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ANOMALOUS MAGNETORESISTANCE OF *n*-TYPE GERMANIUM AT 77 K AND 313 K

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The transverse and planar magnetoresistance MR in a monocrystalline germanium with charge carrier of 1.7×10^{19} cm^{-3} has been measured at 77 K and 313 K. The measurements were done under a weak electric and magnetic fields. It was found that MR exibits two types of anomalous effects. At 77 K the variation of MR with rotating angle Θ between the directions of both H and I is very strong, but at 313 K there is no considerable change. This phenomena may be attributed to the dynamical behaviour of the charge carriers, due to the applied magnetic field.

1. Introduction

It has been established that the resistivity of semiconductors increases when a magnetic field is applied. This increase in resistivity is directly proportional to the square of the magnetic flux density[1–4] and the magnitude of Hall coefficient decreases as the magnetic field strength increases[2].

The previous investigations on the Ge crystals shows the dependence of magnetoresistance MR on the rotating angle Θ between magnetic field and current direction[5,6]. Also the measurements which had been done on *n*-type Ge proved that the $\Theta - MR$ relation is symmetrical at 300 K and deviates from symmetry in a samples of high donor concentration at 77 K[7].

The relation between transverse MR and the direction of magnetic field for n- and p-types Ge were measured at 77 K and $H = 2.5$ T. An anomalous MR were observed[8,9]; this phenomena was attributed to the character of both donor and acceptor wave function[10]. Generally it was found that the anomalous behaviour of MR depends on the crystal orientation of the transverse magnetic field i. e.

$$\frac{\Delta\varrho}{\varrho_0} = \frac{\varrho_{xx}(H) - \varrho_0(0)}{\varrho_{xx}(0)}$$

where

$$\varrho_{xx}(H) = \frac{\sigma_{xx}(H)}{[\sigma_{xx}(H)]^2 - [\sigma_{xy}(H)]^2}.$$

The dependence of $\left(\frac{\Delta\varrho}{\varrho_0}\right)_T$ on the strength and orientation of magnetic field was explained by hopping conduction mechanism[11].

Baranskii et al.[12] have established that the dependence of anomalous MR of p-type Ge on the effective magnetic field $\mu_H H/c$ (H is the magnetic field, c is the velocity of light in vacuum, and μ_H is the Hall mobility of charge carriers) in various electric fields. They explained this behaviour on the basis of the coulomb scattering. Also the negative MR of deformed p-type Ge under various pressures was observed[13].

In this work, the planar and transverse MR of n-type Ge sample which has high donor concentration were measured at 77 K and 313 K, to study the anomalous effect of MR when the current passing through the sample does not flow along any of the symmetry axes related to the set of the ellipsoids.

2. *Experimental*

The investigated n-type germanium sample with carrier concentration of 1.7×10^{19} cm^{-3} was cut from single crystal which has a bridge shape. The sample dimensions are 0.6 mm thickness, 1.5 mm width and the distances between the two resistivity probes is 10 mm, as shown in Fig. 1. Terminals 1 and 2 are for the current passing through the sample in a direction no coinciding with the symmetry axes, while terminals 3,4 and 5,6 are used for measuring the Hall voltage U_H. Terminals 3,5 and 4,6 are used for measuring the magnetoresistivity $\Delta\varrho/\varrho_0$. For low temperature measurements the sample was put in cryostat of type CF_{100} The D. C. magnetic field strength was measured by calibrated gaussmeter.

In the absence of magnetic field ($H = 0$), the resistivity of the sample was measured as a function of current to check the ohmic character of the contacts. The measurements of Hall voltage, electrical resistivity and MR were carried out at weak electric field ($J = 6.6 \cdot 10^3$ A/m^2) and under a magnetic field up to 1.4 T.

