Magnetoresistance oscillations in a 2D electron system with a periodic potential of antipoints

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(Submitted 5 August 1991)
Pis'ma Zh. Eksp. Teor. Fiz. **54**, No. 7, 369–372 (10 October 1991)

The magnetoresistance of a 2D electron gas in a superlattice of antipoints has been studied. Oscillations observed in weak magnetic fields occur because the Larmor radius is equal to the period of the superlattice. Two periods of the quantum oscillations are observed in strong fields.

Two-dimensional electron systems with a spatially modulated electron density have recently attracted interest. Extreme cases of these systems, with a 100% modulation, are (a) a system consisting of isolated points cut out of a plane of a 2D gas and (b) a system of antipoints, at which the density of the 2D electrons vanishes. A periodic lattice of antipoints produced in a system with a 2D electron gas has a superlattice potential of a unique type.[1–3] On the one hand, this is the infinitely strong repulsive potential of the antipoints themselves. On the other, it is a weakly modulated periodic potential which arises because of the rise of the barrier in the constriction region between antipoints. The combination of these two types of potentials can lead to such interesting phenomena as a binding of quantum points into molecules[2] and Aharonov–Bohm oscillations.[3] In the present study we have observed some new oscillations in the magnetoresistance. The behavior of these new oscillations is determined by an effect of the potential of the antipoints on the properties of the 2D electron gas.

A periodic lattice of antipoints was prepared by electron-beam lithography and reactive ion etching on GaAs/AlGaAs heterostructures.[4] For sample N1 the period of the lattice was $d = 1$ μm, and the diameter of the antipoints was $a = 0.3$ μm. The corresponding properties of sample N2 were $d = 0.8$ μm and $a = 2$ μm. The first sample was square. The second was a Hall microbridge, at which the antipoints covered part of the sample between the potential probes.

The introduction of the antipoints reduced the electron mobility in a zero magnetic field by a factor of 8 to 10 for structure N1, and by a factor of 12 for N2. The mobilities of these samples were 60×10^3 cm^2/(V·s) and 20×10^3 cm^2 (V·s), respectively. The mean free paths found from these values turned out to be slightly smaller than the distance between antipoints.

The samples were illuminated continuously by a red light-emitting diode during the measurements. The intensity of this illumination had a negligible effect on the

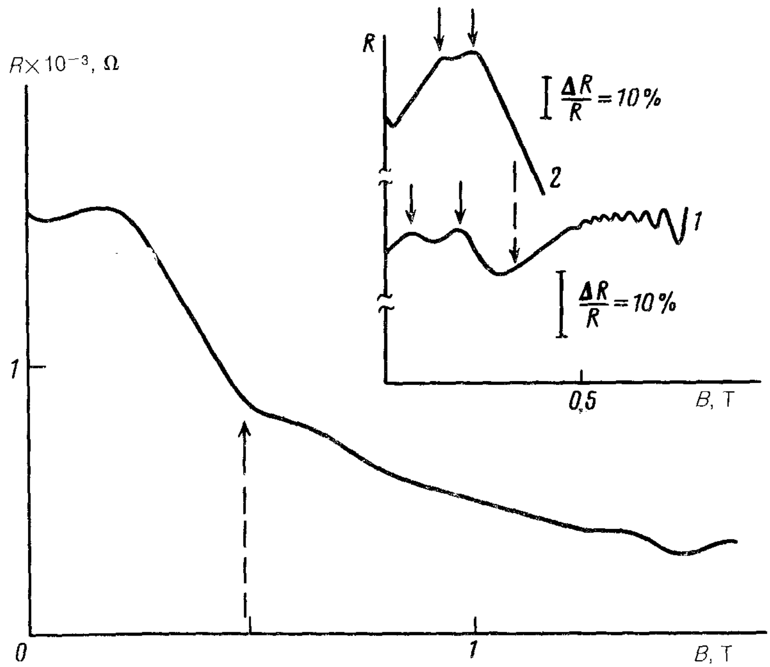

FIG. 1. Magnetoresistance of a sample with antipoints versus the magnetic field (structure N2, $T=1.3$ K). The inset shows the same curves at a higher sensitivity. 1—Structure N1; 2—N2. The solid arrows shows the maxima of the oscillations; the dashed arrows correspond to the change in slope on the curves.

electroresistance, but it significantly changed the shape of the curve in weak magnetic fields. There was a certain optimum illumination level for observing oscillations in weak magnetic fields.

Figure 1 shows the magnetoresistance of the samples in the weak-field region (below the point at which Shubnikov–de Haas oscillations arise). At $B<0.2$ T there are two oscillations, with maxima at positions corresponding to the level $2R_c = nd$, where R_c is the Larmor radius, and $n=1,2$ (see the inset in Fig. 1). Just recently, Weiss *et al.*[5] have observed similar oscillations. The region of a negative magnetoresistance observed on sample N2 may be due to a suppression of the backscattering of quasiballistic electrons in a magnetic field.[6] When the magnetic field reaches the value at which the condition $2R_c = d-a$ holds, the electron orbit becomes smaller than the distance between antipoints, and an electron localizes, tracing out rosette-shaped trajectories near an antipoint.[7] In this case we would expect an increase in the resistance of the sample with increasing magnetic field. The change in slope on the magnetoresistance curve for sample N2 in Fig. 1 can thus be attributed to that effect. Unfortunately, the size a is not known accurately, because of the depletion regions near the antipoints. However, if the suggestion made above is correct, this size can be found experimentally. An estimate from the formula $2R_c = d-a$ yields a value $a=0.34$ μm. Using the geometric size $a=0.2$ μm, we find the width of the depletion region to be $t=0.07$ μm. This value corresponds to data in the literature. Using this value, we can predict the position of the change in slope for sample N1. It is shown by the dashed arrow in the inset in Fig. 1.

