Quasiballistic electronic interferometer

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We have built and investigated an electronic interferometer based on a $2D$ electron gas in a AlGaAs/GaAs heterojunction. This is the smallest interferometer that has ever been built. We established that at $T < 0.1$ K the amplitude of the Aharonov–Bohm oscillations of the interferometer reaches 35% of the resistance of the interferometer in the absence of a magnetic field; this is almost twice the amplitude previously achieved.

Beginning with the work of Webb *et al.*,[1] studies of ring electronic interferometers have been continuing for several years, especially after Aharonov–Bohm oscillations were observed in the quasiballistic regime, where the mean-free path $l > L$ ($L = \pi d_{\text{eff}}/2$).[2,3] Such studies are of interest primarily because the electronic interferometer is the foundation of the quantum interference transistor, which makes it possible to achieve switching powers that are several orders of magnitude lower than for classical transistors. The development of an interference transistor is impeded by a number of difficulties, caused mainly by the suppression of interference by the fluctuation potential of impurities and defects.[4] A possible way to overcome these difficulties is to make the interferometer smaller.

In this letter we report on the fabrication and properties of a quasiballistic electronic interferometer with effective ring diameter $d_{\text{eff}} = 600$–700 nm and conducting channel width $W < 20$ nm. We know of no other papers in which such a smaller interferometer is described. Because of the small size, we observed in the interferometer the Aharonov–Bohm oscillations whose amplitude $\Delta R/R_0$ (R_0 is the resistance of the interferometer in the absence of a magnetic field) reached 0.35 at a certain value of the magnetic field.

The interferometer described above was built using electronic lithography and reactive ionic etching technology, on the basis of the 2D electron gas in an AlGaAs/GaAs heterojunction with a thin spacer prepared by the method of molecular-beam epitaxy. The electron density and electron mobility of the 2D electron gas at $T = 4.2$ K were $N_e = (7\text{–}9) \times 10^{11}$ cm^{-2} and $\mu = 10^5$ cm^2/(V · s), respectively. This corresponds to an electron mean-free path $l = 1.5$ μm. The use of a heterojunction with a thin (3-nm) spacer and, correspondingly, with high 2D electron density made it possible to develop an interferometer with very narrow conducting channels ($W < 20$ nm). It should be noted that the heterojunction mentioned above had no oval defects that could decrease the electron mobility.

Electron lithography was conducted in a stereoscan S-$2A$ scaning electron mi-

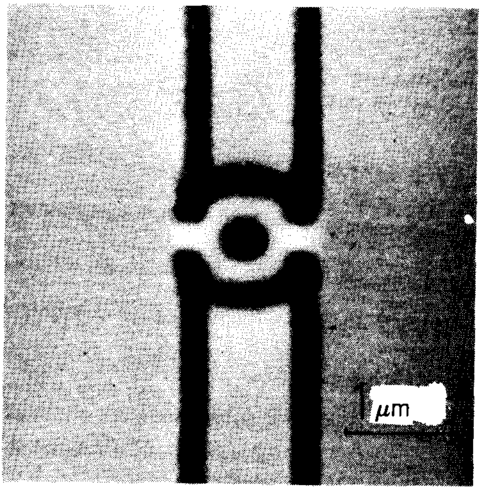

FIG. 1. Interferometer image in a scanning electron microscope.

croscope using a ELPHY-1 image generator. The interferometer was constructed on the basis of a Hall mesa structure, which was obtained by conventional photolithography with a 10-μm-wide bridge and potentiometric contacts separated by 100 μm. The interferometer ring was produced by exposing a circle 400 nm in diameter, around which remained a 200-nm-wide annular space which was bounded by 200-nm-wide lines. After the image was developed in the electron resist, reactive etching of GaAs and AlGaAs was performed so that the etching terminated in AlGaAs. A scanning-electron-microscope image of the interferometer is shown in Fig. 1. A schematic section of the interferometer, indicating the main dimensions, is shown in Fig. 2.

