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Negative Magnetoresistance in *n*-Type Silicon

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Previously, negative magnetoresistance had been observed in many semiconductor materials in the region of so-called metallic impurity conduction. With regard to *n*-type silicon, there is only a brief communication [1], in which the results of measurements on one silicon sample with a phosphorus concentration of $2.3 \cdot 10^{18}$ cm^{-3} are given. Below we present the results of measurements of negative magnetoresistance in *n*-type silicon (phosphorus-doped) with charge-carrier concentrations from $5 \cdot 10^{18}$ to $3 \cdot 10^{19}$ cm^{-3} in the temperature interval from 1.7 to 4.2° K.

Table 1

Main characteristics of the investigated samples at 4.2 and 290° K.
After the sample number, the orientation of its longitudinal axis is indicated.

Sample	4.2° K: ρ, ohm • cm	4.2° K: R, cm^3/C	4.2° K: n, cm^{-3}	4.2° K: μ_H, cm^2/V• sec	290° K: ρ, ohm • cm	290° K: R, cm^3/C	290° K: n, cm^{-3}	290° K: μ, cm^2/V• sec
Si-4 [11$\bar{2}$]	$8.56 \cdot 10^{-3}$	1.09	$5.73 \cdot 10^{18}$	127	$5.77 \cdot 10^{-3}$	0.96	$6.44 \cdot 10^{18}$	168
Si-8 [1$\bar{1}$0]	$7.57 \cdot 10^{-3}$	0.91	$6.86 \cdot 10^{18}$	120	$6.14 \cdot 10^{-3}$	0.78	$8.00 \cdot 10^{18}$	127
Si-10 [1$\bar{1}$0]	$3.22 \cdot 10^{-3}$	0.50	$1.26 \cdot 10^{19}$	154	$4.81 \cdot 10^{-3}$	0.43	$1.45 \cdot 10^{19}$	89
Si-9 [11$\bar{2}$]	$3.67 \cdot 10^{-3}$	0.49	$1.27 \cdot 10^{19}$	133	$4.99 \cdot 10^{-3}$	0.54	$1.16 \cdot 10^{19}$	108
Si-6	$2.47 \cdot 10^{-3}$	0.42	$1.49 \cdot 10^{19}$	170	$3.69 \cdot 10^{-3}$	0.40	$1.56 \cdot 10^{19}$	168
Si-1	$1.44 \cdot 10^{-3}$	0.21	$3.03 \cdot 10^{19}$	146	$2.38 \cdot 10^{-3}$	0.23	$2.71 \cdot 10^{19}$	97

Table 1 gives the main characteristics of the investigated samples at 4.2 K. The measurements were carried out by the standard potentiometric method

Figure 1. Dependence of the magnetoresistance on the magnetic-field strength in sample Si-9 at 4.21 (1) and 1.70° K (2).

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with direct current in a magnetic field up to 16.5 kOe. The absolute error in measuring the magnetoresistance was ±0.01%. Measurements were made on samples cut in the form of a double cross. Ohmic contacts to the samples were prepared by chemical deposition of nickel followed by annealing in vacuum. On sample Si-10, control measurements were carried out after removing the potential probes and regrinding the sample. In this latter case the contacts were made from gold wire 0.1 mm in diameter, welded into the silicon by means of a capacitor discharge. In both cases, the value of $\Delta\rho_H/\rho_0$ and its dependence on the magnetic-field strength coincided.

Figure 1 shows the typical dependence of negative magnetoresistance on magnetic-field strength at temperatures of 4.21 and 1.70° K for sample Si-9. Investigation of the angular dependence of negative magnetoresistance at magnetic-field strengths close to the minimum of $\Delta\rho_H/\rho_0$ showed that the negative magnetoresistance does not depend (within the experimental error) on the angle

between the vectors of current density and magnetic induction. The dependence of the negative magnetoresistance on temperature at low temperatures is practically linear. The coefficient of the temperature dependence

$$\frac{d(\Delta\rho_H/\rho_0)}{dT}$$

decreases as the impurity concentration increases.

Fig. 2 shows the dependence of the magnetoresistance at 16.5 kG and 4.2° K on the impurity concentration in the silicon samples studied. It should be noted that there is a substantial discrepancy between our data and the results of work (1), whose authors observed, in a silicon sample with a phosphorus concentration of $2.3 \cdot 10^{18}$ cm^{-3}, a negative magnetoresistance of about -0.2% at $H = 16.5$ kG. This discrepancy may be connected with the fact that the authors of work (1) apparently carried out measurements on samples which, at low temperatures, were subjected to uniaxial tension. A control experiment on sample Si-10 showed that, in a sample glued to a copper holder, at $T = 1.7$°K a negative magnetoresistance up to -2% is observed. With free mounting of the sample, such large values of $\Delta\rho_H/\rho_0$ are not observed.

Fig. 1. Dependence of the magnetoresistance on the magnetic-field strength in sample Si-9 at 4.21 (1) and 1.70° K (2).

Figure 2. Dependence of the negative magnetoresistance on the impurity concentration in n-type silicon samples. $T = 4.2°K$, $H = 16.5$ kG.

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Fig. 2. Dependence of the negative magnetoresistance on the impurity concentration in n-type silicon samples. $T = 4.2°K$, $H = 16.5$ kG.

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Note: Figure translations are in progress. See original paper for figures.