Decay of magnetoplasma oscillations in 2D electron channel under quantum-Hall-effect conditions

S. A. Govorkov, M. I. Reznikov, B. K. Medvedev, V. G. Mokerov,
A. P. Senichkin, and V. I. Tal'yanskiĭ
Institute of Solid State Physics, Academy of Sciences of the USSR; Institute of Problems of the Technology of Microelectronics and Especially Pure Substances, Academy of Sciences of the USSR

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The linewidth of magnetoplasma oscillations in a 2D channel in a GaAs-AlGaAs heterostructure has been measured in a transverse magnetic field corresponding to a quantized value of the Hall conductivity $[\sigma_{xy} = e^2 i/h = (12.9\ \mathrm{k}\Omega)^{-1}, i = 2]$.

Magnetoplasma oscillations or, more precisely, edge magnetoplasma oscillations in 2D electron channels have recently become the subject of active experimental and theoretical research.[1–6] It has been shown[6] that magnetoplasma oscillations can be observed in GaAs-AlGaAs heterostructures at low frequencies (10^8–10^9 Hz). It is natural to suggest that at low frequencies the electrical conductivity of a 2D channel is the same as the dc conductivity, in which case we know[7] that a dissipationless current flow is possible (a quantum Hall effect). We are thus led to the question of the decay

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of magnetoplasma oscillations under conditions of the quantum Hall effect. In the present letter we report an experimental resolution of this question.

The test samples are GaAs-AlGaAs samples with dimensions of 3×3 mm, with a carrier mobility and density at 4.2 K of 10^5 cm^2/(V·s) and $\sim 2\times10^{11}$ cm^{-2}, respectively. The samples are held in a tunable (in the range 200–300 MHz) feed-through microwave resonator. The microwave electric field is directed along the 2D channel, and the static magnetic field is directed perpendicular to it. We measure the amplitude of the microwave transmitted through the resonator, $A(B,\omega)$, at various values of the magnetic field B and of the frequency of the microwave field, ω. All the measurements are taken at 4.2 K.

If the source frequency coincides with the resonator frequency (and this condition was satisfied throughout these measurements), we have[8]

$$A(B,\omega)\sim A_0 Q_L \tag{1}$$

where A_0 is the amplitude of the incident wave, Q_L is the loaded quality factor of the resonator with the sample, and the proportionality factor depends on neither B nor ω. If the energy loss in the resonator is determined primarily by the sample [i.e., if the relation $A(B,\omega)\ll A(B=0,\omega)$ holds], then (1) reduces to $A(B,\omega)\sim A_0\Pi^{-1}(B,\omega)$. The function $\Pi(B,\omega)$ may be interpreted as the power drawn by the sample from an electric field of constant amplitude and frequency ω. For values of ω near the resonant frequency of the magnetoplasma oscillations, $\omega_0(B)$, the function $\Pi(B,\omega)$ is of a resonant nature and contains essentially comprehensive information on the magnetoplasma oscillations. If we approximate the 2D channel by a conducting oblate ellipsoid,[5] the resonant frequency of the simplest magnetoplasma oscillation is determined by the component σ_{xy}, and linewidth is determined by the component σ_{xx}:

$$\omega_0=\frac{\pi^2\,\sigma_{xy}(B)}{a};\quad \frac{\Delta\omega}{\omega_0}=\frac{2\,\sigma_{xx}(B)}{\sigma_{xy}(B)};\quad \Pi(B,\omega=\omega_0)\sim\sigma_{xx}^{-1}(B), \tag{2}$$

where a is the diameter of the sample. In the present experiments we made a detailed study of the magnetoplasma oscillations at values of B(~ 6.5 T for the particular sample used) which correspond to the quantized value $\sigma_{xy}=2e^2/h=(12.9\ \mathrm{k}\Omega)^{-1}$. For this value of σ_{xy} we find from (2) the value $\omega_0\sim 2\pi\times3\times10^8$ s^{-1} or $f_0\sim 300$ MHz.

We turn now to a description of the results of the measurements. Figures 1 and 2 show curves of $A(B)$ measured at various fixed values of ω. At $B\lesssim 4$ T we see Shubnikov–de Haas oscillations on the curves, and all the curves are essentially identical. At $B>4$ T, there is a "dip" corresponding to an increase in the energy absorption by the sample. This dip results from the excitation of magnetoplasma oscillations in the sample, and the minimum on the $A(B)$ curve (for some value of ω) is reached when B satisfies the condition

$$\omega_0(B)=\omega\ . \tag{3}$$

Since ω_0 is a decreasing function of B [see (2)], the dip shifts up the B scale with decreasing ω. The curves in Figs. 1 and 2 have some important features: 1) The