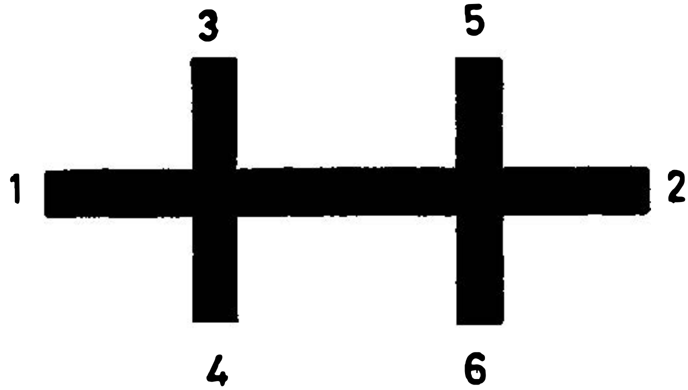

Fig. 1. The shape of Ge sample (Bridge form).

3. *Results and discussion*

The electrical conductivity of n-type Ge crystal was measured as a function of temperature range from 60—500 K. The relation between $\ln \sigma$ vs. $\frac{1}{T}$ is shown in Fig. 2. It was found that the dotted line represented the linear increase of conductivity with temperature. This means that at high temperature the Ge sample behaves as intrinsic semiconductor. As the temperature increases the total charge carriers will be excited out from the impurity level until it becomes empty. This indicates that the lattice scattering is predominant and the resistivity tends to increase until a certain temperature known as Fermi temperature after which the conductivity starts to increase again.

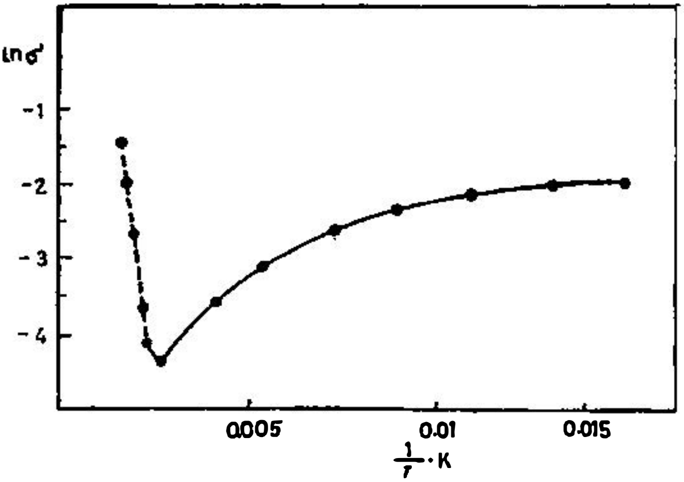

Fig. 2. The dependence of $\ln \sigma$ versus $\frac{1}{T}$ for n-type Ge sample.

A further decrease in temperature will cause the conductivity to rise (solid curve). This represents the extrinsic region. At low temperatures the conduction is mainly due to electrons activated from the donor level to the conduction band.

Let us denote the applied potential difference between the terminals 3 and 5 (Fig. 1) in the presence of the magnetic field by the symbol U_R and the Hall voltage generated between the terminals 3 and 4 by the symbol U_H. Fig. 3 represents the dependence of ratio U_R/U_H as a function of temperature. The value of U_R/U_H was found to increase sharply in the temperature range up to 120 K. Above this temperature U_R/U_H increased smoothly with temperature until it has reached a constant value. It is clear from this behaviour that the conductivity tensor of the cubic Ge crystal has anomalous character at low temperatures, while as the temperature increases the anomaly effect will decrease.

