Investigation of the form of the plateau in the quantum Hall resistance in a two-dimensional layer of carriers in silicon

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The form of the plateau in the Hall resistance is studied in two-dimensional layers of carriers in silicon metal–insulator–semiconductor structures for relative deviations $\delta = 10^{-6}$–10^{-2}. It is found that the width of the plateau depends logarithmically on the deviation δ and linearly on the temperature.

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Up to now, there has been no experimental information on the current and temperature dependence of the form of the plateau in the Hall resistance,[1] which is required to verify different theoretical models[2] of the quantum Hall effect (QHE).[1] In this work, we investigated the form of the plateau in the Hall component of the resistance tensor ρ_{xy} of a two-dimensional layer of carriers while varying the gate voltage V_g of the silicon MIS structure. Measurements of ρ_{xy} were performed in the range of relative deviations $\Delta\rho_{xy}/\rho_{xy} = 10^{-6}$–$10^{-2}$ near the value[1] $\rho_{xy} = h/ie^2 = 6453.20\ \Omega$, corresponding to a single four-fold ($i = 1$) split Landau level filled completely by carriers.

The specimens consisted of metal–insulator–semiconductor structures with an n-type inversion channel, prepared on the (100) surface of p-type Si. Two pairs of voltage electrodes were placed on both sides of the rectangular channel. Two types of specimens were investigated: specimens with a small channel area ($500 \times 50\ \mu m^2$), insulator thickness of 2000 Å, and mobility at maximum $\mu^{max} \approx 1 \times 10^4$ cm^2/V s (Ref. 3) and specimens with a large channel area ($1200 \times 400\ \mu m^2$), insulator thickness of 1300 Å, and mobility $\mu^{max} \approx 1.5 \times 10^4$ cm^2/V s. All measurements were performed in a magnetic field of 80 kOe. For values of V_g, corresponding to the plateau in ρ_{xy}, the component ρ_{xx} was a factor $\sim 10^5$ (at $T = 0.4$ K) smaller than in the absence of the magnetic field.

Reproducibility of the form of the plateau. It is known that the form of the plateau in ρ_{xy} at the level $\Delta\rho_{xy}/\rho_{xy} \lesssim 10^{-5}$ generally is not reproducible from one experiment to another and depends on the past history of the specimen[4]; however, it does remain constant throughout a single low-temperature experiment. Nevertheless, we were able to obtain repeatedly a state of the specimens which we refer to below as the "equilibrium" state. This state is characterized by the following properties: a) symmetry of the distribution of voltages on the contacts of the specimen relative to the center of the specimen; b) maximum value of the mobility μ and minimum threshold voltage $|V_{th}|$, as well as the constancy of these values over the specimen; c) coincidence of the V_g position of the plateau in ρ_{xy} and minima ρ_{xx}^{min}, measured in different sections of the specimen. In the equilibrium state, ρ_{xy} at the center of the plateau is constant to within $\Delta\rho_{xy}/\rho_{xy} \leqslant 10^{-5}$ (Fig. 1) and the dependence of the form of the plateau on different parameters is repeated qualitatively from one experiment to another and for different specimens, while the variation in $|V_{th}|$ from one experiment to another is $\leqslant 0.2$ V.

The nonreproducibility of the form of the plateau in $\rho_{xy}(V_g)$ can be attributed to variations in the distribution and amplitude of voltage fluctuations in the two-dimensional layer of carriers. The equilibrium state corresponds to minimum amplitude and a uniform distribution of voltage fluctuations, which is probably achieved when the

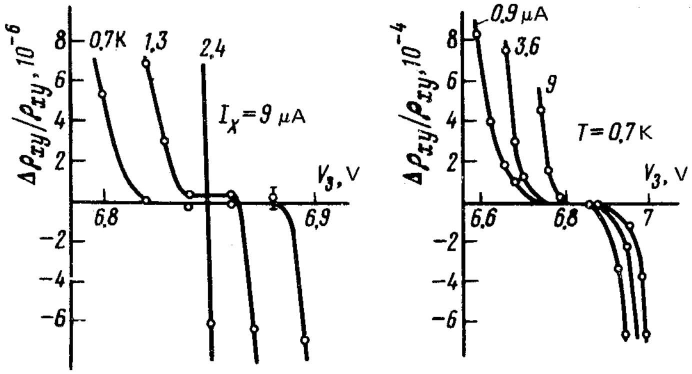

FIG. 1. Typical form of the plateau in ρ_{xy} ($i = 4$) for a specimen with channel area $1200 \times 400\ \mu m^2$: a) for different temperatures T; b) for different currents I_x.

