Transport of 2D electron gas in a system of artificial scatterers: an order–disorder transition

G. M. Gusev, Z. D. Kvon, L. V. Litvin, Yu. V. Nastaushev, A. K. Kalagin, and A. I. Toropov

Institute of Semiconductor Physics, Siberian Branch of the Academy of Sciences of Russia, 630090, Novosibirsk

(Submitted 9 July 1992)
Pis'ma Zh. Eksp. Teor. Fiz. **56**, No. 3, 173–176 (10 August 1992)

The conductivity and negative magnetoresistance of 2D electrons in a periodic lattice and disordered lattice of antipoints have been studied experimentally. The mean free path l and the phase coherence length L_φ have been determined. The lengths l and L_φ were found to depend nonmonotonically on the degree of disorder.

A periodic lattice of scatterers, obtained by etching submicron-diameter holes (antipoints) in a highly mobile 2D electron gas, attracts considerable attention because it allows the shape of the scattering potential to be simulated.[1-3] In particular, this arrangement makes it possible to monitor the change in the electronic properties during the transition from periodically arranged scatterers to a disordered potential which is found in an ordinary electron-impurity system.

In the present letter we report the results of an experimental study of the mobility and negative magnetoresistance due to the interference corrections to the conductivity in a system with artificial scatterers.

As experimental samples we used Hall bridges based on GaAs/AlGaAs heterojunctions containing electron gas. The parameters of the initial layers and the method of fabricating the periodic lattice were described elsewhere.[4] We studied samples with lattice constants $d = 0.6$, 0.7, 0.8, 0.9, and 1.3 μm. Samples in which the lattice of antipoints is disordered with various degrees of disorder were also made for the experiment (curves *2* and *3* in Fig. 1). The disordering of the lattice was accomplished in the following way. The random-number generator determined the shift in the position of the antipoints in the direction of the neighboring antipoints. The deviation of the antipoints from their periodic arrangement in the lattice with a period $d = 0.7$ μm at the peak was $\Delta = 0.1$, 0.25, and 0.35 μm. Consequently, the short-range order of the system was disrupted but its long-range order was preserved.

The magnetoresistance was measured using the four-terminal method, with an active ac bridge, in magnetic fields up to 100 G and at temperatures of 1.3–4.2 K. In samples with a periodic lattice of antipoints the mobility decreased linearly with decreasing period, approximately in accordance with $\mu = 1.3e(d-c)/mv_F$,[4] where $c = 0.35$ μm. This means that the mean free path of electrons is determined by the distance between the antipoints. The effective diameter c is the sum of the geometric dimension of the antipoint and of the depleted region that surrounds it, $c = 2a + 2t$, where $t = 0.07$ μm. The electron scattering in this system is determined by the scatter-

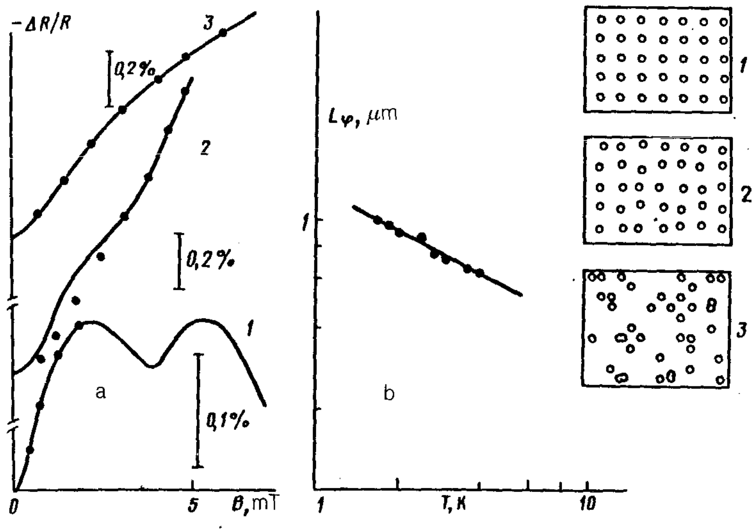

FIG. 1. a: Dependence of the magnetoresistance on B for samples with different degrees of disorder of the antipoints and for the periodic lattice: $d = 0.7$ μm; *1*—$\Delta = 0.0$; *2*—$\Delta = 0.1$; *3*—$\Delta = 0.35$ μm, $T = 1.7$ K. Solid line—Experiment; points—theory[7] with the parameters: *1*—$L_\varphi = 0.75$; *2*—$L_\varphi = 0.42$; *3*—$L_\varphi = 0.95$ μm. b: Dependence of the length L_φ on the temperature for samples with $\Delta = 0.35$ μm.

ing by antipoints. In a simple model for the scattering of 2D electrons by disks the mean free path is $l = d \times d/c$. This value is approximately three times larger than the measured value. The electrons in the periodic lattice of scatterers are a system which has a dynamic chaos, in which the onset of chaos in the motion of electrons occurs in the course of the motion itself, after several collisions with the antipoints.[5,6] A simple estimate of the mean free path evidently is not suitable in this case. Further theoretical analysis of the scattering in the periodic lattice is required.

