Aharonov–Bohm oscillations with fractional filling of a Landau level

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The magnetotransport properties of a ring-shaped electronic interferometer with fractional filling of a Landau level were investigated. For occupation numbers $0.6<\nu<1$ the Aharonov–Bohm oscillations, which correspond to the quantization of the magnetic flux through the ring area, were observed in some narrow ranges of the magnetic field. These oscillations were not observed near $\nu=1/2$. © *1995 American Institute of Physics.*

The theory of "composite fermions,"[1–3] which gives a simple and clear picture of the fractional quantum Hall effect (FQHE), is now at a stage of intensive experimental verification. The basic idea of the theory is that the behavior of a two-dimensional electron gas with fractional occupancy of the Landau level can be described as a gas of noninteracting quasiparticles with the corresponding quasiclassical behavior. Many elegant experiments have now confirmed this idea.[4–6] As soon as the "composite fermions" become a gas of noninteracting particles, they must interfere similarly to electrons. In particular, an Aharonov–Bohm effect should exist on "composite fermions" in a ring structure.[7] However, experimental studies of quantum interferometers under conditions of fractional filling of a Landau level have still not been performed.

In the present letter we report the results of an experimental study of a ring-shaped electronic interferometer under the conditions of fractional occupancy of a Landau level. For occupancies in the range $0.6<\nu<1$ the Aharonov–Bohm oscillations were observed in a narrow range of magnetic fields. It was shown that these oscillations are a consequence of the interference of edge current states. It was determined that no Aharonov–Bohm oscillations occur at or near $\nu=0.5$.

The samples investigated by us consisted of ring-shaped interferometers which were fabricated on the basis of a high-mobility, two-dimensional electron gas in the heterojunction AlGaAs/GaAs with electron density $n_s=(3-3.5)\times 10^{11}$ cm^{-2} and electron mobility $\mu=(6-7)\times 10^5$ cm^2/(V·s) by means of electronic lithography followed by plasma-chemical etching. The measurements were performed on two interferometers, each with the same initial inner diameter $d_{\rm in}=0.2$ μm, but different outer diameters $d_{\rm out}=0.8$ μm (sample 1) and 1 μm (sample 2).

The experiment was performed at temperatures $T<50$ mK in magnetic fields of up to 13 T. The experimental sample consisted of a Hall bridge with the width $W=50$

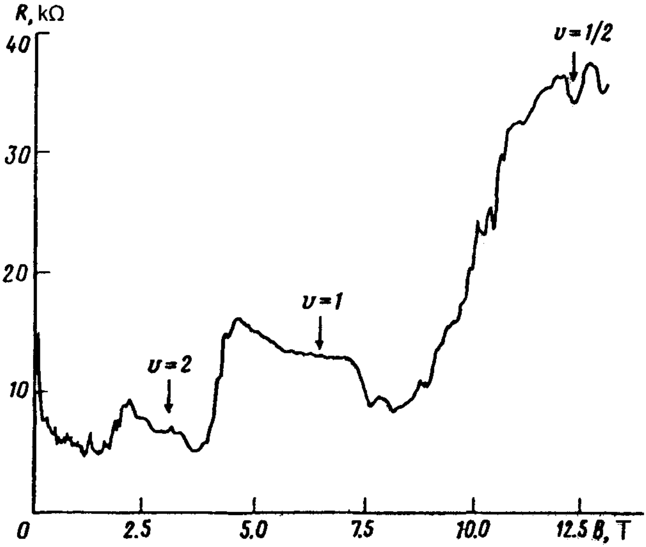

FIG. 1. Behavior of the magnetoresistance $R(B)$ of an interferometer in the entire range of magnetic fields.

μm and spacing $L=100$ μm between the potentiometric contacts. A ring-shaped interferometer was placed in the central part of the bridge.

The resistance R of sample 1 as a function of the magnetic field B in the entire experimental range from $B=0$ T up to $B=13$ T is shown in Fig. 1. As one can see from this figure, negative magnetoresistance is observed in weak magnetic fields and the standard, for a ring-shaped interferometer, Aharonov–Bohm oscillations corresponding to quantization of the magnetic flux with flux quantum $\Phi_0=h/e$ through an area of $\pi d^2/4$, where $d=0.6$ μm is the effective diameter of the interferometer, occur against the background of the negative magnetoresistance (a more detailed view of the dependence is shown in Fig. 2a). In strong magnetic fields, which correspond to the conditions of the quantum Hall effect, we see plateaus on the curves described by us. These plateaus appear as a result of the presence of a barrier between the entrance into the interferometer and the macroscopic part of the sample. In this case the magnitude of the resistance R_L in the region of the plateau makes it possible to determine the number of edge states (and, correspondingly, the value of ν) inside and outside the interferometer from the expression $R_L=(h^2/e)(1/N_{\text{int}}-1/N_{\text{wide}})$, where N_{int} is the number of edge states inside the interferometer, and N_{wide} is the number of edge states in the macroscopic part of the sample. We thus find that the first plateau corresponds to $N_{\text{int}}=2$ and $N_{\text{wide}}=4$ and the second plateau corresponds to $N_{\text{int}}=1$ and $N_{\text{wide}}=2$. Therefore, a transition to $\nu<1$ occurs in the interferometer in fields $B>8$ T. Figure 2b shows the function $R(B)$ for the occupancies in the range $0.6<\nu<0.65$. As one can see from these figures and by comparing them to Fig. 2a, the Aharonov–Bohm oscillations (which exist in a narrow range of magnetic fields), whose period is equal to that of the standard Aharonov–Bohm oscillations, are observed in the region of fractional occupancy of the Landau level. The behavior of $R(B)$ near

