Magnetoresistance Oscillations from Collective Ballistic Dynamics in Two-dimensional Systems

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Ballistic electron transport occurs when electrons scatter predominantly against the device boundaries [1, 2, 3]. A requirement is a long mean-free path, as in the high-mobility 2D electron systems in GaAs/AlGaAs heterostructures used here (65 μm at 4 K) [1, 2, 3]. Under strong electron-electron scattering, hydrodynamic transport occurs, leading to collective charge flow akin to a fluid [1, 4]. Yet due to interactions of electrons with the boundaries, ballistic transport can also lead to collective phenomena, experimentally studied here. Unlike diffusive transport (governed by local resistivity and Ohm's law), ballistic and hydrodynamic transport are non-local and exhibit complex non-Ohmic current flow patterns, including current vortices [1, 3]. We studied several types of confined device geometries with specular boundaries in the ballistic regime, exemplified by Fig. 1(a), with internal size L and current source and drain point contacts (S and D PCs) near two corners distanced by $L_{\rm sd} < L$. Figure 1(b) depicts current and voltage 3-terminal configurations. Under perpendicular magnetic field B, electrons undergo semi-classical cyclotron orbits with diameter $d_c(B)$ (Fig. 1(a)). Measurements at 4 K are shown in Fig. 1(c) where $R_{\rm nl}$ is the voltage measured between a detector PC (at $L_c < L_{\rm sd}$ from S) and D divided by injected current. $R_{\rm nl}$ shows a positive peak whenever $d_c = L_c/n_c$ ($n_c = 1, 2, 3$ and $L_c = 2, 4, 6\,\mu$m, Fig. 1(c)) representing transverse magnetic focusing prototypical of single-particle ballistic transport. In Fig. 1(c) peaks also occur at low B for $d_c = L_{\rm sd}/n$ ($n = 1, 2, \ldots 5$), denoting a novel *source-drain resonance* corresponding to d_c as depicted in Fig. 1(a), independent of the location of the detector PC. The resonances occur for fractional $n_c = n(L_c/L_{\rm sd})$, seen in Fig. 1(c). The experiments joined with Boltzmann equation simulations show that the fractional peaks cannot be attributed to any particular particle trajectory: they only occur from the *collective dynamics* arising from a particle distribution. The magnetoresistance is further correlated with current flow vorticity, a collective phenomenon. Our experiments on other geometries in 3- and 2-terminal configurations have revealed additional examples of magnetoresistance due to collective ballistic dynamics.

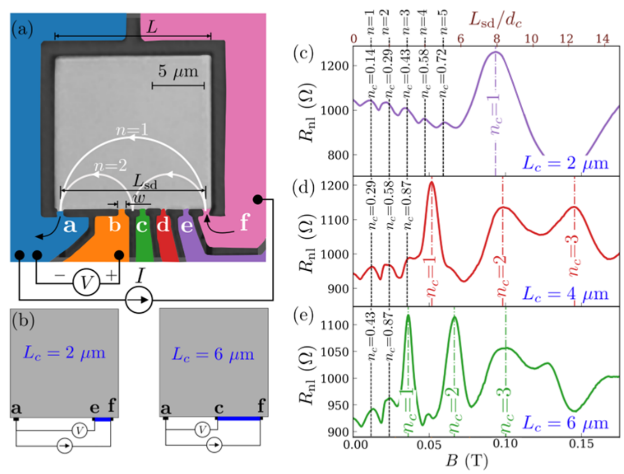

Fig. 1. (a) Example of confined geometry with $L = 15\,\mu$m, source/drain/measurement PCs with $w \approx 0.6\,\mu$m, and $L_{\rm sd} = 13.8\,\mu$m. (b) 3-terminal measurement configurations referring to (c). (c) Experimental $R_{\rm nl}$ vs B at 4 K for $L_c = 2, 4, 6\,\mu$m, showing peaks for $n_c = 1, 2, 3$ and novel resonance peaks for $n = 1, 2, \ldots 5$ [3].

References

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