Quantum Transport in an Aharonov-Bohm Electron Interferometer

Wei Zhou, F. E. Camino, and V. J. Goldman

Department of Physics, Stony Brook University, Stony Brook, NY 11794-3800, USA

Abstract. We report experiments on quantum electron interferometers fabricated from GaAs/AlGaAs heterojunctions. In this kind of devices, an electron island with two nearly open constrictions is defined by etched trenches. In the quantum Hall (QH) regime, two counterpropagating edge channels are coupled by tunneling in the constrictions, thus forming a closed interference path. We observe periodic Aharonov-Bohm oscillations in the four-terminal magnetoresistance on the i = 1, 2 and 4 QH plateaus. The period of the oscillations ΔB scales with i so that $i\Delta B = const$ = 2.7±0.1 mT. For i = 1, we determine the dependence of the area enclosed by the electron interference path on the front-gate voltage, and find a constant integrated compressibility of the island electron system with respect to the front gates. We further compare the experimental results with two classical electrostatics models of the electron density profile in the island.

Keywords: Aharonov-Bohm, electron interferometer, edge channel
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INTRODUCTION

Quantum interference between edge channels [1,2] encircling a quantum antidot has revealed valuable information about the underlying quantum Hall (QH) excitations [3]. Here we present results obtained with devices of the complimentary geometry, in which an electron island with two nearly *open* constrictions is defined by etched trenches (Figure 1). In the QH regime, counterpropagating edge channels are coupled by weak tunneling within the constrictions, forming a closed interference path and thus giving rise to Aharonov-Bohm (AB) oscillations in the magnetoresistance. In this report, we present results of AB oscillations on several quantum Hall plateaus, and study the dependence of the oscillations on front-gate voltage for the QH plateau i = 1.

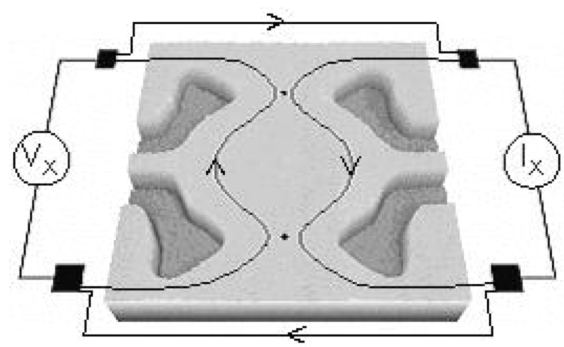

FIGURE 1. Atomic force micrograph of the central region (~4x4 μm) of an electron interferometer. An island is defined by four wet-etched, metal-covered trenches. Black squares represent Ohmic contacts at the corners of the sample. Arrowed lines indicate edge channels. Tunneling at the two wide constrictions (black dots) enables electrons to perform closed loops, thus causing an oscillatory AB signal, which is measured directly in $R_{XX} = V_X/I_X$.

SAMPLE PREPARATION AND EXPERIMENTAL SETUP

Two samples (A and B) were fabricated from low density, low disorder and high mobility GaAs/AlGaAs heterojunctions. After exposure to a red LED at 4.2 K, electron densities of 1.2×10^{11} cm^{-2} (sample A) and 9.7×10^{10} cm^{-2} (sample B) were obtained. Ohmic contacts at the corners of each sample were prepared on a pre-etched mesa. Then, an electron island of lithographic radius 1,050 nm (1,300 nm) was defined by four wet-etched trenches of depths 140 nm (82 nm) for sample A (B). Au/Ti front gates, whose voltage can be adjusted independently, were subsequently deposited into the trenches. The samples were cooled in a top loading into mixture dilution refrigerator down to 10 mK. Extensive radio frequency filtering reduces background electrical noise on the samples. The four-

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terminal magnetoresistance $R_{XX} = V_X/I_X$ was measured using standard low-frequency lock-in technique.

RESULTS AND ANALYSIS

Figure 2 shows the four-terminal magneto-resistance of sample A obtained for QH fillings i = 1, 2 and 4. To tune the symmetry of the two constrictions, the front-gate voltages are varied as well, as shown in the graph (V_{FG} is defined as the average of the four gate voltages). We observe that the AB oscillation period ΔB scales with i such that the product $i\Delta B$ = 2.7±0.1mT. From the AB quantization condition $\Delta\Phi = Si\Delta B = h/e$, the area S enclosed by the electron interference path is 1.48×10^{-12} m^2, independent of QH filling. We interpret this fact as the validity of the AB quantization condition without any detectable correction due to the finite confining potential, similar to what was reported for quantum antidots [3].

