Magnetoplasma oscillations in a GaAs–AlGaAs heterostructure

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Magnetoplasma oscillations have been observed in a $2D$ electron channel in a GaAs–AlGaAs heterostructure. Oscillations of this nature have been observed previously in $2D$ channels only at the surface of liquid helium.

In this letter we are reporting a search for the natural oscillations of the Hall current in a $2D$ channel in a GaAs–AlGaAs heterostructure in a magnetic field which had been described in Ref. 1. The oscillations arise because under the condition $\sigma_{xy} \gg \sigma_{xx}$ (σ_{xy} and σ_{xx} are components of the electrical conductivity tensor of the $2D$ layer) the charge which arises at the boundary of the $2D$ layer causes Hall currents which in turn cause a motion of this charge along the boundary (and not a neutralization of it). From Ref. 1 we find an estimate of the natural frequency:

$$\omega \simeq 10\,\sigma_{xy} a^{-1} \qquad (1)$$

where a is a characteristic dimension of the sample. In a strong magnetic field ($\mu B > 1$, where μ is the mobility of the electrons in the $2D$ channel) we have $\sigma_{xy} \sim B^{-1}$ and $\omega \sim B^{-1} a^{-1}$. It should be noted that recent studies of $2D$ electrons at a liquid-helium surface[2,3] have revealed numerous peaks of resonant absorption in the range 1–50 MHz. The resonant frequencies of these peaks behaved in an unexpected manner: they decreased with increasing magnetic field. This effect was called a "dynamical Hall effect" in Ref. 2 and "edge magnetoplasmons" in Ref. 3. These names stress different aspects of the effect: the presence of a Hall current and a violation of electrical neutrality in the system. The theoretical description of Refs. 3 and 4 was constructed for a semi-infinite $2D$ layer and a metal half-plane oriented parallel to the $2D$ layer (this half-plane corresponded to the field electrode in the experiments of Refs. 2 and 3). It is difficult to apply that description to a $2D$ layer in a heterostructure because there is no field electrode and because the size of the sample is comparable to the length scale of the magnetoplasma oscillations. The problem can be approached in a different way. A bounded (ellipsoidal) superlattice was analyzed in Ref. 1. A very simple uniform oscillation was derived in Ref. 1 in the approximation in which the superlattice is described by an average electrical conductivity tensor. By generalizing the analysis of Ref. 1, we can show that a set of natural oscillations exists in bounded superlattices. It turns out that these oscillations are so similar to Walker modes[5] they can be called an "electrical" analog of Walker modes. The magnetoplasma oscillations can be calculated exactly in an oblate ellipsoid of revolution, and then the dimension (Δ) of the ellipsoid along the axis of revolution can be allowed to go to zero, as the electrical conductivity is increased by a factor of Δ^{-1}. In the limit, we find a disk-shaped 2D channel with a conductivity which falls off toward the edges of the disk in accordance with $\sigma(r) \sim [1-(r/a)^2]^{1/2}$, where a is the disk radius. In this manner we obtain a representation (which is only qualitative) of the oscillations in real heterostructures [with $\sigma(r) = \text{const}$], and we can estimate the natural frequencies in order of magnitude.

Let us describe the experiment. Expression (1) yields $f \sim 5\times10^8$ Hz for $\sigma_{xy} \sim (10\ \text{k}\Omega)^{-1}$ and $a \sim 3$–4 mm. We accordingly searched for the magnetoplasma oscillations in the frequency range 10^8–10^9 Hz. We used heterostructures with a mobility $\sim 10^5$ cm^2/(V·s) at 77 K and an electron density of 2.4×10^{11} or 5×10^{11} cm^{-2} (samples No. 1 and No. 2, respectively) in the 2D layer. The samples, which are rectangular with dimensions $\sim 3\times4$ mm, are placed in a transmission microwave resonator at an antinode of the electric field (with an amplitude ~ 5 mV/cm), so that the microwave electric field was directed along the surface of the sample, while the static magnetic field (B) was directed perpendicular to it. The resonator was connected by two coaxial lines to the source and a superheterodyne receiver.

