Extreme Quantum Limit of Electrons in Strontium Titanate

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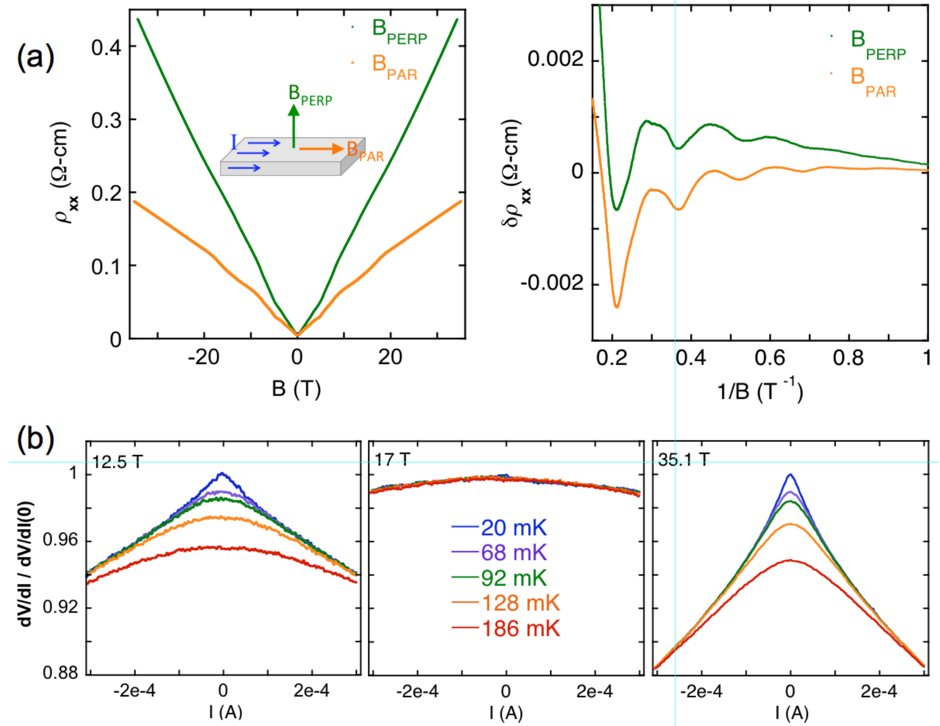
When an electronic system is subjected to a high magnetic field such that the cyclotron energy of the electrons are much larger than the Fermi energy, the system enters a new kind of quantum state - the extreme quantum limit (EQL).

By going to very low temperatures (20 mK) and using a suite of the wide range of magnets available at the NHMFL DC Field Facility we were able, for the first time, to deeply probe the EQL in lightly doped bulk strontium titanate (STO) crystals which were grown at Argonne National Lab expressly for this experiment.

Analysis of the Shubnikov-de Haas (SdH) oscillations and Hall effect measurements performed at various crystal orientations in the magnetic field with respect to the applied current showed a fairly isotropic and homogeneous electron system at low fields. Surprisingly, at high magnetic fields in the EQL, we discovered that the formerly homogeneous electron system breaks up into disconnected puddles that are localized in potential wells created by the disorder. This puddle formation leads to saturation of the quantum limiting field in our low density samples.

We also observed strong nonlinearity in the electron transport (dV/dI) when the system was in the EQL and also at the maxima of the SdH oscillations at fields below the EQL. However, the nonlinearity vanishes at the oscillation minima. Further studies of this nonlinearity may provide important insights into extreme quantum limit state.



(a) The period of the Shubnikov-de Haas oscillations is independent of whether the magnetic field is applied perpendicular or parallel to the current. (b) Nonlinearity of the electron transport at various temperatures observed in the quantum limit (35.1 T) and a maximum of SdH oscillations (12.5 T) disappears at a minimum of these oscillation (17 T).

Facilities: DC Field facility:18 T Superconducting (SCM 1), 35 T Resistive (Cell 8) & 45 T Hybrid magnet (Cell 15) with dilution refrigerators.

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