Observation of mesoscopic potential fluctuations in a sample of macroscopic dimensions

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Reproducible voltage fluctuations have been observed during current flow through an antimony film on a potential electrode of submicron dimensions. The fluctuations are aperiodic in a magnetic field.

Spatial fluctuations of the current in a disordered conductor at low temperatures were calculated in Ref. 1. It was shown that a quantum interference of the electrons moving along different diffusion paths during current flow in an infinite, macroscopically homogeneous, disordered medium gives rise to large spatial fluctuations of the current density. Consequently, only a small fraction of the current is directed along the external electric field **E**. The fluctuations of the local potential which arise in the process are given in order of magnitude

$$< \Delta\mu^2 > \simeq \left(\frac{eE\hbar}{p_F}\right)^2 \frac{L_T}{l},$$

where $L_T = [\hbar D/(kT)]^{1/2}$, $D = lv_F/3$, l is the mean free path with respect to scattering by impurity particles, and p_F and v_F are the Fermi momentum and velocity. The average is over realizations of the random potential.

In this letter we are reporting direct measurements of potential fluctuations of this nature in an antimony film. To permit observation of this effect, one of the potential electrodes applied to the film had minimal dimensions, while the other was of macroscopic size. As in the measurements of mesoscopic conductivity fluctuations in small samples, the potential fluctuations were studied during the variation of a magnetic field directed perpendicular to the plane of the film. The geometry of the sample and the measurement layout are shown in the inset in Fig. 1.

An antimony film 1000 Å thick and 0.15 mm wide was vacuum-deposited on a glass substrate at room temperature. The resistance of the film at room temperature was 17 Ω/□. A point contact was fabricated by the following technique: A layer of SiO was deposited on the test film through a mask consisting of a filament 1 μm in diameter. The filament was then rotated 90°, and a second layer of insulator, of the same thickness, was deposited. The window of uncoated SiO that remained constituted the contact between the film and the antimony film which was deposited on top of this sandwich. The area of this contact thus could not exceed 1 μm^2, but the size of the contact could be controlled by varying the thickness of the SiO, since the insulator tended to slip under the mask. The total thickness of SiO was about 2000 Å and corresponded to the region of a transition from a metallic point contact to a tunnel junction between films. The experimental results reported below were obtained with

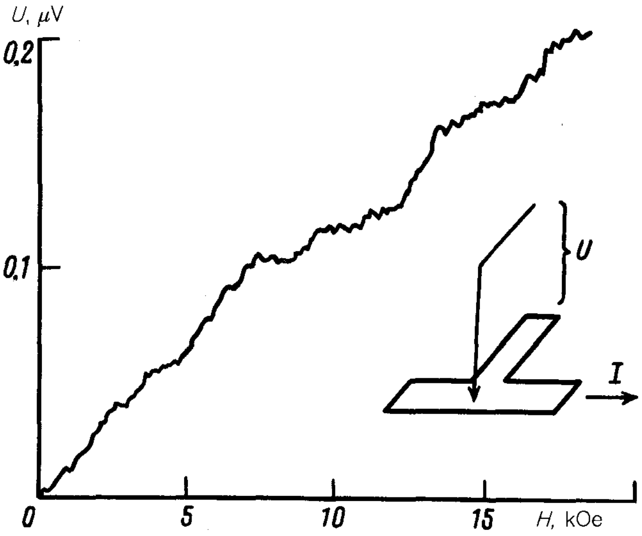

FIG. 1. Representative recording of the voltage on the contact versus the magnetic field. The inset shows the experimental layout.

the help of a tunnel junction with a resistance of about 1 MΩ; such a junction causes only a slight perturbation of the distributions of the current and the potential in the film. When a high-impedance voltmeter is used, the properties of the point contact itself do not have any substantial effect on the results of the measurements; the only important factor is the small size of the junction.

The measurements were carried out at an alternating current with a frequency of 9 kHz. The signal U varied in time: At liquid-helium temperature we observed a noise at a level of a few nanovolts, which undoubtedly reflected fluctuations in the properties of the sample. As a rule, the nature of this noise changed in the course of an experiment, from a "telegraphy" noise with two signal levels to an ordinary continuous set of levels. A telegraphy noise is characteristic of the resistance of mesoscopic samples (Refs. 2 and 3, for example) and is usually linked with a motion of impurity particles.

It can be seen from Fig. 1 that the fluctuations of interest are seen only weakly against the background of the Hall voltage (which is linear in H) and the noise of the sample. We accordingly measured the derivative dU/dH by the method of magnetic field modulation. The field was varied at a frequency of 17 Hz and an amplitude of 500 Oe. The amplitude of the alternating current through the film was chosen to be 0.1 mA, in order to keep the effect linear in the current. The results of these measurements are shown in Fig. 2. The curves of $dU/dH(H)$ are even in the magnetic field. A Fourier analysis of these curves brought out several structural features in the spectrum which indicate the existence of favored electron paths in the film. Figure 3 shows a corresponding part of a Fourier spectrum. The structural features correspond to char-