This slope change on the magnetoresistance curve constitutes the first observation of a localization of electrons near an artificially produced scatterer. This observation opens up the possibility of studying electron localization in a system of scatterers with controllable parameters.

With further increase in the magnetic field, we find the usual Shubnikov–de Haas oscillations, but at $B > 1.5$ T some new oscillations appear (Fig. 2), with a second, and

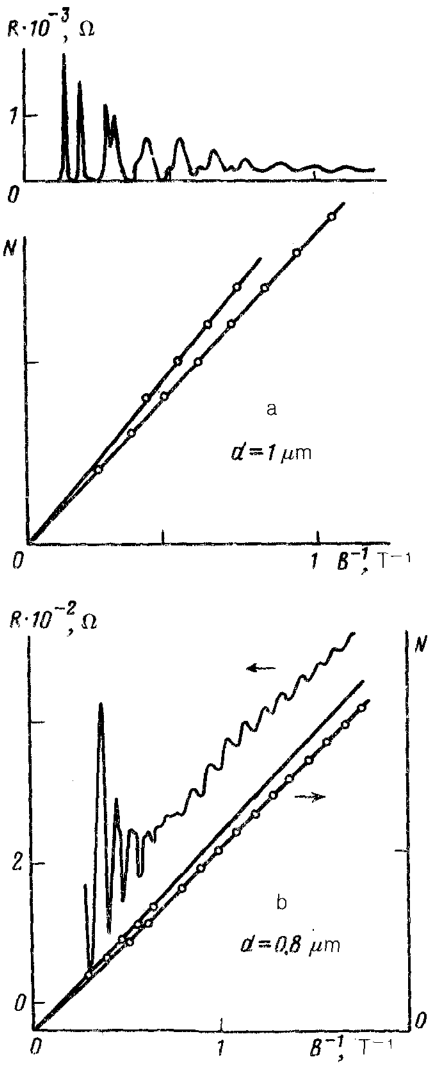

FIG. 2. Quantum oscillations in samples with antipoints; positions of the oscillation minima versus the magnetic field. a—Sample N1, $T = 0.2$ K; b—N2, $T = 1.3$ K.

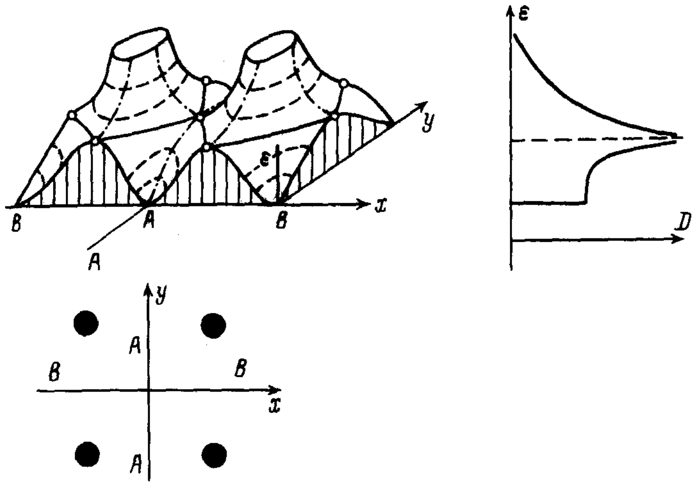

FIG. 3. Rough sketch of the potential in a system with antipoints. Saddle points and contour lines passing through them are shown. The dashed lines are other equipotential lines. The system of antipoints is shown at the bottom; shown at the right is a rough sketch of the density of states in the Landau band.

smaller, period in the reciprocal of the magnetic field. These oscillations cannot be due to an inhomogeneity of the sample, since if they were, the two oscillation periods would exist over the entire magnetic field range. For the sample with the lattice period $d = 0.8$ μm the oscillation picture changes fundamentally (Fig. 2): The oscillation period is disrupted, and in strong fields the deep minima have a second period, while the oscillations with the old period gradually fade away.

The reasons for the appearance of this second period of the quantum oscillations are not completely clear. One possibility arises from a consideration of the superlattice potential of the antipoints (Fig. 3). The periodic potential spreads each Landau level out into a band, whose width in strong fields is equal to the potential V (Ref. 8). The density of states in the Landau band has structural features associated with singular points of the periodic potential (Fig. 3). One of these points corresponds to an energy minimum and leads to a jump in the density of states. The saddle points lead to divergences of the density of states in the upper part of the Landau band.[9] In relatively weak magnetic fields, the conductivity oscillations are due primarily to states corresponding to a point of divergence. As the field is raised, however, states belonging to a minimum of the periodic potential come into play. Since the conductivity is determined not only by the density of states but also by the relaxation time, one may observe different situations, in which the conductivity has minima associated with either one or both of the singularities in the density of states in the Landau band. From the difference between the periods we find the width of the Landau band to be $V = 1.4$ meV.

In summary, measurements of the magnetoresistance of 2D electrons in a system with antipoints have revealed two different periods of th quantum oscillations. These two periods correspond to two groups of carriers, which move along different trajectories in the periodic potential of the antipoints. The contribution of these groups to the conductivity depends on the lattice period and the strength of the magnetic field.

We wish to thank M. V. Éntin and A. O. Govorov for many productive discussions, H. Reich for furnishing the ELPHY electron-beam-lithography system, and V. G. Plyukhin for carrying out the reactive etching.

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Translated by D. Parsons