Conductance Fluctuations in a Mesoscopic Conductor with Antidots

G.M.Gusev*, P. Basmaji and M. H. Degani
Instituto de Física e Química de São Carlos, Universidade de São Paulo
Caixa Postal 369, 13560-970 São Carlos, SP, Brasil

J. C. Portal, P. W. H. Pinkse
Service National des Champs Intensse, Centre National de la Recherche Scientifique
F-38042, Grenoble and INSA-Toulouse, 31077, France

Z. D. Kvon, L. V. Litvin, Yu. V. Nastaushev and A. I. Toropov
Institute of Semiconductor Physics, Russian Academy of Sczences
Siberian Brnnch, Novosibirsk, Russia

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Magnetoresistance fluctuations of a mesoscopic conductor, in which two-dimensional electrons are scattered not by impurities but by a disordered lattice of antidots fabricated using electron litliography and plasma etching, have been found. Comparison with theory of conductance fluctuations in chaotic billiard has been made.

I. Introduction

Intcrfereice of electrons scattered by impurities at low temperature plays an important role in a sample with small size. In particular, this interference is responsible for the dependence of the sample resistance on the specific realization of its randoin potential. A change in the configuration of the scattering potential gives rise to an alteration in the value of the conductaiice (recipiocal resistance) of tlie order e^2/h[1]. Magnetic field also influences the electron interference because of the Aharonov-Bohm effect, therefore universal conductance fluctuations have been observed as a function of magnetic field[2]. Recently, new microstructures based on a high mobility two-dimensional (2D) electron gas in GaAs/AlGaAs heterostructures have been fabricated, in which the electron transport is ballistic: electrons collide with the sidewall of the microstructure, but are not scattered by impurities[3].

In this systein, which is actually a version of the electron billiard, conductance fluctuations with magnetic field have been found recently[4], and investigation of its correlation properties gave the information of what type of billiard is really chaotic[5,6]. In particular, the billiard with the shape of a "stadium" is more chaotic than the "circle" shape billiard as has been found iii Ref. [4].

Another type of chaotic billiard is a 2D electron gas in a lattice of antidots: holes with submicron size etched in heterostructures AlGaAs/GaAs[7]. In this system electrons are scattered by the antidot strong repulsive potential. At a zero or weak magnetic field this billiard is also chaotic (see, for example Ref.[8]), but Gusev et al.[9] have found that the inagnetoresistance of these structures exhibited some feature which was connected witli interference of the specific trajectories when the electron moves clockwise and counterclockwise. The existence of stable trajectories which contribute to the conductivity is contradicted to the conclusion that this billiard is chaotic. The test samples investigated in

*Permanent address: Institute of Semiconductor Physics, Russian Academy of Science. Siberian Branch, Novosibirsk, Russia.

Ref.[9] have microscopic dimensions, therefore interference was attributed to tlie trajectories during backscattering at tlie starting point. For observation of interference of different trajectories and *investigation* of its contribution to tlie concluctivity, a sample with size less than the electroii coherence length $\mathbf{L}_{\varphi}$, wliicli is 2-4μm at low temperature, should be used.

In this work we measured magnetoresistance in mesoscopic samples with artificially created scatterers (aiitidots), arranged in periodic or disordered configurations. The magnetoresistance fluctuations due to interference of the electron trajectories during tlie elastic scattering of electrons by antidots have been observed.

II. Experimental details

The test samples were Hall bridges based on GaAs/AlGaAs heterostructures with 2D electron gas. In tlie initial heterostructures, the electron density was $n_s = 4 \times 10^{11}\text{cm}^2$, and the electroii mobility $\mu = 2 \times 10^5 \text{cm}^2/(Vs)$. In the midclle part of the sample between potentiometric probes, we have drawn a pattern using tlie electroii beam; the sample was split off, and the middle part hacl a bridge shape with the 4×4 μm^2 size (Fig.1). In this bridge a disorderecl lattice of antidots was patterned. Antidots were shifted from tlie average position in a periodic lattice in any direction along a main axis, obtainecl by a random number generator. The shift from periodic position was $\Delta = 0.3\mu$m, i.e. half of tlie average period $d = 0.6\mu$m; diameter of antidots was $2a = 0.1 - 0.15\mu m$. Thus, tlie long order in this system was violated, but tlie sliort orcler was preserved. After electron beam lithography, samples were etched using reactive plasma etching. The magnetoresistance was measured by the four-probe method, except that potentiometric probes were connected to a wide part of the sarnple with 2D electron gas as in quantum point-coiitact *measurements*[10]. *Thus, the* sample consists of two seas with high mobility electrons connected by a bridge with artificial scatterers. Tlie measurements were done at frequencies 70 - 700 Hz in a. magnetic field up to 8T at temperatures 0.3- 4.2 K. We also measured *differential* resistance as a. function of a constant bias current applied in parallel to the AC current. Two samples with different arrangement of disordered lattices and one with a periodic lattice of antidots were measured.