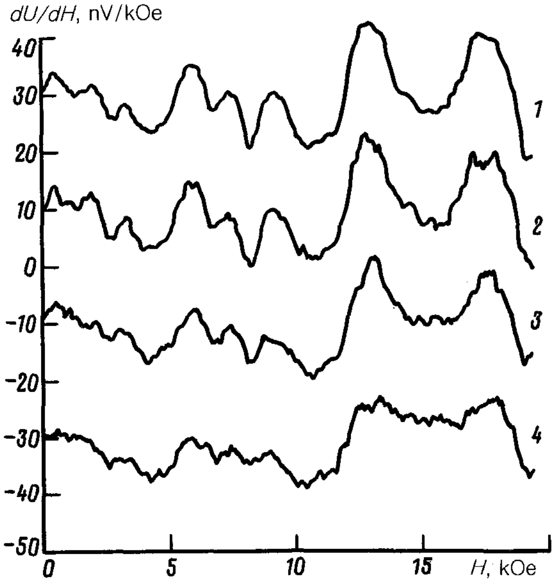

FIG. 2. The derivative dU/dH versus the magnetic field. The curves have been displaced along the ordinate axis for clarity. *1*—The result of an averaging over eight passes at a temperature of 1.46 K; *2–4*—single passes at 1.46, 2.53, and 4.2 K, respectively.

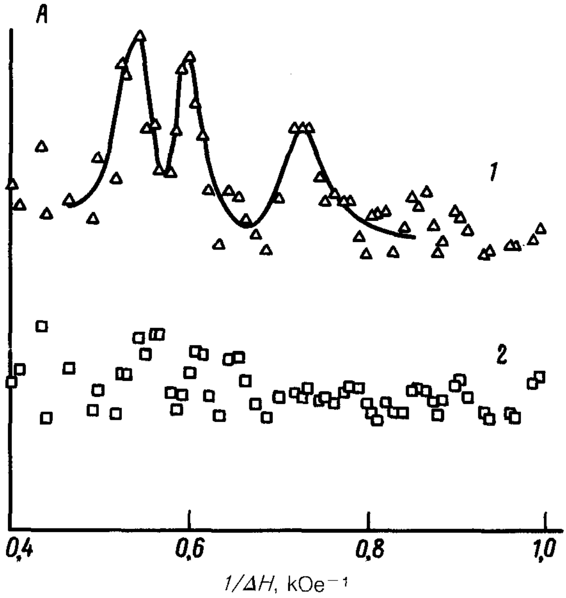

FIG. 3. Parts of the Fourier spectra of the curves from Fig. 2. *1*—Curve 1; *2*—curve 4. The ordinate scale is the same; the spectra have been shifted vertically for greater clarity.

acteristic areas of about 10^{-10} cm^2. A spectrum of mesoscopic resistance fluctuations of this sort was also observed in Ref. 4, where it was attributed to a grainy structure of the film.

The mean square value of the fluctuations of the electrochemical potential on an ideally conducting contact of size a on a film of thickness L_z was estimated in Ref. 5:

$$< \Delta\eta^2 > \simeq \left(\frac{eE\hbar^2}{p_F^2 l}\right)^2 \frac{L_T^2 l}{L_z a^2} \ln\frac{L_\varphi}{L_T}.$$

Here L_φ is the phase relaxation length of an electron. This estimate is also good in order of magnitude for a high-resistance contact. In an antimony film we have $p_F/\hbar \simeq 10^7$ cm^{-1}; at temperatures of 1–2 K we would have $l \simeq 10^{-5}$ cm according to data on the conductivity of the film; and we have $L_T \simeq L_\varphi \simeq 5 \times 10^{-5}$ cm (measurements of L_φ were carried out in Ref. 6). For the observed fluctuations, on the order of 10^{-8} V in size, the size of the contacts should thus not be greater than a few tens of angstroms. This conclusion corresponds to our understanding of the dimensions of the contact region.

In summary, the new method for experimental study of mesoscopic phenomena, which was proposed by Aronov *et al.*,[1] has been realized in the present study. Because of the comparative simplicity of the technique for fabricating the samples, this method may hold promise for further research on mesoscopic fluctuations.

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[1] A. G. Aronov, A. Yu. Zyuzin, and B. Z. Spivak, Pis'ma Zh. Eksp. Teor. Fiz. **43**, 431 (1986) [JETP Lett. **43**, 555 (1986)].
[2] K. S. Ralls, D. C. Ralph, and R. A. Buhrman, Phys. Rev. B **40**, 11561 (1989).
[3] T. L. Meisenheimer, D. E. Beutler, and N. Giordano, Jpn. J. Appl. Phys. **26**, Suppl. 26-3, 695 (1987).
[4] V. T. Petrashov, P. Reinders, and M. Springford, Pis'ma Zh. Eksp. Teor. Fiz. **45**, 565 (1987) [JETP Lett. **45**, 720 (1987)].
[5] A. Yu. Zyuzin and B. Z. Spivak, Zh. Eksp. Teor. Fiz. **93**, 994 (1987) [Sov. Phys. JETP **66**, 560 (1987)].
[6] R. A. Webb, S. Washburn, and C. P. Umbach, Phys. Rev. B **37**, 8455 (1988).

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