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# Outline of Thesis

Title: Energy relaxation of non-equilibrium electrons in quantum Hall edge channels
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By applying a strong magnetic field perpendicular to a two-dimensional electron system, the classical cyclotron motions are quantized to Landau levels. When the Fermi energy lies between the Landau levels, the system is called quantum Hall state, where electrons flow along the sample edges in one direction without backscattering. In contrast to diffusive transport in normal conductors where carriers are stochastically scattered by impurities, the chiral one-dimensional transport in the edge channels should be phase coherent unless the electron's energy is not dissipated. It gives us a prospect that quantum interferences of electrons can be designed and investigated using edge channels as waveguides for quantum electronic states. This research field is called electron quantum optics. Differences from quantum optics are statistics, namely photons are bosons and electrons are fermions, and strength of interactions. Strong Coulomb interactions in electronic systems can be used to control entangled electronic states for understanding electron propagation and realizing quantum computing and information devices. However, interaction with nearby electrical channels induces decoherence of electrons in the target channel. Recent theoretical and experimental researches on Mach-Zehnder interferometers imply that the coherence is mainly broken by energy relaxation induced by electron-electron interactions between co-propagating channels. In this thesis, relaxation dynamics of non-equilibrium electrons are studied in some different conditions for reducing the relaxation.

Firstly, decoherence induced by coupling to co-propagating edge channels can be eliminated by focusing on a single edge channel at bulk filling factor $\nu = 1$ in a higher magnetic field. In an ideal $\nu = 1$ quantum Hall state, low energy excitations are expected to flow without energy relaxation, because electron-electron scattering within the channel is absent due to cancellations of the direct and exchanged scattering terms. However the absence of energy relaxation had not been checked in actual samples, because a conventional energy spectroscopy scheme, quantum dot spectroscopy, does not work in the very strong magnetic field. Thus, we propose and demonstrate a novel energy relaxation measurement scheme where two quantum point contacts (QPCs) are used as an injector and an energy spectrometer. An initial non-equilibrium state is injected into an edge channel from the injector QPC, and the state after propagating a single edge channel is investigated with the detector QPC. Between the two QPCs, there should be no energy relaxation for an ideal single edge channel. The energy relaxation can be evaluated by measuring energy distribution function in the edge channel. We propose a current noise measurement at the output of the detector QPC working as an electronic beam splitter. In practice, cross-correlation current noise is measured for the two outputs of the detector QPC. We find that the cross-correlation turns from a negative value to a positive value depending on the energy relaxation. As a first step, we demonstrate the validity of the scheme by inserting a floating ohmic contact between the QPCs. In the ohmic contact, the non-equilibrium state is fully relaxed by interactions with many electrons and phonons. Observed noise agrees well with the theoretical value for the fully relaxed case. This clearly demonstrates that the noise is sensitive to the energy relaxation. Next, we apply this scheme to investigate energy relaxation in a single edge channel at $\nu = 1$. In contrast to the naive expectation of no relaxation, we find that the electronic state experiences significant relaxation showing positive cross-correlation noise even for a short channel of 3 μm in length. This suggests unwanted coupling to the environment, which should be investigated further for reducing the energy relaxation.

Secondly, we systematically investigated relaxation dynamics in a wide energy region from the vicinity of the Fermi energy to a few hundred meV above the Fermi energy. Here we focus on a hot electron in the lowest Landau level, whose energy increases gradually with approaching the edge of the sample. Considering this soft edge potential with a quadratic term, electron-electron scattering between the hot electron and the electrons below the Fermi energy should become weaker for higher energy. To investigate the energy relaxation, we employed hot electron spectroscopy, in which a hot electron is injected by a QPC to an edge channel and the electron is detected by an energy spectrometer made of another QPC. This scheme allows us to investigate energy relaxation in the wide energy range. We observed a systematic variation of electronic excitations including ballistic transport, multiple emission of optical phonons showing phonon replicas, electron distribution in higher Landau levels, partially relaxed electrons under weak electron-electron scattering, and electron-hole plasma near the Fermi energy. Notably, we found that energy dependence of optical phonon emission rate can be understood by considering the edge potential profile. By tuning the edge potential by a gate voltage, the phonon emission rate can be tuned from fully relaxed limit to nearly ballistic limit. The tuning technique is useful as not only for suppressing the phonon emission but also for intentionally relax the electron when desired. The technique might facilitate development of electron quantum optics.