Real-space imaging of fractional quantum Hall effect

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Electrons in semiconductors usually behave like gas. However, in a special case when electrons are confined two-dimensionally under strong perpendicular magnetic field at low temperatures, they behave as incompressible quantum liquid―the fractional quantum Hall (FQH) effect. The FQH is a quantum mechanical manifestation of macroscopic behavior of electrons, in which longitudinal resistance reduces to zero and the Hall resistance is quantized to a universal values irrespective of the microscopic details of the sample interior as the same as the Integer quantum Hall effect.

In this paper, we present real-space images of FQH liquids by spin-resolved scanning optical microscopy and spectroscopy. Our scanning optical microscopy apparatus collects light from the two-dimensional electron system (2DES) under illumination, where each photo-excited hole binds to two electrons, forming a trion. Using appropriate optics, we performed polarization-selective photoluminescence (PL) spectroscopy of trions in a microscopic region with size comparable to the diffraction limit of light.

We show two distinctive spatial patterns: first, for a non-degenerate fully-spin polarized FQH state, compressible and incompressible FQH liquids are formed subjected to the intrinsic disorder potential, and the spatial pattern directly reflects the disorder (short-range patterns). Secondly, when differently spin-polarized FQH liquids are degenerate, real-space images show domain structures with spontaneous quasi-long-range order (long-range patterns). The two-dimensional random-field Ising model theoretically reproduced the long-range patterns from the short-range patterns [1].

Our imaging method relies on introducing trions, *i.e.*, a photo-excited hole that effectively correlates with electrons, as an internal probe. This allows for imaging genuine FQH liquids that could not be accessed through scanning probe-type microscopy. This technique can shed new light on various aspects from a microscopic viewpoint for diverse range of many-body systems not limited to FQH systems.

[1] J. Hayakawa, K. Muraki, G. Yusa, *Nature Nano*. **8**, 31 (2013).