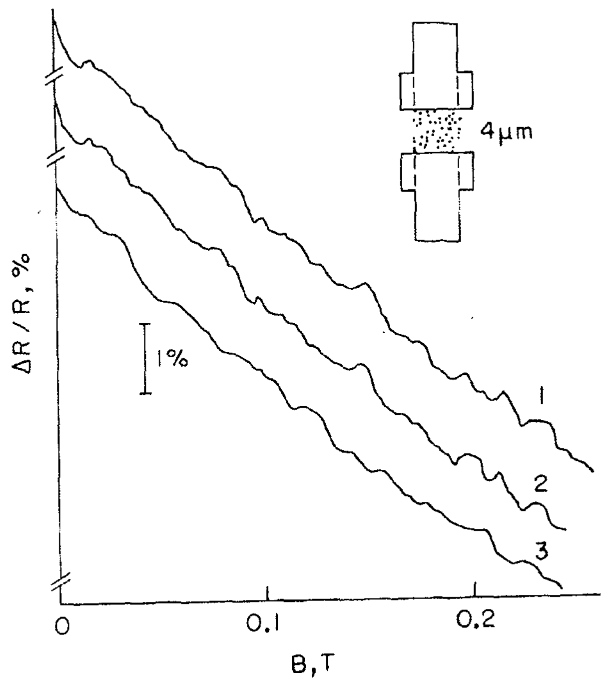

Figure 1: Magnetoresistance of the sample with disordered lattice of antidots measured after different intervals of time: 1 - A t=0; 2 - A t=5 min, 3 - A t=40 min; T = 1.7 K. Insert - sketch of tlie sample.

At zero magnetic field the electrons in the bridge have a mobility (8 – 10) x 10^3 $\text{cm}^2/(Vs)$, i.e. a factor of 20-30 smaller than the sample without antidots. It gives evidence that scattering of electrons by antidots is dominant. Also this value is two times smaller than for tlie systein with periodical lattice of antidots for period $d = 0.6\mu m$[9]. Gusev et al.[11] have fouiid that in macroscopic samples with a disordered lattice of antidots, mobility can decrease with increase of disorder.

III. Magnetoresistance fluctuations

Fig. 2 shows the magnetoresistance of a mesoscopic sample as a function of magnetic field B. We see several curves measured after different intervals of time. There are the following features in the magnetoresistance behavior: 1) Magnetoresistance is negative and

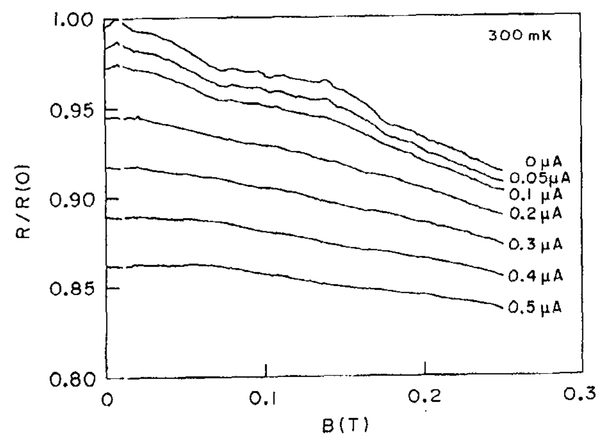

Figure 5: Magnetoresistance for different DC bias current. sample resist ince R = 9800 Ohm.

amplitude of fluctuations decrease. A change in the pattern of these fluctuations is also observed. Next we discuss these features.

The behavior of the differential resistance a.t zero magnetic field is very similar to the reduction of the resistance, a id further parabolic increase in resistance, which was previously observed in a ballistic quantum point contact[13]. This feature was attributed to the nonequilibriim transport through unoccupied higher quantuin subbands in a point contact. We suggest that in our case tlie narrow region between antidots behaves like a point contact. Under this circumstance, our sample can be divided into three parts (Fig. 1): the right side, which contains a. single row of the point contacts with different width; the middle part, whicli is a cavity with artificial scatterers; and left the side, which also contains a row of point contacts. Nonlinear behavior is due to the predominant voltage drop between a large 2D electron reservoir and the first row of antidots.

We see asymmetry of the differential resistance because of tlie different arrangement of point contacts on tlie left and the right parts of tlie sample. In this case a rectifying current is possible iii our sample with a disordered array of antidots. The effect of a. large DC current on a universal conductance fluctuation in samples with impurity dominant scattering was observed in Ref. [14], becsuse applying a. high voltage results in a change of all phases of interfering paths[15]. This voltage should be comparable to the characteristic energy of the electronic system

$$E_T \approx hD/L^2 , \quad (4)$$

where D denotes the diffusion coefficient. There is no calculation of the nonlinear effect in a billiard system, therefore we can only suggest that this characteristic energy exists in our system too. Analysis of the fluctuations in Fig. 5 gives the value $E_T \approx 4$ meV, which is much higher than the temperature. More experiments for determination of this energy at different sample resistivity and temperature is necessary.

In summary, these experiments have revealed mesoscopic fluctuations of the magnetoresistance in sample with artificial scatterers. The amplitude of these fluctuations is not described by the traditional theory of mesoscopic fluctuations in samples with impurity dominant scattering. Nonlinear effect. at high DC bias current was observed. Asymmetry of the differential resistance, wliich can produce rectification of current passed through tlie sample, was found.

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