Conductance and anomalous magnetoresistance of germanium bicrystals at low temperatures

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Observation of quantum corrections to the resistance[1)] and anomalous magnetoresistance (AMR) in ~100-Oe fields in Ge bicrystals at low temperatures is reported.

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It is well known that the internal interface in Ge bicrystals exhibits two-dimensional metallic conductivity, which does not depend on the temperature (T) at least at temperatures $T < 20$ K.[1,2] However, according to the theoretical models developed in recent years, it may be expected that quantum corrections to the resistance, as well as AMR in weak magnetic fields, may be expected to appear in two-dimensional conducting systems.[3–6] In the present work, we attempted to observe the indicated effects in Ge bicrystals at low temperatures.

Germanium bicrystals were grown using Czochralski's method with double seeding and a procedure analogous to the one described in Refs. 1 and 2. Specimens with dimensions $4\times4\times0.5$ mm, which contained a boundary of inclination with disorientation angle $\cong 16°$, were cut out of the bars obtained, so that the plane of the boundary was perpendicular to the wide faces, on which indium contacts were then deposited. In this work, we investigated p-Ge specimens which had the following characteristics: resistivity $\rho_{300K} \cong 15$ Ω cm, resistance $R_{4.2K} \cong 400$–800 Ω, resistance of the conducting layer on the boundary (resistance "on a square") $R^{\square}_{4.2K} \cong 4600$ Ω. The resistance was measured in a He^3/He^4 dilution refrigerator in the temperature range 0.045 K $\leqslant T \leqslant 4.2$ K. The temperature was determined with the help of a carbon resistance thermometer, calibrated from measurements of susceptibility of the paramagnetic salt CMN. The magnetoresistance was studied in a transverse magnetic field at 1.3 K $\leqslant T \leqslant 4.2$ K.

The results of the measurements of the temperature dependence of the resistance of a Ge bicrystal with $R_{4.2K} \cong 700$ Ω and $R^{\square}_{4.2K} = 4.6$ kΩ are shown in Fig. 1. The measuring current I was varied in the experiments. At $I = 3$ μA, the power liberated in the specimen is $P \cong 6\times10^{-9}$ W, the voltage on the specimen is $U \cong 2\times10^{-3}$ V, and the electric field is $E \cong 4\times10^{-2}$ V/cm; $I = 0.1$ μA, and correspondingly, $P \cong 7\times10^{-12}$ W, $U \approx 7\times10^{-5}$ V, and $E \cong 10^{-3}$ V/cm. It is evident from the figure that as T is decreased, R increases, so that $\Delta R/R \sim \ln 1/T$. The solid-line corresponds to the theoretical dependence,[3,6] $\Delta R/R = -\alpha R^{\square}(e^2/2\pi\hbar)\ln T$, where the coefficient α is deter-

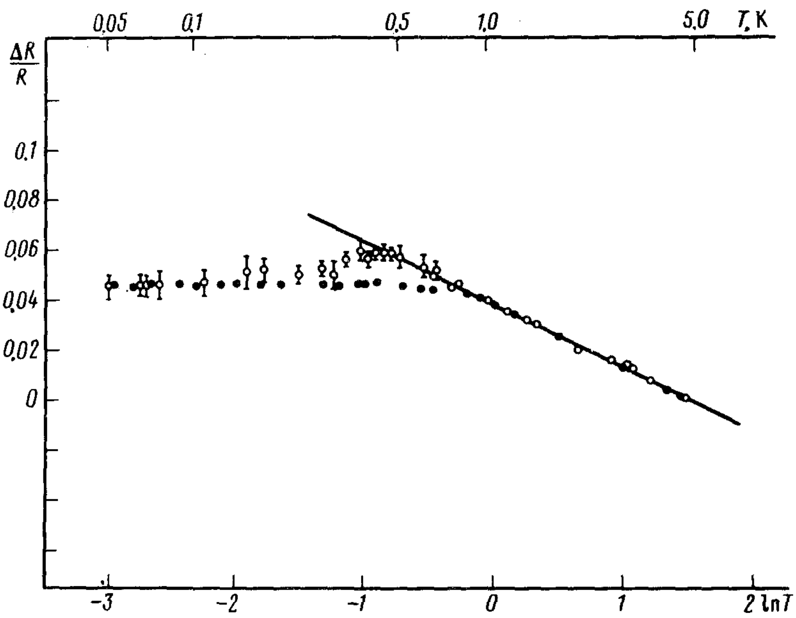

FIG. 1. Temperature dependence of the resistance of a Ge bicrystal. Measuring current: ● — 3 μA; ○ — 0.1 μA.

