ANISOTROPY OF TRANSVERSE MAGNETORESISTANCE OF THIN n-Si FILMS

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1. Various mechanisms have been proposed in theoretical papers [1 - 3] to explain the anisotropy of magnetoresistance in thin films of semiconductors and metals. These size effects can be observed when the crystal thicknesses d are commensurate with the cooling length ℓ_ε and with the Larmor radius R_H. In addition, if the sample has a layered structure with different layer mobility, an effect connected with the mean free path ℓ_p is possible. The anisotropy of magnetoresistance of Ge plates ($d > 2 \times 10^{-2}$ cm) was first observed in [4] at room temperature. These results, however, cannot be easily explained by means of the foregoing mechanisms because (i) the sample thicknesses exceeded the characteristic lengths of the material by at least three orders of magnitude, and (ii) the anisotropy of the magnetoresistance was maximal when the sample had no layered structure.

We have investigated the anisotropy of magnetoresistance in thin plates of n-Si at low temperatures (20 - 77°K) and have demonstrated the possible existence of a size effect over the cooling length and the mean free path. The samples were cut from single-crystal silicon in such a way that the surface was oriented parallel to the (100) crystallographic plane and the current direction coincided with [010]. Since the presence of macroinhomogeneities is important in magnetoresistance measurements, we shall subdivide the results into two groups: 1) results obtained for homogeneous systems, namely, the bending of the bands at the sample surface is zero or depleting, and 2) results for inhomogeneous system - strong enrichment on the surface.

2. The following was observed for homogeneous systems: 1) The anisotropy of the magnetoresistance depends strongly on the sample thickness. Figure 1 shows the angular dependence of the transverse magnetoresistance, in polar coordinates, for samples 4.5×10^{-2} cm (curve 1) and 4×10^{-3} cm thick (curve 2) at a temperature 30°K and a magnetic field intensity 15 kG. It is seen from the figure that the magnetoresistance in a magnetic field parallel to the plane of the sample $(\Delta\rho/\rho_0)_\parallel$ is 50% smaller than the magnetoresistance in a perpendicular field $(\Delta\rho/\rho_0)_\perp$, and the values of the latter are the same for a thin and for a thick sample. 2) The magnetoresistance depends on the temperature; When the temperature increases from 20 to 77°K, the ratio $(\Delta\rho/\rho_0)_\perp/(\Delta\rho/\rho_0)_\parallel$ decreases. 3) When the magnetic field intensity varies in the range $0 < \omega_H\tau < 3$, where ω_H is the cyclotron frequency and τ is the momentum

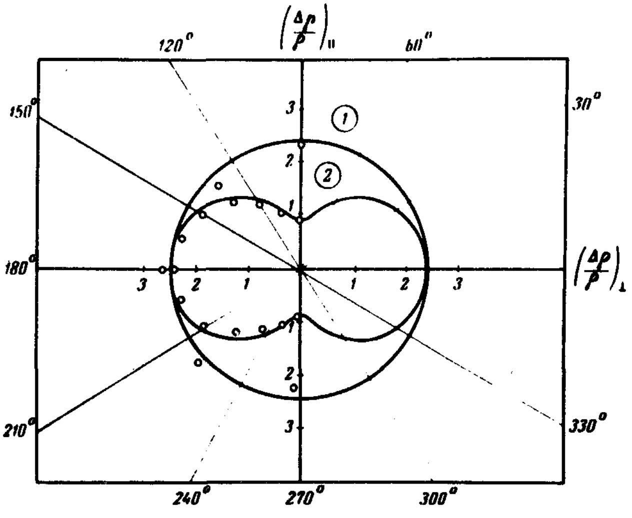

Fig. 1

relaxation time, does not lead to an appreciable change of the magnetoresistance anisotropy. 4) The drawing (heating) electric field was found to exert a strong influence on the magnetoresistance. Figure 2 shows the angular dependences of the transverse magnetoresistance for different electric fields. We see that the degree of anisotropy increases with increasing field intensity. In drawing fields, corresponding to the region of the "bend" on the current-voltage characteristics, the magnetoresistance becomes negative, and the inequality between $(\Delta\rho/\rho_0)_\perp$ and $(\Delta\rho/\rho_0)_\parallel$ reverses sign (see curve 4 of Fig. 2).

3. In inhomogeneous systems (strong enrichment on the surfaces), the degree of magnetoresistance anisotropy increases. Figure 3 shows plot of the magnetoresistance for two surface treatments of a sample 8×10^{-3} cm thick at T = 30°K and H = 15 kG. Curves 1 and 2 correspond to strong enrichment and depletion of the majority carriers, respectively. Attention is called to the fact that both $(\Delta\rho/\rho_0)_\parallel$ and $(\Delta\rho/\rho_0)_\perp$ change in inhomogeneous systems (relative to the volume value).

