Anomalies of the boundary potential of a 2*D* electron system under Hall quantization conditions

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In the absence of a steady current in the measuring circuit, the equipotential state of the internal and external contacts of a MIS structure is disrupted under conditions corresponding to the Hall resistance quantization. The MIS structure is arranged in the Corbino geometry. Under steady-state conditions this "topological" potential difference does not change after short-circuiting of the contacts is lifted.

The development of conceptual understanding of the nature of the quantum Hall effect has shown that the electronic states at the boundaries of the system have an important function. Specifically, the charge exchange of these states accounts for the Hall potential difference when the current flows along the dissipation-free paths.[1] In a multiply connected 2*D* electron system with internal boundaries, one must consider the charge redistribution between these boundaries. We know that when the Fermi level in the "bulk" of a 2*D* system is situated in the gap between the allowed states at the Landau levels, the longitudinal conductivity of the system tends to zero. This circumstance may lead to the "freezing-in" of the charge and hence the potential at the internal boundary states.

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We have attempted to detect this effect. The electrometric and potentiometric measurements of the potential difference U between the internal and external contacts of an MIS structure were carried out in the Corbino geometry.

The structures were synthesized at the (100) surface of a p-type silicon with a resistivity of $\approx 10\ \Omega\cdot$cm. The thickness of the insulator was $d \cong 40$ nm. The mobility of electrons in the inversion layer was determined from the measurements of the Hall structure. At $T = 4.2$ K this mobility was $(3\text{–}5)\times 10^3$ cm^2/(V·s) for $N_s \cong 5\times 10^{11}$ cm^{-2}. The bulk of the experiments was carried out in a water-cooled Bitter magnet at $T = 1.6\text{–}1.5$ K. For the electrometric measurements we used a TR-2501 apparatus with an input resistance of $10^{12}\ \Omega$.

The dependence of U on the strength of the magnetic field B (up to 15 T) was studied at temperatures between 1.1 K and 1.5 K when there was no steady current flowing in the measuring circuit.

The qualitative behavior of the experimental curve for $U(B)$ is shown in Fig. 1 (the upper curve). The lower curve [the $\rho_{xx}(B)$ curve] was obtained by passing a current (while applying the same voltage to the gate) through the Hall sample mounted on the same crystal. The amplitude of the signal in fields $B \cong 10$ T was 80–600 μV, depending on the quality of the sample; the samples with higher carrier mobility in the channel had higher signal amplitudes. The trace of a more frequently encountered shape of the signal is shown in Fig. 1. Signals with a slightly deformed shape were observed in some experiments.

A comparison of the curves in Fig. 1 shows that the equipotential state of the internal and external contacts is disturbed near the minima of the longitudinal resistance and hence the minima of the longitudinal conductivity between the internal contact and the external contact of the Corbino disk. Similar results were obtained in a

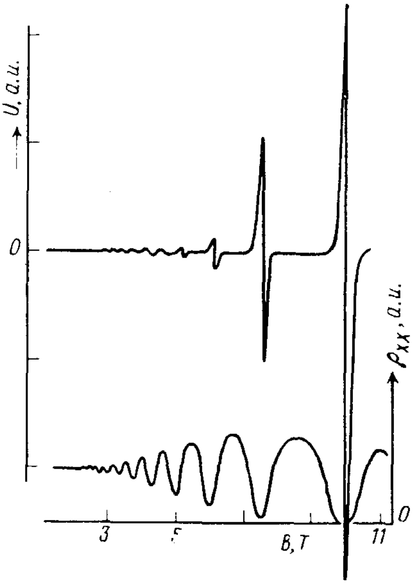

FIG. 1. Magnetic-field dependence (V_G = const) of the potential difference between the internal and external contacts of a Corbino disk in the absence of a steady current between them and the magnetic-field dependence of the longitudinal resistance of a 2D system (lower curve).