We investigated the magnetoresistance of the interferometer at temperatures $T = 20$ mK–4.2 K and in magnetic fields up to 10 T. The resistance measurements were performed on a 30-Hz alternating signal in a four-point scheme using a phase detector. Figure 3 shows the results of these measurements as a function of the magnetic field at $T \approx 20$ mK. Clearly, we see Aharonov–Bohm oscillations, whose amplitude is comparable to the total resistance of the sample, and the period in the magnetic field is $\Delta B = 0.0115$ T, which corresponds to quantization of magnetic flux, with a flux quantum $\Phi = h/e$, through an area with effective diameter $d_{\text{eff}} = 660$ nm (the h/e oscillations). It is also evident from Fig. 3 that the amplitude of the oscillations depends strongly on the magnetic field. Oscillations with the highest amplitude, where $\Delta R/R_0 = 0.35$, were observed in the field $B = 0.75$ T. Before the result obtained by us, the highest amplitude was observed in Ref. 3, where at $B = 0.1$ T $\Delta R/R_0 = 0.2$. Together with the fundamental period, there were also observed beats with ten times longer period, and the amplitude of the fundamental oscillations decrease strongly (in some magnetic fields almost to zero) at the moment of the appearance of the beats. These beats are probably associated with the finite width W of the conducting channels of the interferometer. The period of the beats makes it possible to estimate W. This estimate

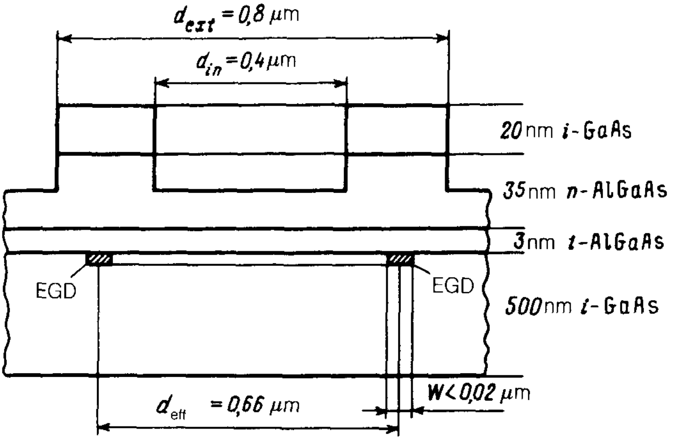

FIG. 2. Schematic section of the interferometer with an indication of the main dimensions.

gives W= 15–20 nm. Thus, for fields of the order of 10 T the width of the conducting channel of the experimental interferometer is comparable to the magnetic length. Because of this circumstance, and because of the small value of d_{eff}, large amplitudes of Aharonov–Bohm oscillations are observed in the interferometer, despite the fact that the mobility of the $2D$ electrons is lower than in Refs. 2 and 3. For the same

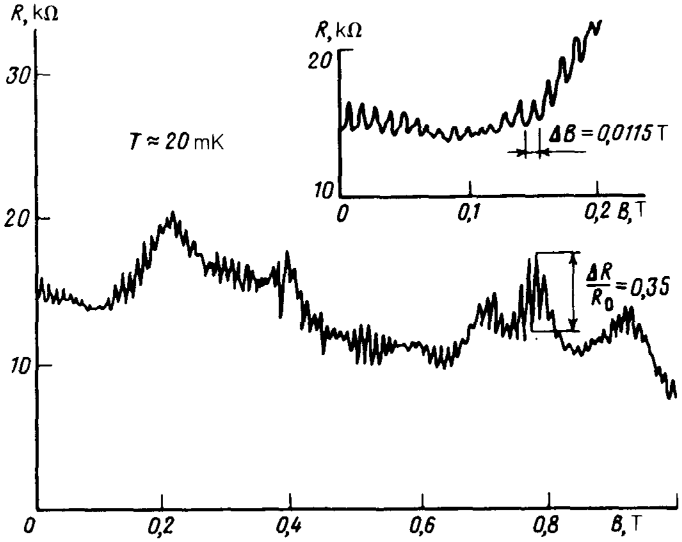

FIG. 3. Interferometer resistance versus magnetic field at $T \approx 20$ mK. Inset: -- behavior of the Aharonov–Bohm oscillations in the region of the lowest beats.

reason, the Aharonov–Bohm oscillations are not suppressed up to magnetic fields of 7 T; i.e., they even exist in the quantum Hall effect regime. Aharonov–Bohm *h/2e* oscillations were observed in addition to the *h/e* oscillations described above. The *h/2e* oscillations are an order of magnitude smaller in amplitude; they manifest themselves in the form of inflections and weak additional minima in the region where the fundamental oscillations predominate. These are the dominant oscillations, however, at the moment the beats appear (see the inset in Fig. 3). It should be noted that in this case the *h/2e* oscillations are not associated with weak localization, since they exist in magnetic fields for which weakly localized *h/2e* oscillations are impossible.[5] We assume that they arise due to the interference of two independent trajectories with backscattering. A similar picture was observed in Ref. 3. It should be noted that high-amplitude *h/2e* oscillations have been observed in the quantum Hall effect regime. However, we have not analyzed their behavior in the present study. The results of the study of their behavior will be published in a separate paper.

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