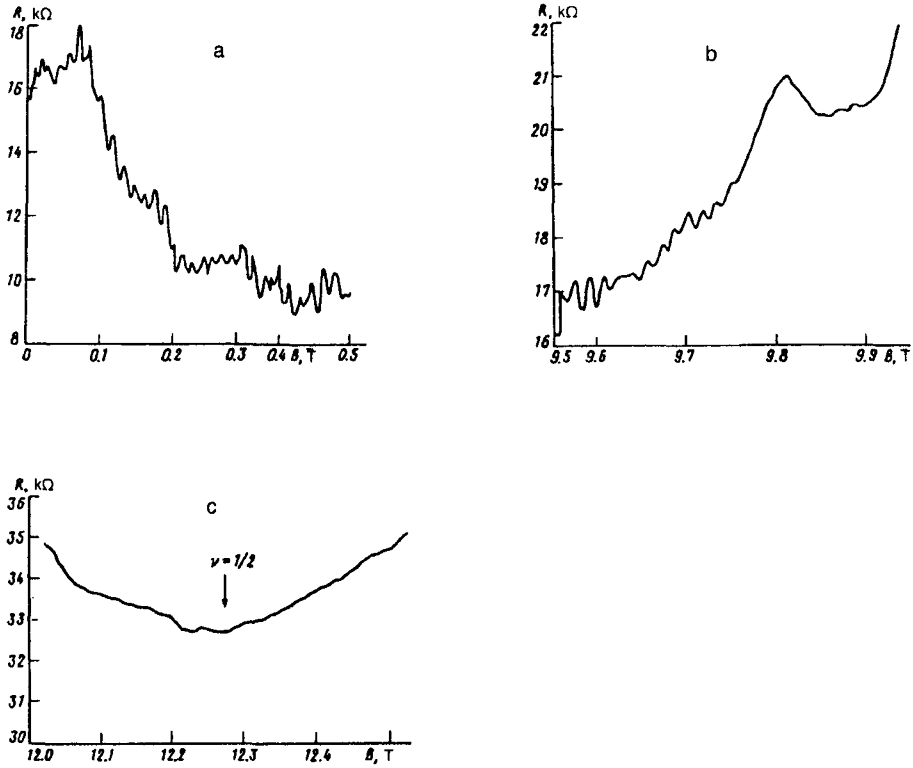

FIG. 2. a—The $R(B)$ curve for weak magnetic fields; b—$R(B)$ for $0.6<\nu<0.65$; c—$R(B)$ near $\nu=0.5$.

$\nu=1/2$ is most interesting from the standpoint of the concept of "composite fermions." Figure 2c shows the plot of the resistance as a function of the magnetic field for this occupation number. It is obvious that there are no magnetoresistance oscillations.

Let us now discuss the results which we obtained. The behavior of the Aharonov–Bohm oscillations in Fig. 2b (strong dependence of the amplitude on the magnetic field, appearance of oscillations in a narrow range of magnetic fields) indicates that these oscillations are a consequence of the interference of tunneling-coupled edge current states previously observed in the region[8] $\nu>1$. This assumption has been confirmed by experiments with illumination and application of a strong electric field pulse (10^4 V/cm). The point is that the actions indicated, which leave the electron concentration virtually unchanged, either increase (illumination) or decrease (strong electric field pulse) the effective width W of the conducting channels in the interferometer. The results of the experiments described show that oscillations with $\nu<1$ vanish completely after illumination and reappear, but in different ranges of the magnetic field, after the application of the electric field pulse. We note that at $\nu=1/2$, there were no Aharonov–Bohm oscillations for any situations. The interference of the edge current states appears as a result of the existence of tunneling between these states at the locations where the interferometer channels become narrower.[8] The probability of a tunneling transition is an exponential function of the channel width at these locations. Hence it is obvious that even a small increase in the width of the conducting channels can completely suppress the tunneling coupling between the edge states and, correspondingly, their interference and vice versa. Which interfering edge states are responsible for the experimentally observed Aharonov–Bohm oscillations? Since the oscillations shown in Fig. 2b appear in the region $0.6<n<0.65$, they could be due to edge states with $N_{int}=2/3$. In the present work, however, we did not observe a plateau corresponding to $\nu=2/3$, apparently because of the relatively low mobility of the electrons in the interferometer. It cannot be ruled out, therefore, that the observed oscillations are due to the interference of edge states with $N_{int}=1$ or, more likely, a mixture of edge states with $N_{int}=1$ and $N_{int}=2/3$. It should be noted that such oscillations were evidently recently observed in a system with two close-lying point contacts.[9]

As we have noted above, the region of magnetic fields near half-occupancy of a Landau level is of special interest. The observation of Aharonov–Bohm oscillations in this region of magnetic fields would be convincing evidence of the adequacy of the interference properties of electrons near zero magnetic field and "composite fermions" near $\nu=1/2$. As Fig.2c shows, however, there are no magnetoresistance oscillations under these conditions. This result could be attributed to the strong influence of the fluctuation potential or it could be due to more profound reasons. The solution of this problem requires further experimental studies, especially with samples with a higher mobility.

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