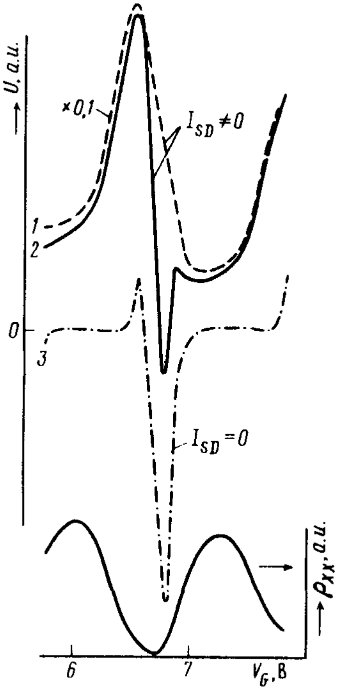

FIG. 2. The voltages between the external and internal contacts of a Corbino disk when a direct current is flowing between them (curves 1 and 2) in the presence of two currents differing by an order of magnitude and in the absence of a drawing current (curve 3) and of the longitudinal resistance of a $2D$ system as functions of the control voltage points ($B=\text{const}$).

constant magnetic field when we studied the effect as a function of the gate voltage (V_G), which determines the initial concentration of $2D$ electrons (the dot-dashed curve in Fig. 2).

In first approximation, the amplitude of the signal (U) is independent of the variation rate of the parameter (V_G, B); the amplitude remains constant for a long time (up to 30 min) in constant fields (V_G and B) corresponding to the maximum of the signal U. The observable signal is an even signal with respect to the direction of the magnetic field B and its polarity does not depend on the direction in which the parameter B (or V_G) is swept.

The following are the important (in our view) features of the effect which we observed:

- If the contacts are short-circuited to the sample through the external electrode or through a shunt resistor under steady-state conditions (B and $V_G=\text{const}$), and then the short-circuiting is removed, the signal and its correct polarity will be restored.

- The plot of the magnitude of the effect as a function of the drawing current does not have a clearly defined threshold, as illustrated in Fig. 2 which shows the results of the measurements of the voltage (U) between the external contact and the internal contact of the Corbino disk when a direct current I_{sd} flows between them. At a reasonably high current, the $U(V_G)$ curve (the dashed curve in Fig. 2) is qualitatively different from the curve at $I_{sd}=0$ (the dot-dashed curve). As the measuring current is decreased (by increasing the ballast resistance in the current circuit), the $U(V_G)$

curves begin to exhibit features which are caused by the boundary-potential anomalies and which apparently appear additively in the net potential difference.

To eliminate the possible influence of low-frequency oscillations of the magnetic field (characteristic of the Bitter magnet) on the effect under study, we carried out a series of control experiments using a NbTi solenoid in magnetic fields up to 5 T at $T = 1.2$–1.0 K. These experiments have confirmed the results obtained by us in the resistive magnet.

In a field transistor the potential of one of the contacts relative to the gate is always set by the control voltage supply and is equal to V_G. The short-circuiting action of the "channel" of the MIS structure accounts for the fact that the potentials of the other ohmic contacts also are equal to V_G in a zero magnetic field and in the absence of the flow of current through the structure. In strong magnetic fields the energy spectrum of a $2D$ system becomes discrete. Under these conditions the nature of the interaction of a $2D$ conducting system with $3D$ contacts may change. The disruption of the equipotential state of the internal and external contacts of the MIS structure of ring-shaped geometry, in which there are no edge-state short-circuiting effects, is evidence of the importance of the interaction of $3D$ contacts with a $2D$ system, which may lead to a change in the charge state of the $2D$ system under conditions corresponding to the quantum Hall effect.

In several theoretical studies[2] it was indicated that a domain instability of a homogeneous state of a $2D$ system can be developed under conditions corresponding to the quantum Hall effect. According to these studies, electric fields are localized in the domain walls which divide the regions of Landau levels with different occupation numbers. The symmetry of the Corbino disk allows the formation of a domain wall around the internal contact and the system in this case acquires a "built-in" topological potential. The results which we obtained in our experiment is quite likely associated with the formation of a domain structure of this sort.

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