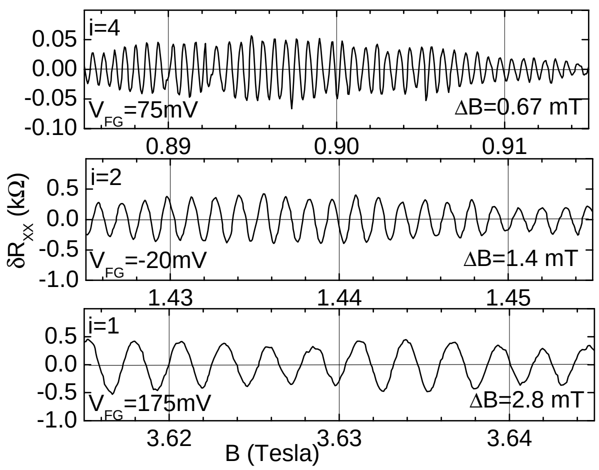

FIGURE 2. Four-terminal magnetoresistance of sample A for QH fillings i = 1, 2 and 4. A smooth background, on which the oscillations are superimposed, is subtracted from each trace.

For the i = 1 case, we study the dependence of S on V_{FG}, using sample B. With increasing positive V_{FG}, we observe a monotonic shift to higher values of the midpoint magnetic field B_M of the oscillation range, as illustrated in Figure 3. From each trace, we calculate S, and find a linear relationship between S and V_{FG} with $dS/dV_{FG} = 1.44\times10^{-12}$ m^2/V. Further analysis shows that the product of $S\Delta V_{FG}$ is approximately constant, where ΔV_{FG} is the change of front-gate voltage needed to increase by one the number of electrons N inside S. Since the inverse integrated compressibility of the 2D electrons in the island: $dn/d\mu \propto dn/dV_{FG} \propto (dN/dV_{FG})/S = \Delta N/S\Delta V_{FG} = 1/S\Delta V_{FG}$, where n is the electron density in the island and μ is the chemical potential. The constancy of $S\Delta V_{FG}$ thus is quite fundamental: it follows from the fixed density of states in the island area encircled by the i = 1 edge channel. The constancy of $S\Delta V_{FG}$ can also be viewed as a constant differential capacitance per area of the island: C/S = 64 μF/m^2, where $C = dQ/dV = e/\Delta V_{FG}$. We also compare our results with two classical electrostatics models: one modeling the 2D electron density due to depletion from an etch trench, and another modeling the front-gate voltage dependence of the electron density in the island. Good agreement is obtained for the range of front-gate voltages studied. Details of this analysis are available in Ref [4].

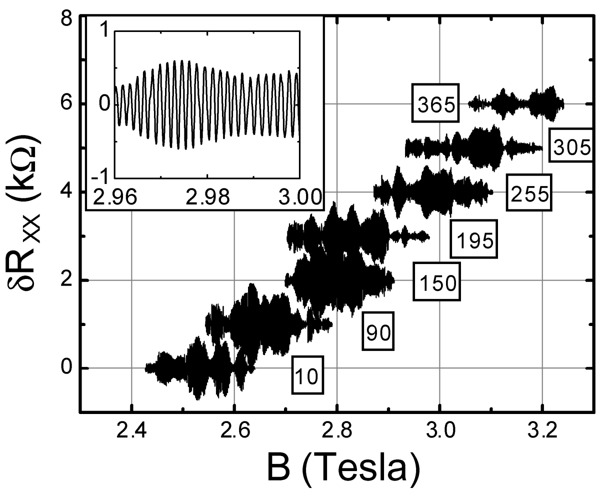

FIGURE 3. Four-terminal magnetoresistance of sample B for LL filling i = 1 at different front-gate voltages (shown in mV next to each trace). Successive traces, with the respective smooth background subtracted, are offset by 1 kΩ for clarity. Inset: a blow up of the V_{FG} = 255 mV trace.

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