Motivation

Interference phenomena are a fundamental manifestation of the quantum mechanical nature of electrons and have promising applications in solid-state quantum information technology. In particular, the realization of electronic Mach-Zehnder (MZ) interferometers in Quantum Hall (QH) systems appears at present a sound technology for the implementation of quantum information schemes [5]. Despite this success, the edge topology of the single-channel MZ limits the complexity of these circuits to a maximum of two interferometers [2]. In order to overcome this constraint, new device architectures were recently proposed [6], where interference paths are built using two different parallel edge channels. In this configuration, control over the interaction between the different edge channels is challenging owing to the complex edge structure.

In order to address these issues we are exploring the use of scanning gate microscopy (SGM) to control the trajectory and interaction of edge channels based on our previous results on quantum point contact (QPC) devices in the QH regime [4]. In the present work, the two-split gates of the QPC play a double role: they not only allow us to bring the edges in close proximity, but they also provide the ability to select the edges that are sent to the center of the QPC.

The SGM setup

The fundamental element of our setup is the AFM head. It is constructed with a stack of actuators for both the coarse and fine control of the tip-sample position. The sample mounted on a chip carrier, is positioned on top of this stack, while the tip is connected to a tuning fork (TF) which is fixed. The AFM head is mounted on the cold finger of a He cryostat with a base temperature of 400 mK. A superconducting coil can provide a magnetic field up to 9 T. The AFM tip is connected to the TF and acts as a movable scattering center which is able to induce interaction between edge states travelling across the QPC gap.

Selecting the conductance of edge channels by SGM

We are exploring the use of SGM to control the trajectory and interaction of edge channels in quantum point contact (QPC) devices in the QH regime. Sample fabrication starts from high-purity GaAs/AlGaAs heterostructures and photolithography split-gate QPCs. SGM experiments were performed at 400 mK. The figures below show the QPC conductance as a function of the position of the biased tip (\(g\nu = 0\)). The conductance plateau is set to \(g = 2\) (2 spin-degenerate edge channels). In our experiments, this conductance plateaus are partially or completely depopulated by the SGM technique. In (a) the tip is located under the upper gate, while in the other cases the tip is located close to one of the channel edges, allowing control over the interaction between the edge channels.

The characteristic branched flow observed in zero-field SGM measurements. The dark regions in the color plot (low conductance) correspond to the actual depletion spots. The signed color bar is the logarithmic conductance scale. With a negatively biased tip, the interaction between the edge channels is almost completely removed. The negatively biased tip yields a local depletion of the 2DEG. Conductance maps are obtained in constant height mode. The negatively biased tip yields a change in the conductance which depends on the local electronic paths. The conductance map shows the characteristic branched flow of electrons. These branches are decorated with fringes due to the self-interference of the electrons. They extend over a length scale of several microns, due to the high mobility of the 2DEG.