The flow of current between adjacent inversion layers in a quantizing magnetic field

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The quantum Hall effect was studied for the first time in a special silicon MIS structure with two field electrodes separated by an ~500-Å-thick insulating film. A rule which describes the flow of current through a boundary between two ideal Hall conductors and which makes it possible to calculate any connection of such conductors is formulated.

We studied the flow of current through a boundary between two electronic layers at the surface of silicon in a quantizing magnetic field. Such a boundary has a potential relief, whose "height" depends on the difference in the electron densities of the layers. Since in a strong magnetic field the electrons move along the equipotential surfaces, the potential relief should hinder the flow of electrons from one layer to the next. If the transition between the layers is (as in our case) reasonably rapid (i.e., the change in the potential along the magnetic length is comparable to $\hbar\omega_c$), the boundary region generally would not be described by the local electrical-conductivity tensor. A theory which can describe the flow of current in this situation has so far not been formulated.

The measurements were carried out with use of a special silicon MIS structure with two field electrodes (gates) separated by a 500-Å-thick insulating film (SiO_2). The gate insulators (SiO_2) were 740 Å and 520 Å thick. With the use of gates we were able to set up independently two inversion channels (spaced ~500 Å apart) with the desirable electron densities. The inset in Fig. 1 shows the topology of the MIS structure. This topology enabled us to study the properties of each $2D$ channel separately and the flow of current from one channel to the next. Figure 1 shows the results of measurements of the components of the magnetoresistance tensor, ρ_{xx} and ρ_{xy}, for

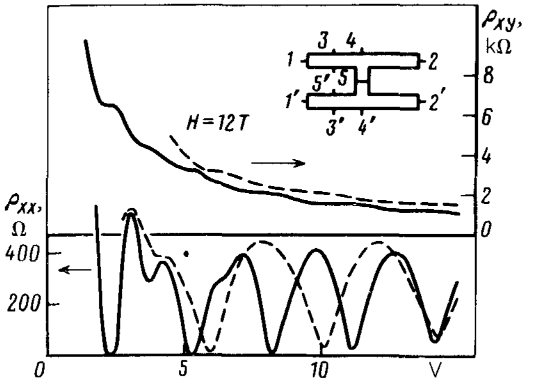

FIG. 1. The components of the magnetoresistance tensor ρ_{xy} and ρ_{xx} versus the gate voltage. Solid curves—for the first channel (a 1-μA current is transmitted through contacts 1 and 2); dashed curves—for the second channel (current contacts—1′ and 2′), $T = 1.9$ K.

each layer. The electron mobility in the layers was $\sim 3\times 10^3$ cm^2/(V·s). The complex technology required for the fabrication of two-gate MIS structures is responsible for the not too high mobility. In the analysis of the flow of current through the boundary between the channels, the voltage accross the second gate was set at such a level that an integral number of Landau levels would be filled in the corresponding channel and the voltage across the first gate would vary. The current was transmitted through contacts 1 and 1′ (the inset in Fig. 1) and the voltage across contacts 2 and 2′ was measured ($\Delta U_{2,2'}$). These contacts are on the right side (with respect to the current) of the channels. The plot of $\Delta U_{2,2'}$ versus the voltage (V) across the first gate is shown in Fig. 2 (the solid curve). The contacts 2 and 2′ were then used as current contacts (here the direction and magnitude of the current flow between the channels were constant) and contacts 1 and 1′ were used as potential contacts (the dashed curve in Fig. 2 corresponds to $\Delta U_{1,1'}$). The potential contacts were then placed on the left side (with respect to the current) of the channels. A change in the direction of the magnetic field caused the curves in Fig. 2 to exchange places. Let us examine those voltages on the first gate which correspond to the conditions under which there is a quantum Hall effect. We see that when the conditions in both channels correspond to the quantum Hall effect, so that the Hall resistance of the first channel (R_1) is higher than the Hall resistance of the second channel (R_2) ($V = 2.4$ V, Fig. 2), $\Delta U_{2,2'} \approx I(R_1 - R_2)$ and $\Delta U_{1,1'} \approx 0$ [the values $\Delta U = I(R_2 - R_1)$ are denoted by bars]. The Hall resis-

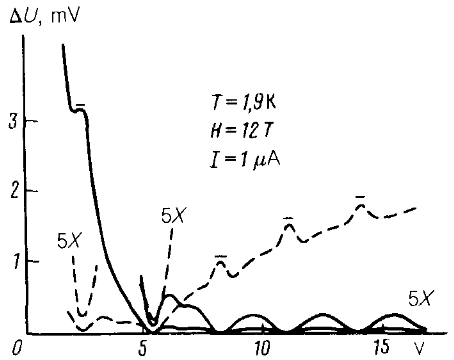

FIG. 2. The voltages $\Delta U_{2,2'}$ and $\Delta U_{1,1'}$ (see the text proper) versus the voltage across the first gate. Solid curve—$\Delta U_{2,2'}$; dashed curve—$\Delta U_{1,1'}$. The symbol 5X—fragments of corresponding curves blown up five times.

tance of the first channel R_1 decreases (R_2 is constant) as the voltage on the first gate is increased, and when the first channel is again under conditions corresponding to the quantum Hall effect, we have $\Delta U_{2,2'} \approx 0$ and $\Delta U_{1,1'} \cong I(R_2 - R_1)$, where now $R_2 > R_1$. With $R_1 = R_2$ ($V \approx 5.3$ V) we have, as expected, $\Delta U_{1,1'} = \Delta U_{2,2'} = 0$. The accuracy of the relations given above improves with decreasing ρ_{xx} and hence with decreasing distance between the layers and the ideal Hall conductors. Let us summarize the results which we obtained. When two ideal Hall conductors are connected in series, the potential on one side of the channels remains constant after crossing the boundary between the channels and the potential on the other side changes abruptly by an amount equal to the difference in the Hall voltages of the channels. The side on which the potential changes abruptly can be determined by applying the following rule. We introduce an auxiliary vector $\vec{\mu}$ which lies in the plane of the ideal Hall conductors and which is directed perpendicular to the boundary between them toward the region with a higher Hall resistance. The vector $[\vec{\mu}\mathbf{H}]$ (which is directed along the interface) will then indicate the side of the channels on which the potential changes abruptly. Several papers in which such topics have been discussed were published previously.[1-3] Stiles *et al.*[1,2] studied the flow of current between a metallic electrode and a 2*D* channel[1] and between two 2*D* channels.[2] Syphers and Stiles[2] reached the same conclusions as we have in the present study. They used an MIS structure with a single field electrode and a gate insulator consisting of two regions of different thicknesses. Such a structure is not nearly as useful in studying the interaction between ideal Hall conductors as a two-gate structure, since it does not allow the carrier densities to be changed independently in 2*D* channels. Syphers and Stiles,[2] however, were able to choose a gate voltage and a magnetic field in such a way that the quantum Hall effect would appear in both layers. The MIS structure which we have used has enabled us to demonstrate more covincingly the validity of our conclusions. Bruls *et al.*[3] studied the flow of current across the boundary between two metallic films of different thicknesses. They found the potential drop to be different on the opposite sides of the film on passing through the interface between the films.

The use of the rule which we formulated (along with the rule which describes the flow of current between the metallic contact and the ideal Hall conductors[1]) makes it possible to calculate any connection of ideal Hall conductors. In particular, it can be shown that when two ideal Hall conductors are connected in series, the total resistance is equal to the larger Hall resistance and when two ideal Hall conductors are connected in parallel, the total resistance is equal to the smaller resistance.

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