**Splitting of the Fermi Contour of Quasi-2D Electrons in Strong Parallel Magnetic Fields**

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**Introduction**

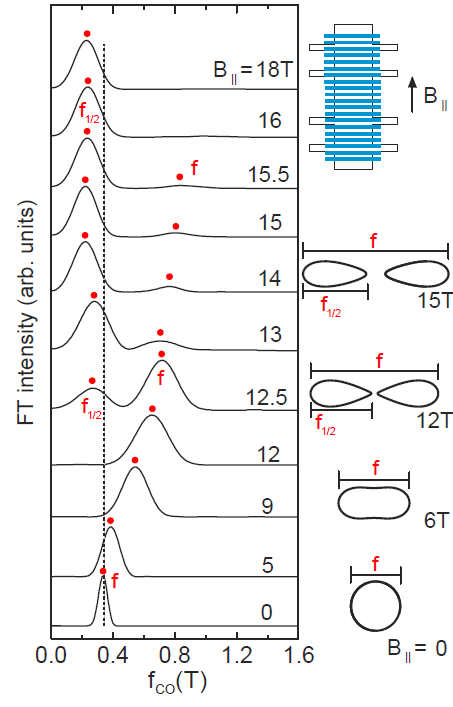
In a strictly two-dimensional electron system (2DES) with zero layer thickness, the electrons’ in-plane motion is unaffected by a parallel magnetic field (B||). However, for a quasi-2DES, such as electrons in a quantum well (QW) with finite width, B|| can couple to electrons’ out-of-plane motion, thus also affect their in-plane motion. This can have profound consequences. For example, the Fermi contour, which is circular in an isotropic system such as the 2DES in GaAs QWs, becomes severely distorted by B|| and eventually splits into a pair of smaller contours in the presence of a sufficiently large B|| (Fig. 1).

**Experimental**

We studied 2D electrons confined to GaAs QWs flanked on each side by undoped Al0.24Ga0.76As barrier layers and Si δ-doped layers. The sample is a standard Hall bar covered with periodic gratings of negative electron-beam resist (shown as blue stripes in Fig. 1) which induce a periodic and small density modulation through the piezoelectric effect in GaAs. We used SCM2 for measurements.

**Results and Discussion**

Through measurements of commensurability oscillations (COs), stemming from the lateral density modulation of the 2DES, we directly and quantitatively probe the evolution of the Fermi contour as B|| causes its distortion and eventual disintegration into two pieces [1]. Here, in Fig. 1, we present the Fourier transform (FT) spectra of the COs as a function of B||.On the right side, we also show four Fermi contours of the majority spin species, calculated for B|| = 0, 6, 12 and 15 T, which quantitatively capture the splitting phenomenon.

 The bottom FT spectrum in Fig. 1 exhibits a single peak (**f**) whose position (≃0.35 T) is consistent with the commensurability frequency (the dotted line) expected for a circular Fermi contour. With increasing B||, this peak **f** moves to higher frequencies in the FTs, suggesting that the Fermi contour is getting elongated. However, at B|| ≅ 12.5 T, a new peak **f1/2**emerges at approximately **f**/2. This is an indication that the elongated contour has split into two smaller ones. Even after the splitting, we continue to observe both **f** and **f1/2** up to B|| ≅ 15.5 T implying a magnetic breakdown between the split contours. As B|| gets larger,the **f1/2**peakbecomes the strongest feature in the FT spectra while the strength of **f** diminishes progressively. We conclude that the FT data demonstrate the breakdown of the Fermi contour (at B|| ~12 T) consistent with calculations. Note that, since the majority and minority spin contours are similar in size, COs cannot resolve the splitting of both contours.

In our studies, we also probed the *warped* Fermi contour of 2D holes and hole-flux composite fermions via the COs induced by the surface grating [2]. Similar technique was also used to explore the phase boundary between a composite fermion Fermi sea and fractional quantum Hall liquid state [3]. In these two studies, we used the SCM1, SCM2 and the 31-T-magnet facilities.

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**FIG. 1:** On the right side, we show a schematic of the Hall bar (top) along with the calculated Fermi contours for B|| = 0, 6, 12 and 15 T. On the left, we show a series of FT spectra as a function of B||.

**References**

[1] M. A. Mueed *et al.*, Phys. Rev. Lett. **114,** 236404 (2015).

[2] M. A. Mueed *et al.*, Phys. Rev. Lett. **114,** 176805 (2015).

[3] M. A. Mueed *et al.*, Phys. Rev. Lett. **114,** 236406 (2015).