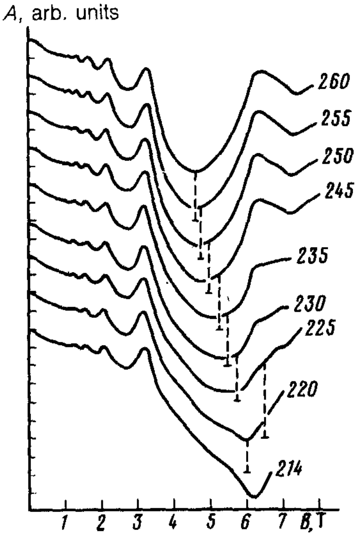

FIG. 1. Curves of $A(B)$ (see the text proper for an explanation). The curves are labeled with the measurement frequency, in megahertz. For clarity, the curves have been displaced along the vertical (without any change in scale). The vertical dashed line and the short horizontal bar show the position of the horizontal axis for each curve.

minimum value of A is observed at $\omega \sim 214$ MHz and $B \sim 6.5$ T. 2) The shape of the $A(B)$ curves in the field interval $B \sim 6$–7 T changes markedly upon slight changes in ω near 214 MHz. Each of these features can be explained in a natural way by expressions (2). The value $B = 6.5$ T corresponds to the quantum Hall effect and to a minimum value of σ_{xx}. As a result [according to (2)], there is a strong absorption, and the width of the magnetoplasma oscillation line is small (and thus the ω dependence of the absorption is strong). It thus follows from the curves in Figs. 1 and 2 that the quantized value $\sigma_{xy} = 2e^2/h$ corresponds to the magnetoplasma-oscillation frequency

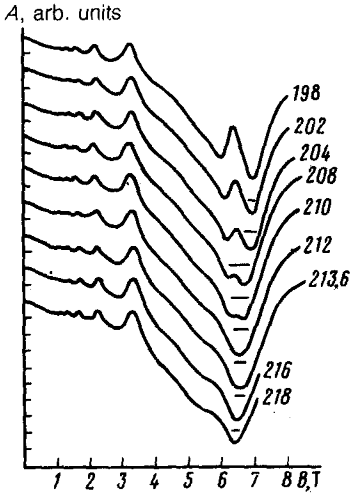

FIG. 2. The same as in Fig. 1.

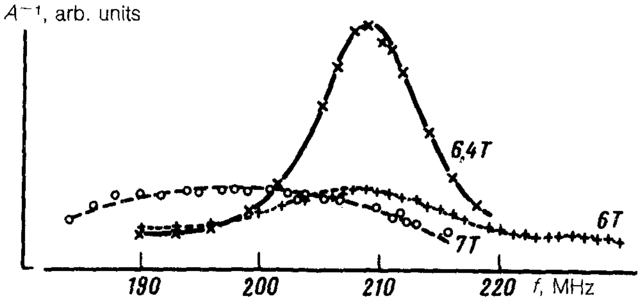

FIG. 3. Curves of $A^{-1}(f)$ for various values of B.

$f_0 \cong 214$ MHz. The difference between this value and that calculated from (2) ($f_0 = 300$ MHz) might have several causes: the approximate nature of expression (2) for ω_0 and a depolarizing effect of the GaAs substrate and the resonator walls (a corresponding question for edge plasmons is discussed in Ref. 9). Figure 3 shows the measured dependence $A^{-1}(\omega) \sim \Pi(\omega)$ for certain fixed values of B. We see that at $B \sim 6.5$ T the magnetoplasma oscillations are a weakly damped excitation: $\Delta\omega/\omega_0 \sim 1/20$. Slight changes in B lead to a broadening of the magnetoplasma oscillation line (apparently because of an increase in σ_{xx}). The linewidth found for the magnetoplasma oscillations ($\Delta f \sim 10$ MHz) under conditions of the quantum Hall effect is much larger than we would expect on the basis of (2) and the dc value of σ_{xx}. For the particular sample used, the minimum dc value of σ_{xx} under quantum-Hall-effect conditions is $\sim (1\Omega/\Box)^{-1}$. Substituting this value into (2), we find $\Delta\omega/\omega_0 \sim 10^{-4}$. The reason for this discrepancy is not clear at this point. It is possible that expression (2) is an overly crude approximation for estimating the width of the magnetoplasma oscillation band, but we cannot rule out the other possibility that the value of σ_{xx} at the measurement frequency is much larger than the dc value. Magnetoplasma oscillations under quantum-Hall-effect conditions were recently studied in Ref. 10. It was concluded in Ref. 10 that the linewidth of the magnetoplasma oscillations is determined by the component σ_{xy}. Our measurements do not agree with this conclusion: It can be seen from Fig. 3 that slight changes in B lead to a significant change in the decay of the magnetoplasma oscillations, although there is essentially no change in σ_{xy}. Furthermore, the linewidth found for the magnetoplasma oscillations in our study, $\Delta f \sim 10$ MHz is at least an order of magnitude smaller than the value found in Ref. 10. It is possible that the discrepancies in the results stem from the use of heterostructures differing in quality.

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