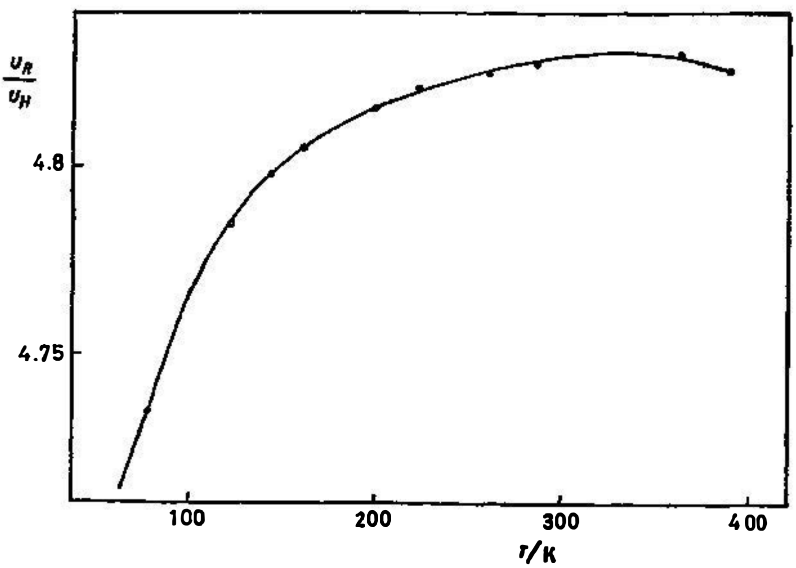

Fig. 3. The dependence of $\frac{U_R}{U_H}$ ratio on temperature T.

The planar and transverse MR were measured as a function of angle Θ between H and I at both temperature 77 K and 313 K for different magnetic field strengths as ahown in Figs. 4, 5, 6 and 7. From this experimental data it was found that the MR exibts two types of anomalous effects.

The first type of anomalous MR are shown in Figs. 4 and 5. At 313 K it was observed that there is no considerable change in the values of planar and transverse MR with the angle Θ. This means that MR does not respond to the reverse of the direction of the magnetic field, and therefore the following relationship is valid:

$$\frac{\Delta \varrho}{\varrho_0}(\Theta) \cong \text{constant}.$$

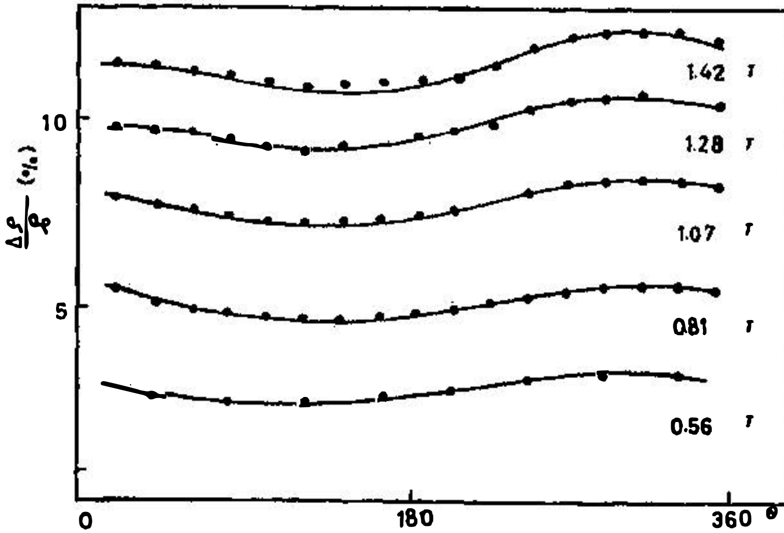

Fig. 4. Dependence of planar *MR* on angle Θ between magnetic field and current direction for different field strengths at 313 K.

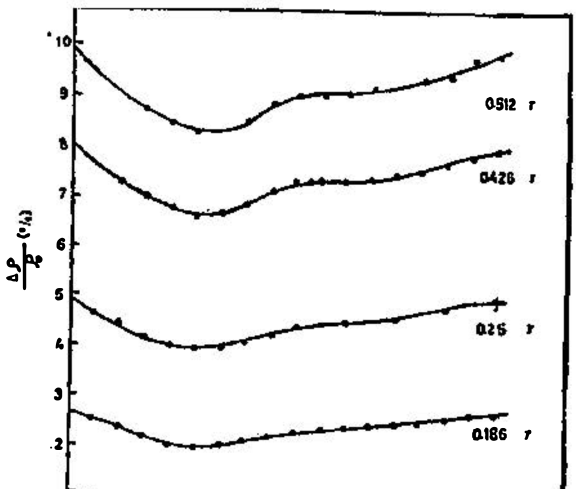

Fig. 5. Dependence of transverse *MR* on angle Θ for different field strengths at 313 K.