Let us consider the measurements of this mean free path in samples with a disordered arrangement of antipoints. The length l versus the degree of disorder is plotted in Fig. 2. We see that with an increase in Δ, the length l initially decreases, and then increases, remaining at the same time slightly shorter than that in the sample with a periodic lattice. Accordingly, a change in the degree of disorder causes the mobility or the mean free path to behave in a highly unusual way, especially when the mobility increases wtih increasing Δ. This behavior raises many questions with regard to the transport theory of systems which simultaneously have a static chaos and a dynamic chaos.

A negative magnetoresistance, which is attributable to the suppression of the weak localization, has been observed in all of the samples with an artificial lattice of scatterers in weak magnetic fields.[7] Since the dominant scattering in the system being studied is the scattering by antipoints, rather than the scattering by residual impurities, we can assume that the localization is also attributable to the electron interference as a result of scattering by antipoints. It was reported in Ref. 8 that structural features

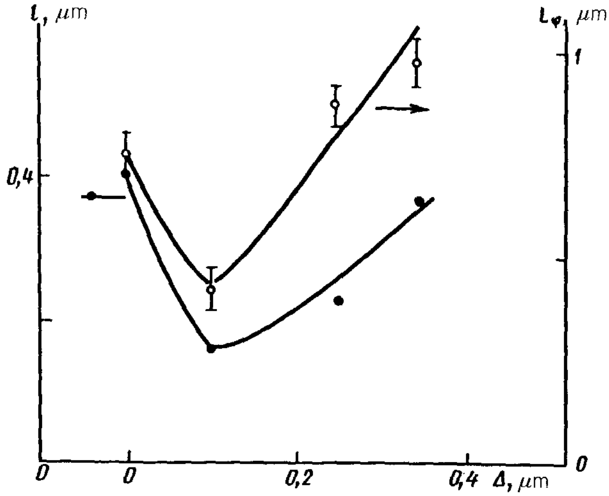

FIG. 2. Mean free path l and phase coherence length L_φ versus the degree of disorder of the antipoints, Δ.

stemming from the Aharonov–Bohm effect on stable, closed trajectories have been observed in a system with a periodic lattice, against a negative magnetoresistance background. We studied the monotonic part of the negative magnetoresistance which is caused by the interference on all of the trajectories in the periodic lattice and in the disordered lattice. The plot of the negative magnetoresistance versus B is shown in Fig. 1 for three samples with an average period of 0.7 μm and various degrees of disorder of antipoints. We see that a sample with a periodic lattice exhibits a structural feature which stems from the Aharonov–Bohm effect, and which gradually disappears with an increase in Δ. The points represent the theoretical curves of the negative magnetoresistance for the 2D case in an electron-impurity system.[7] As the adjustable parameter we used the phase coherence length L_φ. The plot of L_φ versus the temperature is shown in Fig. 2b for a sample with $\Delta = 0.35$ μm. We see that $L_\varphi \propto T^{-0.5}$, as in the case of the electron-impurity system. Such a dependence has been observed in all of the samples. The length L_φ versus the degree of disorder is shown in Fig. 2, It is evident that this plot correlates with the plot of the mean free path, and hence with the conductivity. Such a behavior corresponds to electron–electron scattering in a system with impurities.[9] The value of L_φ, however, was found to be much smaller than the value measured for GaAs/AlGaAs heterojunctions with the same electron mobility and the same electron density, in which the dominant scattering is the usual electron-impurity scattering.[10] In particular, for a periodic lattice with $d = 0.7$ μm we have $L_\varphi^{\text{theor}} = 2.5$ μm, which is three times larger than the value measured experimentally. A more correct comparison of the theoretical analysis of negative magnetoresistance with the experimental observation requires the use of samples with less pronounced structural features attributable to the Aharonov–Bohm effect, in particular, those with a smaller period ($d = 0.6$ μm) and with a lower mobility of the initial samples. In all of the cases, however, the experimental value of L_φ is much smaller than the calculated value. Such a divergence also occurs in the case of disorder in a sample with $\Delta = 0.1\ \mu$m. As is evident from the figure, in a system with a strong disorder, the value of L_φ increases and the disagreement with the theory decreases ($L_\varphi^{\text{theor}} = 2.4\ \mu$m, $L_\varphi^{\text{exp}} = 0.95\ \mu$m). Note that the value of L_φ, which was determined from a comparison of the monotonic part of the negative magnetoresistance with theory, does not correspond to the condition suitable for observation of the Aharonov–Bohm effect, for which the perimeter of the trajectories of the interfering electrons, $L = 2.5\ \mu$m, is on the order of L_φ.

In summary, a system with a dynamic chaos gives rise to several singularities in the classical transport and in the weak localization, which distinguish it from ordinary systems with impurity scattering. These structural features must be further studied, both theoretically and experimentally.

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Translated by S. J. Amoretty