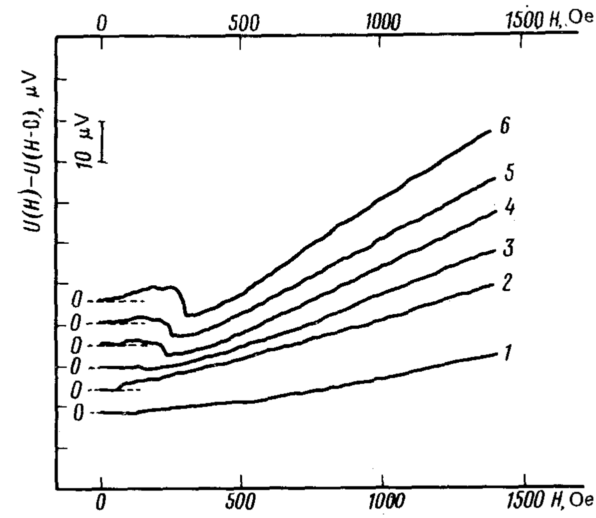

FIG. 2. Transverse magnetoresistance of Ge bicrystals at different temperatures: $T = 4.2$ K (1), 3.1 (2), 2.6 (3), 2.13 (4), 1.79 (5), and 1.34 (6). For clarity, the curves are shifted along the vertical axis. The remaining notation is described in the text.

mined by the temperature dependence of the energy relaxation time of electrons. In our measurements, the value of α measured for different specimens was 0.5. As the temperature is reduced to $T \cong 0.7$ K and $I = 3$ μA, saturation sets in, which could be attributed to the overheating of the electronic subsystem.[7] At $I = 0.1$ μA, the behavior of $R(T)$ is more complicated: The logarithmic growth in R continues to $T \cong 0.5$ K; a maximum is observed at $T \cong 0.35$ K; and then R gradually decreases and again saturates at $T \lesssim 0.1$ K.

We shall now describe the results of measurements of the transverse magnetoresistance, obtained for the same specimen. The curves in Fig. 2 were recorded with the help of a "Bryans" automatic plotter as follows. The signal from the Hall sensor was introduced to the X axis of the automatic plotter and the voltage on the specimen $U(H)$ with a constant measuring current $I \simeq 5$ μA minus the voltage on the specimen in zero magnetic field $U(H = 0)$ at a given temperature was introduced to the Y axis of the automatic plotter, while the difference $U(H) - U(H = 0)$ was amplified as much as possible. The ordinate of the initial point (at $H = 0$) thus corresponds to zero voltage on the specimen to within $\simeq 0.5$ μV, while the recorded curve reflects the changes in $R(H)$ related with the magnetic field at given T. It is evident from the figure that in Ge bicrystals the AMR for weak fields ($\sim 10^2$ Oe) has a complicated dependence $R(H)$. We see maxima and minima on the curves, whose absolute magnitude increases and whose position is displaced toward higher fields with decreasing temperature. The magnitude of the effect at $T = 1.34$ K is $\simeq 10$ μV, which is 0.5% of the specimen's resistance. As the magnetic field is increased further (up to 15 kOe), $R(H)$ increases monotonically.

The results obtained lead to the following preliminary conclusions. The temperature dependence $R(T) \sim \ln 1/T$ and AMR for $H \sim 10^2$ Oe, i.e., in the region of classically weak fields $\omega_c \tau \ll 1$ ($\omega_c = eH/mc$, and τ is the momentum relaxation time), could indicate processes that are weakly localized in the specimens investigated. However, the complicated and nonmonotonic nature of the $R(H)$ curves, as well as the presence of maxima in the dependence $R(T)$ cannot be described within the framework of the simple theory[3] and apparently require taking into account effects such as spin-orbit interaction, electron-electron interaction, etc.[4-6] Further experiments will be performed to clarify the nature of the quantum corrections to the resistance and the AMR in germanium bicrystals.

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[1)]While this paper was being prepared for publication, the paper of B. M. Vul and É. I. Zavaritskiĭ, in which the observation of quantum corrections to the conductivity of a germanium bicrystal at low temperature was also reported [Pis'ma Zh. Eksp. Teor. Fiz. **37**, 571 (1983)], came to the author's attention.

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