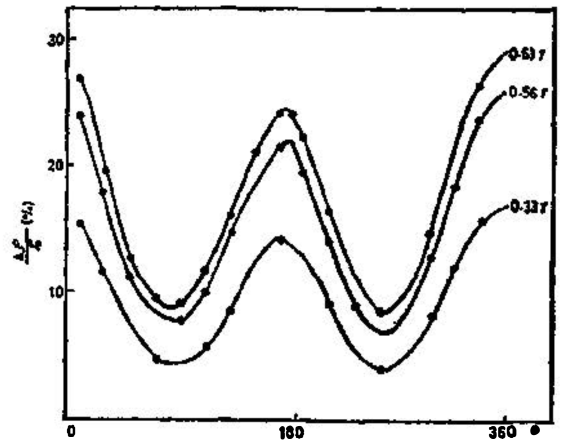

Fig. 6. Dependence of planar MR on angle Θ for different field strengths at 77 K.

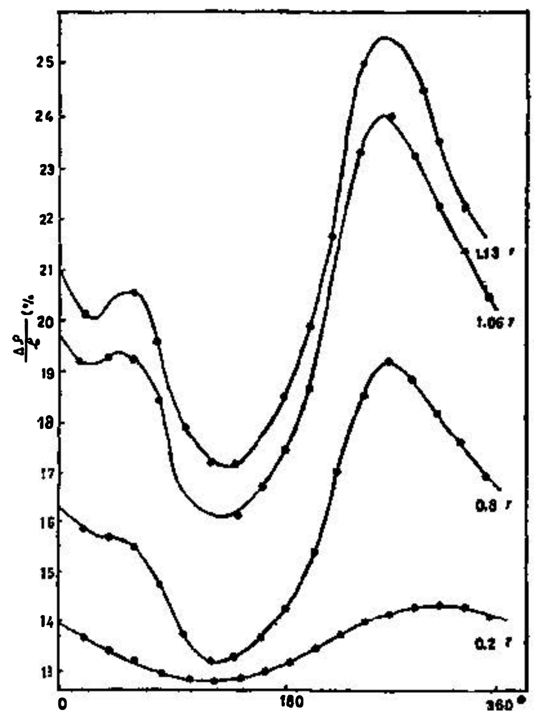

Fig. 7. Dependence of transverse MR on angle Θ for different field strengths at 77 K.

The second type of anomalous MR is shown in Figs. 6 and 7, which were measured at 77 K. The angular dependence of anomalous effect was observed. In Fig. 6 the anomalous behaviour of planar MR is more clearly at $\Theta = 180°$ for different magnetic field strenghts. A clear picture for a good anomalous character is given in Fig. 7, where the transverse MR is very sensitive for any small variation in angle Θ. The values of anomalous MR were found to increase as the magnetic field strength increases. On the other hand the anomalous effect in the transverse MR (Fig. 7) is larger than the planar MR (Fig. 6). In all cases at a fixed magnetic field strength the following relationship is valid:

$$\frac{\Delta \varrho}{\varrho_0}(\Theta) \neq \frac{\Delta \varrho}{\varrho_0}(\pi + \Theta).$$

From the observed experimental data of MR at 77 K and 313 K for different values of H, one can notice the following:

1. The total variation in the values of MR at 77 K under different magnetic field strengths (30%) is larger than at 313 K (10%).

2. The transverse MR is strongly magnetic field dependent than the planar MR at 313 K, while the reverse occured at 77 K.

The anomalous effect of MR for n-type Ge may be explained by considering the dynamical behaviour of the carriers, taking into account the dynamic motion of charge carriers in the $\vec{k}$-space, as well as the dependence of the effective mass variation on the actual direction of the carrier motion. This can be seen from the following equation

$$m_{ij}^{*-1} = \frac{1}{\hbar^2} \frac{\partial^2 E}{\partial k_i \, \partial k_j}.$$

The applied electric field and Hall field cause a resultant drift field in the $\vec{k}$-space which in turn changes the mobility of charge carriers [14].

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ANOMALNA MAGNETOOTPORNOST *n*-TIPA GERMANIJA NA 77 K I 313 K

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Mjerena je transverzalna i planarna magnetootpornost monokristala germanija koncentracije nosilaca naboja $1{,}7 \times 10^{19}$ cm^{-3} na 77 K i 313 K. Mjerenja su učinjena u slabom električnom i magnetskom polju. Nađena su dva tipa anomalnog ponašanja magnetootpornosti.