4. The results obtained for homogeneous systems can be attributed to a phenomenon first predicted and calculated by Gribnikov and Mel'nikov [1] for weak electric and magnetic fields, and by Bochkov and Gurevich [2] for heating fields (single-valley model) and strong magnetic fields. The phenomenon consists of energy separation of the carriers by a magnetic field located in the plane of the sample. The resultant temperature gradient decreases the ordinary, volume magnetoresistance in samples whose thicknesses are comparable with the cooling length ℓ_ε, the length over which the carriers lose their energy in excess of the thermal energy.

The cooling length of n-Si at 77°K was measured in [5] in the region of weak carrier heating, and amounts to 5×10^{-4} cm. Assuming an acoustic energy-scattering mechanism, which holds for weak heating and low temperatures, we can calculate the cooling length for T = 30°K, namely $\sim 1.5 \times 10^{-3}$ cm. Thus, the sample thicknesses at which anisotropy of the magnetoresist-

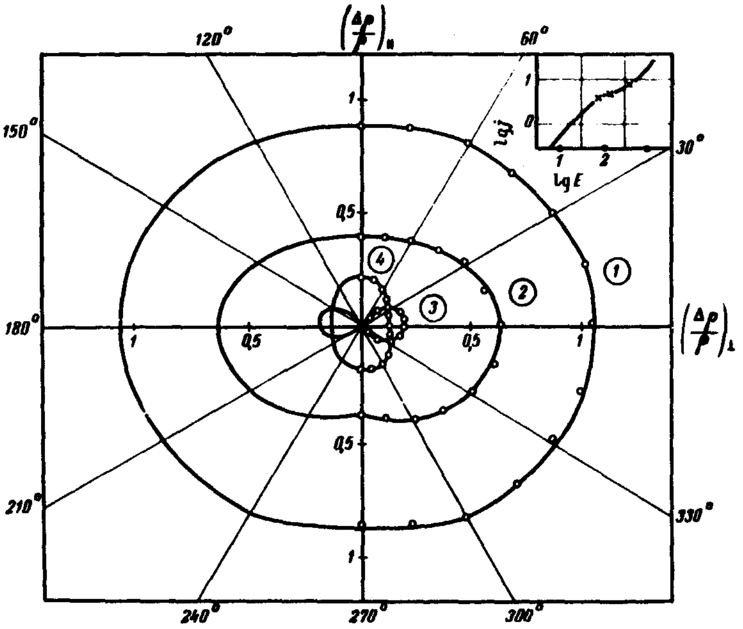

Fig. 2. Angular dependence of the transverse magnetoresistance of a sample 8×10^{-3} thick, at T = 77°K and various drawing electric fields (curves 1, 2, 3, and 4 correspond to fields of 1, 83, 158, and 334 V/cm. In the right-hand corner is shown the current-voltage characteristic of the sample, on which the fields corresponding to curves 2 - 4 are marked.

ance is observed are comparable with the cooling length. According to [1], in the case of the acoustic scattering mechanism the ratio of the changes of the conductivity in the magnetic field, $\Delta\sigma d_1(H)/\Delta\sigma d_2(H)$ for a thin ($d_1 = 1.3\ell_\varepsilon$) and thick ($d_2 >> \ell_\varepsilon$) plate is 0.70. The value obtained from the experimental data is 0.67 (see Fig. 1), in satisfactory agreement with the theory.

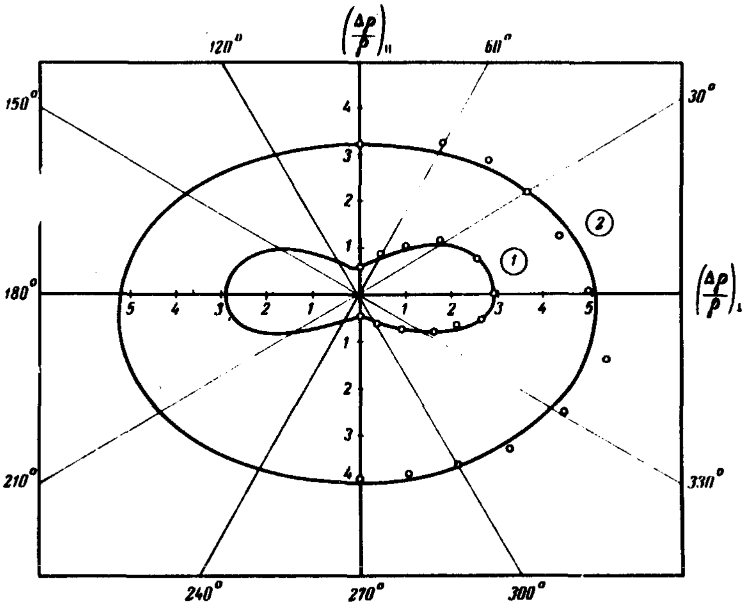

Fig. 3

It is shown in [2] that an increase of the magnetic field intensity leads to an increase of the size-effect addition to the magnetoresistance, so that in strong magnetic fields this increase becomes comparable with the volume magnetoresistance. However, an increase of the magnetic field decreases the cooling length, and therefore some degree of cancellation of these two influences on the magnetoresistance anisotropy is to be expected. A weak decrease of the anisotropy with increasing magnetic field was observed up to fields $\omega_H\tau \approx 3$.

