CHANGE IN THE MAGNETORESISTANCE OF n-GaAs IN AN ELECTRIC FIELD

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The effect of an electric field on the magnitude of the magnetoresistance in epitaxial n-GaAs films with free carrier concentrations \( n_e = 4.0 \times 10^{12} \) cm\(^{-3}\) at \( T = 4.2^\circ\text{K} \) was investigated. It was found that in weak electric and magnetic fields for \( E < E_b \) (\( E_b \) is the intensity of the low-temperature impurity breakdown field) the magnetoresistance (MR) is negative, and for \( E \geq E_b \) only a positive magnetoresistance is observed. The experimental results are explained by a change in the concentration of centers with a magnetic moment and of electrons in the impurity band in prebreakdown electric fields.

At low-temperatures in gallium arsenide with carrier concentrations \( n_e < 10^{16} \) cm\(^{-3}\) conditions are realized for a transition from impurity to intrinsic conductivity due to low-temperature impurity breakdown in electric fields \( E < 10 \) V/cm [1, 2]. At the same time, we can expect a significant change in the magnitude of the measured magnetoresistance (MR). The negative MR of gallium arsenide in weak electric fields at low temperatures was thoroughly studied in [3-7]. However, the effect of the electric field on the magnitude of the negative MR was studied only in strongly compensated n-GaAs [8], in which at helium temperatures the overwhelming majority of electrons was delocalized, while breakdown conditions were not realized [9]. The decrease in the negative MR, observed in fields \( E = 5-50 \) V/cm, is related to the increase in the effective temperature of the electron gas, which agrees with the behavior of the current-voltage characteristics of strongly compensated gallium arsenide.

The purpose of the present work is to investigate the effect of the electric field on the magnitude of MR in gallium arsenide both in prebreakdown electric fields as well as under conditions of low-temperature impurity breakdown. We investigated quite pure, weakly compensated (\( \kappa \approx 0.6 \)), epitaxial n-GaAs films not specially alloyed and specially alloyed with shallow-nonmagnetic Te, Se, and Sn impurities. The crystals were grown on semiinsulating substrates consisting of gallium arsenide by gas epitaxy and had a free electron concentration of \( n_e = 4.0 \times 10^{12} \) cm\(^{-3}\), ensuring maximum negative MR [3, 4].

The measurements were carried out in longitudinal (\( E \parallel H \)) and transverse (\( E \perp H \)) magnetic fields. In addition, the transverse MR was measured both in a Hall geometry, when the normal \( n \) to the film surface is parallel to the direction of the magnetic field \( H \), as well as for \( n \perp H \). The nature of the dependences of the MR on the magnetic and electric fields differs little from the cases \( E \parallel H \) and \( E \perp H \) with \( n \parallel H \) and \( n \perp H \). For this reason, for definiteness, the behavior of the transverse MR with \( n \perp H \) is shown on the graphs.

The current-voltage characteristics of the specimens studied at \( T = 4.2^\circ\text{K} \) had, in an electric field \( E = 6-10 \) V/cm, regions with a sharp increase in current with practically no change in voltage, caused by impact ionization of the neutral level of the shallow donor. For \( E < E_b \) (\( E_b \) is the impurity breakdown field intensity), two regions can be distinguished on the current-voltage characteristic (Fig. 1, curve 1): region A (\( E < E_o \)), in which Ohm's law \( j = \sigma E \) (\( \sigma = \text{const} \)) is satisfied and region B (\( E > E_o \)) with prebreakdown fields, in which the electrical conductivity \( \sigma \) increases monotonically. The increase in \( \sigma \) in region B,


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generally speaking, could be related to the increase in the mobility $\mu$ or free electron concentration $n_e$ in the conduction band. Analysis of the temperature dependence of Hall's constant $R_H$ shows that in the specimens studied at $T = 4.2^\circ$K the conductivity in the impurity band predominates. Indeed, the function $R_H(T)$ (curve 2) has a maximum characteristic for two-band conductivity [10]. The dependence of $R_H$ on the electric field intensity also has a maximum for $E > E_o$ (curve 3) and decreases sharply in the breakdown region. In the case of the two-band conductivity $R_H$ attains maximum magnitudes with $\sigma_1 = \sigma_2$, where index 1 corresponds to the conduction band and index 2 to the impurity band. Therefore, the maximum on the curve $R_H(E)$, just as on $R_H(T)$, can be related to carrier redistribution in the electric field between the impurity and conduction bands. Thus, in region A, impurity-band conductivity predominates, while in B, intrinsic conductivity predominates, and the nonlinearity of the current--voltage characteristic in prebreakdown fields is caused not by carrier heating, but by transfer of carriers into the conduction band by the fastest electrons. As is evident from the jump in the current on the current--voltage characteristic at $E = E_b$, the carrier mobility in the conduction band is much greater than the impurity mobility, which is what leads to the nonlinear conductivity in prebreakdown fields.

Analysis of the magnetoresistance of such specimens showed that in weak magnetic and electric fields up to the onset of impact ionization of the shallow impurity, MR is negative and its magnitude depends on the intensity of the electric field applied to the specimen. Figure 2 shows the field dependence of MR for two specimens with different electric field intensities. It is evident that for specimens with $n_e = 4.2 \times 10^{15}$ cm$^{-3}$ the measured MR consists of negative ($H < 5$ kOe) and positive ($H > 5$ kOe) components and the contribution of each of them varies according to the increase in the electric field. The magnitude of the negative MR component decreases with increasing $E$ (curves 1-4) and for $E \geq E_b$ only positive MR are observed (curves 6), whose field dependence is close to quadratic in accordance with the classical theory. For a number of specimens in a weak electric field the amplitude of negative MR ($\Delta \rho/\rho_0$) constituted (5-7)% and the transition to positive MR was not observed (curves 7). However, the decrease in negative MR and the transition to positive MR in an electric field were characteristic for them as well.

The dependence of negative MR on the electric field intensity for the same specimens is shown in Fig. 3. It is evident that the transition from negative to positive MR occurs in an electric field $E_C$ that is less than the low temperature impurity breakdown field $E_b$ and the transition to positive MR was not observed (curves 7). However, the decrease in negative MR and the transition to positive MR in an electric field were characteristic for them as well.

![Fig. 1](image1.png)

![Fig. 2](image2.png)

**Fig. 1.** 1) Current--voltage characteristic of the specimen with $n_e = 4 \times 10^{15}$ cm$^{-3}$ at $T = 4.2^\circ$K; 2) temperature dependence of the Hall constant; 3) electric field intensity (3).

**Fig. 2.** The field dependence of transverse MR for different electric field intensities. $n_e$, cm$^{-3}$: 4\( \times \)10$^{15}$ (1-6); 7.5\( \times \)10$^{15}$ (7). $E$, V/cm: 1) 1.2; 2) 2.3; 3) 4.7; 4) 5.9; 5) 7.1; 6) 10; 7) 0.4.