We measured the amplitude (A) of the microwave signal transmitted through the resonator as a function of B. These measurements were taken at $T = 4.2$ and 2.2 K. For the resonator without a sample, the transmitted signal is essentially independent of the magnetic field. Figures 1 and 2 show the results of the measurements for two samples. Curve 1 in Fig. 1 was measured at a frequency of 388 MHz. We see that at a field ~ 3 T the absorption introduced into the resonator by the sample increases sharply. When the frequency is doubled (curve 2 in Fig. 1), the absorption peak is observed even at the other field value (half as strong). A similar pattern is observed for the second sample (Fig. 2). We can thus conclude that the strength of the resonant magnetic field (that which corresponds to the absorption peak) is inversely proportional to the measurement frequency. This is precisely the relation that follows from (1). Comparing the curves in Figs. 1 and 2, we conclude that the resonant fields are

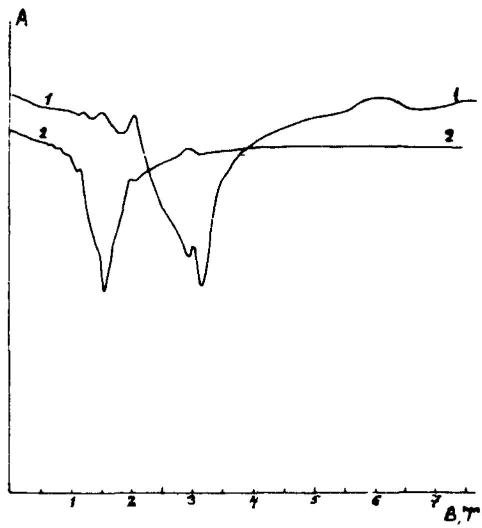

FIG. 1. Amplitude of the microwave signal transmitted through the resonator versus the magnetic field for sample No. 1. 1—$f = 388$ MHz; 2—$f = 765$ MHz. $T = 4.2$ K.

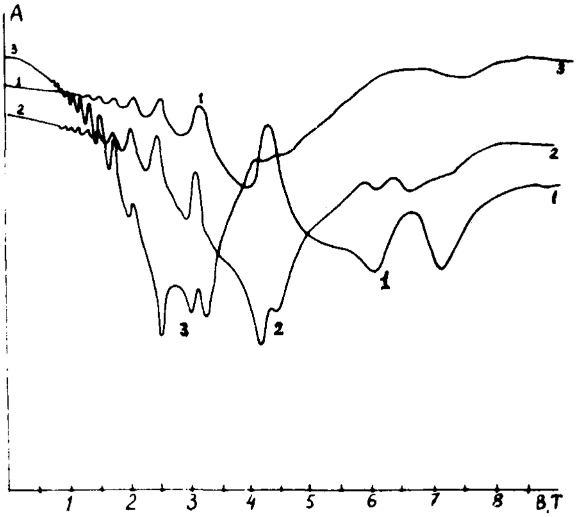

FIG. 2. The same as in Fig. 1, for sample No. 2. 1—f = 388 MHz; 2—f = 538 MHz; 3—$3f$ = 768 MHz. T = 2.2 K.

proportional to the carrier densities (and thus to the values of σ_{xy}) in the corresponding samples. As the dimensions of the sample are reduced, the resonant field increases, but we did not make a quantitative study of this dependence because of the small initial dimensions of the samples. We believe that these results warrant the conclusion that the absorption peaks arise because of the excitation of magnetoplasma oscillations in the sample when the strength of the magnetic field corresponds to the equality of the magnetoplasma-oscillation frequency and the frequency of the microwave field. Since the carriers in the $2D$ channel are degenerate, a change in B is accompanied by not only a change in the frequency of the magnetoplasma oscillations but also a modulation (due to Shubnikov–de Haas oscillations) of the damping. The shape of the curves (especially in Fig. 2) is thus distorted by Shubnikov–de Haas oscillations. It should be noted that a shunting conduction channel through the doped region of the AlGaAs may exist in GaAs–AlGaAs heterostructures.[6] The thickness of this region in our samples is on the order of 500 Å; the carrier mobility in it is $\sim 10^3$ cm^2/(V·s); and at fields up to $B \lesssim 10$ T the component σ_{xy} of the shunting channel is an increasing function of B. Since our measurements show that the frequency of the magnetoplasma oscillations has the behavior $\omega \sim B^{-1}$ (and $\sigma_{xy} \sim B^{-1}$ at $B > 0.1$ T for the $2D$ layer), we can conclude that the shunting channel does not affect the frequency of the magnetoplasma oscillations. However, it may determine the damping of the magnetoplasma oscillations.

In talking about "magnetoplasma oscillations" above we meant the simplest oscillation[1] having a dipole moment. Such an oscillation could be excited by a uniform microwave electric field, as has occurred in our case. In order to excite magnetoplasma oscillations of other types, it will be necessary to put the sample in a region in which the microwave field is very nonuniform.

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