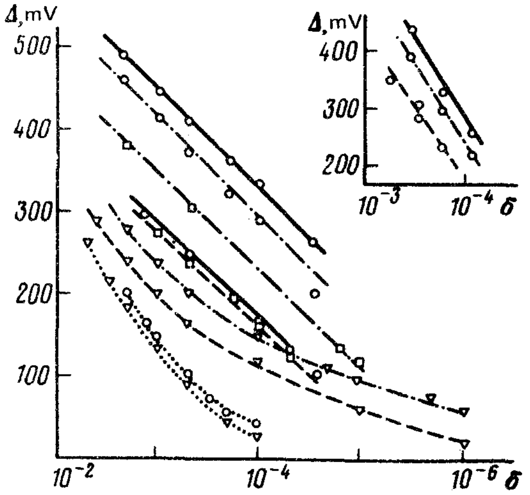

FIG. 2. Plateau width Δ as a function of the modulus of the fixed deviation δ: ○ — $I_x = 0.9\ \mu A$, □ — $3.6\ \mu A$, ∇ — $9\ \mu A$; solid lines are for $T = 0.4$ K; dot-dashed lines are for 0.68 K; dashed lines are for 1.3 K; and, the dotted lines are for 2.36 K.

carriers fill all traps on the Si/SiO_2 interface. In the nonequilibrium state, properties (a)–(c) are missing; the value of $\rho_{xx}^{\min}$ increases sharply at the same time (for example, from $8\times 10^{-3}\ \Omega$ to $\sim 1\ \Omega$ at $T = 0.4$ K) and, as a rule, a nonmonotonic dependence of $\rho_{xy}(V_g)$ appears in the region of the plateau.

Form of the plateau. The width Δ, measured at a fixed relative deviation δ of the Hall resistance ρ_{xy} from the reference value, taken as the value of ρ_{xy} at the center of the plateau at $T = 0.7$ K and with $I_x = 9\ \mu A$, was chosen as a quantitative measure of the form of the plateau. The dependence of the width of the plateau on δ is shown in Fig. 2 for different values of the current I_x and temperatures T. The family of curves in the figure was constructed for a specimen with a large channel area; the data in the insert are for specimens with small channel area.

This dependence is logarithmic over a fairly wide range of deviations δ, currents, and temperatures. In addition, as is evident from Fig. 2, the slope of the corresponding straight lines is independent of the temperature and current. The region of high temperatures $T = 2.4$ K and high currents $I_x \geqslant 9\ \mu A$, where the logarithmic dependence, if it exists at all, exists over a much smaller range δ, is an exception. Under the same conditions, the temperature dependence of the width of the plateau is nearly linear (Fig. 3), while $\Delta\rho_{xy} \propto \rho_{xx}$.

It follows from Figs. 2 and 3 that the relation between the width of the plateau, the temperature, and the relative deviation of the resistance has the form

$$\Delta = f(T) + B\ \ln\delta\ . \tag{1}$$

Such a dependence cannot be explained by the model with isolated carrier bound states in short-range voltage fluctuations[2,5] and by the activation mechanism for conductivity.[6,7] From this model, which is often used to obtain a qualitative explanation of

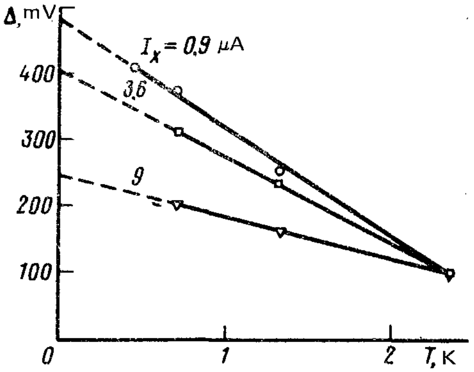

FIG. 3. Plateau width Δ (for deviation $\delta = 5\times10^{-4}$) as a function of temperature for a specimen with large channel area.

QHE,[5–7] it follows that the dependence of the width of the plateau must have a different form:

$$\Delta = A + T^{\alpha}\ln\delta,$$

where A is a constant; $\alpha = 1$ or 1/3, depending on the conductivity mechanism.[2]

To make quantitative refinements in relation (1) and to develop a different model, it is necessary to perform measurements at high currents and with better voltage resolution ($\lesssim$ 10 nV), as well as to establish the magnetic field dependence.

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