

論文の内容の要旨

Transport dynamics in the spin-resolved quantum Hall edge states
(スピンの分離した量子ホールエッジ状態における輸送ダイナミクス)

氏名 清水 貴勢

In this thesis, we investigate the transport dynamics in the spin-resolved quantum Hall edge states, which form spin-resolved one-dimensional conduction channels at the edges of the two-dimensional electron system in the integer quantum Hall state [Quantum Hall edge channels (QHECs)]. In the spin-resolved QHECs, the spin and orbital degrees of freedom of electrons are strongly coupled. In other words, there is a one-by-one correspondence between the spin and orbital degree of electrons in spin-resolved QHECs. The primary interest of our studies here is whether it is possible to make quantum operations on one degree of freedom through manipulations of the other in such a strongly coupled system. More specifically, our question is what sort of quantum operations on electron spins are possible via the control of electron orbitals in the spin-resolved QHECs.

When we take the quantization axis of the spins along the magnetization axis, the zenith angle is determined by the partition rate of the spin-resolved QHECs, while the azimuth angle is defined as the phase difference between them. Thus, unitary operation on the spin is done by gate-controlled beam splitters, which partially transmit electrons between the spin-resolved QHECs, and phase shifters. Because of the preparation of the initial state with no entanglement, the first target should be to create a maximally entangled state if we set our goal to complete control of spin.

The previous studies found that the transmission between the spin-resolved QHECs occurs at the

corner of the QHECs because effective magnetic fields arising from the spin-orbit interactions (SOI) change non-adiabatically. In addition, the phase difference, which corresponds to the azimuth angle, is shifted through the Aharonov-Bohm phase by changing the distance between the spin-resolved QHECs. However, independent control of the beam splitter and phase shifter was not established. In the present thesis (chapter 4), we show a concrete method for this independent control with a device consisting of multiple metallic gates. Notably, we find that the transmission probability at the corner of the QHECs is affected by the curvature.

In the experiment in chapter 4, the estimated transmission probability of the beam splitter was about 2%. However, a beam splitter with 50% of transmission probability, namely a half-mirror, is required to create a maximally entangled state, hence for the arbitrary unitary operations. Such a small transmission probability of the experiment in chapter 4 is attributable to the right-angled gate shape, limiting the rotation angle of the effective magnetic field of SOI. In chapter 5, we realize such a half-mirror by using an acute angle gate. We confirm coherent transmission at the BS by observing the Aharonov-Bohm interference with significantly high visibility of about 60%. The results indicate that we have realized a quantum state with a high degree of entanglement, probably the maximal entanglement. We also show the results of transport simulation using the tight-binding model, indicating that the transmission probability of the beam splitter is affected by the angle of the gate corner and SOI strength, as well as the gradient of confining potential at the position of QHECs.

A remaining problem in getting our first target, a maximally entangled state, is the proof of quantum coherence. The interferometry guaranteed 60%, and we have tried a different approach henceforth. Although the coherence length of QHECs is significantly extended due to the chirality, it is still finite, which means that the decoherence does take place during the transport. Under highly-nonequilibrium conditions, e.g., finite voltages between the adjacent channels, inelastic inter-channel transmission is expected to be involved, leading to the enhancement of decoherence. Such an inelastic transmission should be measured as a reduction of shot noise in principle. However, the resolution of shot noise measurement required for this study is significantly high. In chapter 6, we show a novel high-resolution shot noise measurement system, which comprises homemade-HEMT-based cryogenic transimpedance amplifiers. In the subsequent chapter 7, we describe measurement of the shot noise generated by the transmission between the spin-resolved QHECs for the first time. The shot noise amplitude has asymmetric behavior for the sign of the bias voltage originating from the edge channel reconstruction. We have shown that the inter-channel transmission is elastic at the small source-drain bias condition, which supports the realization of the spin-orbit maximally entangled state.