The growth of the intensity of the electric heating field decreases the cooling length, and this should decrease the magnetoresistance anisotropy. However, in a multivalley semiconductor, the electric field exerts a stronger influence on intervalley transitions, so that even a small change of the electron temperature causes an appreciable redistribution of the carriers in the non-equivalent valleys, thereby increasing the magnetoresistance anisotropy.

5. In homogeneous layered systems (enriched layer on a surface, with a mobility different from the volume mobility), short circuiting of the Hall emf's of various (surface, volume) layers should take place in a magnetic field perpendicular to the plane of the layers. As a result, the total Hall field will not cancel the Lorentz forces in any of the layers, leading to a change of the magnetoresistance in each of them. Indeed, experiment reveals a change of magnetoresistance in a perpendicular field. At the same time, however, a change of $(\Delta\rho/\rho_0)_\parallel$ is observed, indicating the existence of other effects in the layered systems. One of them may be the aforementioned effect of Gribnikov and Mel'nikov, as well as others, such as the growth of carrier mobility in a magnetic field in a surface layer of thickness equal to the Larmor radius r_H, which is an effect similar to that calculated in [4].

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INVESTIGATION OF PARITY NONCONSERVATION IN THE REACTION $n + p \rightarrow d + \gamma$

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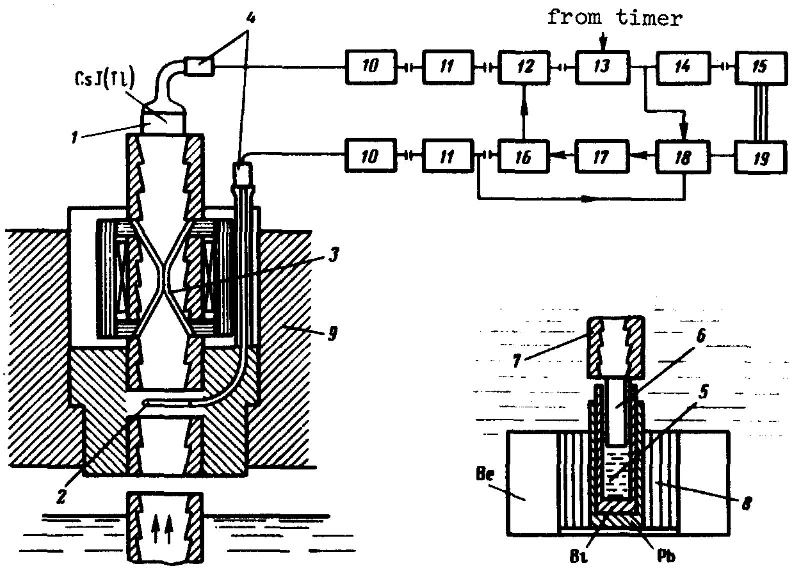
Measurement of the circular polarization of the γ quanta in the reaction $n + p \rightarrow d + \gamma$ makes it possible to determine directly the isoscalar part of the amplitude of the weak nucleon-nucleon interaction [1]. The absence of any appreciable amplification in this case causes the magnitude of the effect to be of the order of the ratio of the weak interaction to the strong one. Measurement of so small a polarization is a rather difficult task, but can be accomplished by using the procedure of integral γ-quantum detection [2]. The most important in this case is to obtain as powerful a source of gamma quanta of this reaction.

We describe here the organization of an experiment and preliminary results of the measurement of the circular polarization of gamma quanta in radiative capture of thermal neutrons in hydrogen. The experimental setup is shown in the figure.

The gamma source was a light-water neutron trap in the active zone of the VVR-M reactor of the A. F. Ioffe Physico-technical Institute. The trap was protected against gamma radiation from the zone by a screen of lead and bismuth. The effective source activity was about 10^{16} gamma-kV/sec at a volume trap of about 3 liters and a neutron flux $\sim 3 \times 10^{14}$ neut/cm^{2}sec at its center.

The gamma quanta from the trap were fed to the polarimeter through a 4-meter collimator channel. A "flow-through" collimator was used with an effective magnetized-absorber thickness



Experimental setup: 1 - measuring detector, 2 - monitoring detector, 3 - magnetized absorber, 4 - photodiodes, 5 - target, 6 - evacuated cylinder, 7 - 4-meter collimator, 8 - active zone, 9 - reactor shield, 10 - dc amplifier, 11 - amplifier, 12 - differential amplifier, 13 - erase circuit, 14 - tuned amplifier, 15 - output amplifier, 16 - rgulated amplifier, 17 - control circuit, 18 - correlator, 19 - pendulum filter.