.77$. Again, $f_{pk}$ spans from 120 MHz to 500 MHz.

In figure 2, we show the Re[$\sigma_{xx}$] from 80 MHz to 4 GHz at $\nu = 4.01$ and $\nu = 4.14$ for $T = 50$ mK. This resonance exists from about $\nu = 4.06$ to 4.18 and has a higher typical $f_{pk}$ of order 1.5 GHz. The inset shows $f_{pk}$ versus $\nu$ for both resonances for $\nu$ from 4.0 to 4.5. The two branches of $f_{pk}$ do not meet and have different slopes.

[1] M. Lilly *et al.* , Phys. Rev. Lett. **82**, 394 (1999). R. R. Du *et al.* Solid State Comm. **109**, 390(1999).
[2] M. M. Fogler *et al.* Phys. Rev. B **54**,1853 (1996). R. Moessner and J. T. Chalker, Phys. Rev. B **54**, 5006 (1996). N. Shibata and D. Yoshioka, Phys. Rev. Lett. **86**, 5755 (2001).
[3] P.D. Ye *et al.* Phys. Rev. Lett. **89** 176802(2002).
[4] R.M. Lewis, *et al.* Phys. Rev. Lett. **89** 136804(2002).

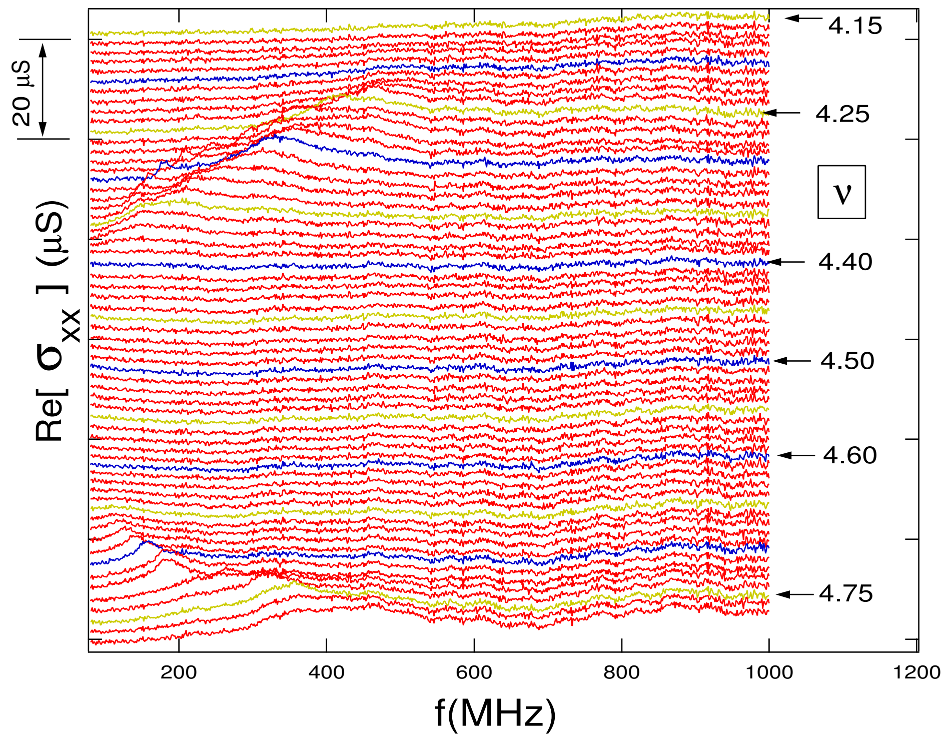


FIG. 1: The real part of the diagonal conductivity, Re[$\sigma_{xx}$] versus $f$ at several filling factors, $\nu$, from 4.15 to 4.77. Frequencies from 80 MHz to 1 GHz are shown. Temperature is 50 mK.

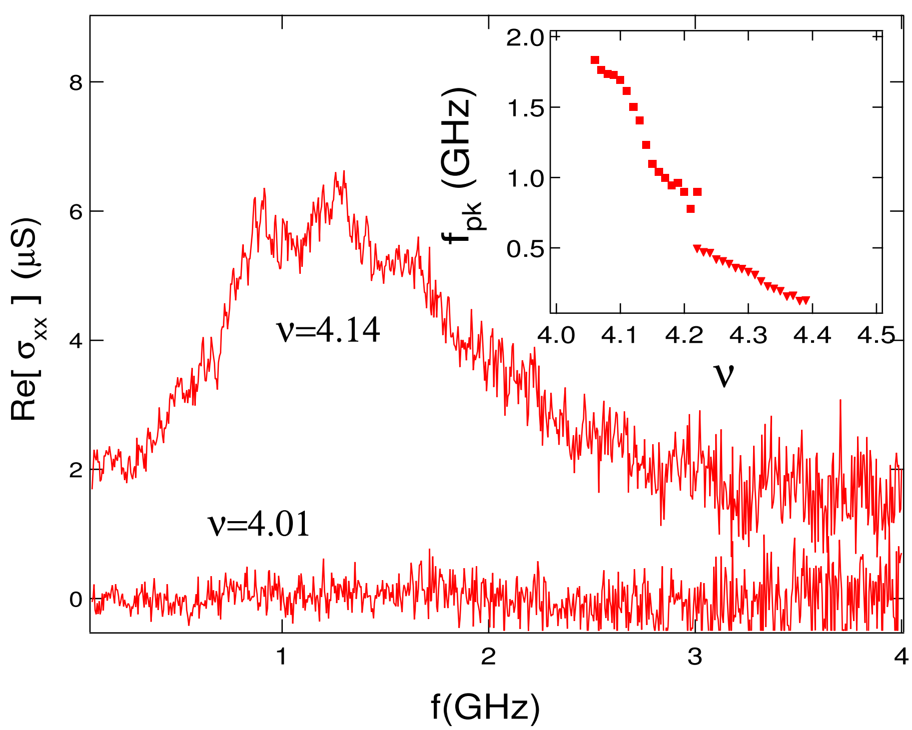


FIG. 2: Re[$\sigma_{xx}$] versus $f$ from 50 MHz to 4 GHz at $\nu = 4.14$.**Inset:** Peak frequency, $f_{pk}$ vs $\nu$ shows 2 branches. T = 50 mK.