RF SPECTRA OF BUBBLE PHASES OF 2D ELECTRON SYSTEMS IN TILTED FIELDS

G. Sambandamurthy, R. M. Lewis, Yong P. Chen (NHMFL and Princeton); L. W. Engel (NHMFL); D. C. Tsui (Princeton); L. N. Pfeiffer and K. W. West (Lucent Bell Labs)

When high Landau levels (LL’s) are occupied, clean two-dimensional electron systems appear to exhibit a variety of phases with fixed spatial modulation of charge density. These include anisotropic, stripe phases, and also solid, “bubble” phases in which clusters (bubbles) of two or more electron guiding centers arrange themselves on a lattice. The stripe phases appear around $\nu^*=1/2$, where $\nu^*$ is the partial filling of the top LL with occupation, and the bubble phases flank it on either side, appearing around $\nu^*=1/4$ and $3/4$. Besides a distinct signature in dc transport [1], the bubble phases exhibit striking resonances [2] in their rf spectra; these resonances are interpreted as a pinning mode of the bubble phases, in which solid within the pinning potential due to the disorder. The stripe direction is known to switch direction [3] on application of an in-plane magnetic field ($B$).

Using a recently constructed, high magnetic field, microwave-connected, tilting stage in a dilution refrigerator, we have begun to study the evolution of the spectra with in-plane $B$ for LL filling $\nu$ between 4 and 5. Figure 1 shows typical results, as maps of the real part of the diagonal conductivity, Re($\sigma$), in the $\nu$-$f$ plane. Re($\sigma$) is measured along the hard direction (that of higher dc resistance) in perpendicular magnetic field ($\theta=0^\circ$) and in-plane $B$ is applied along the easy direction. For $\theta=0^\circ$ the bubble phase resonances appear for frequency $f$ from 0.15 to 0.4 GHz, in $\nu$ ranges centered around 4.7 and 4.3; the resonance around 0.8 GHz and $\nu = 4.8$ is interpreted as a pinning mode of a Wigner crystal of individual holes in the top LL [4]. Increasing $\theta$ shifts all the resonances to higher $f$, leaving the only the bubble phase resonances in by 40° as shown in the figure. Application of in-plane $B$ significantly alters the spectrum in the striped phase as well.

The observed increase in resonance frequency on applying in-plane B are likely due to its effect on 1) the elastic properties of the electron solids, or 2) the effective pinning disorder.

![Figure 1. Two-dimensional map of Re($\sigma$) values in the v-f plane at two tilt angles, $\theta = 0$ and 40°, measured at 65 mK. The vertical bands are due to standing waves between the sample and the input of a room temperature preamplifier.](image)

Acknowledgements

We acknowledge support from the AFOSR and from the NHMFL in-house research program.

References