Effects of weak electron localization in thin GaAs films

A. K. Savchenko, V. N. Lutskiĭ, and V. I. Sergeev
Institute of Radio Electronics, Academy of Sciences of the USSR, Moscow

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Negative magnetoresistance of GaAs films, which is interpreted on the basis of the theory of localization, is observed. The temperature dependences of the resistance and magnetoresistance are measured; the values of parameters entering into the theory are determined.

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We examined thin (200–1,000 Å) GaAs films, grown by gas epitaxy from metal-organic compounds on a semi-insulating, single-crystal GaAs substrate. The observed dependences of the resistance (R) of the specimens on the temperature (T) and magnetic field (H) had a form characteristic of electron-localization effects in the two-dimensional case: a logarithmic increase in R with decreasing T, negative magnetoresistance (NMR) in weak fields and presence of a logarithmic section on the curve $\Delta R(H)$.

A "frozen" photoconductivity was discovered in the films investigated: the resistance of the film at $T = 4.2$ K decreases significantly under the action of light and essentially retains its value when the light source is switched off (the time constant is equal to several hours). R returns to the dark level when the film is heated. This

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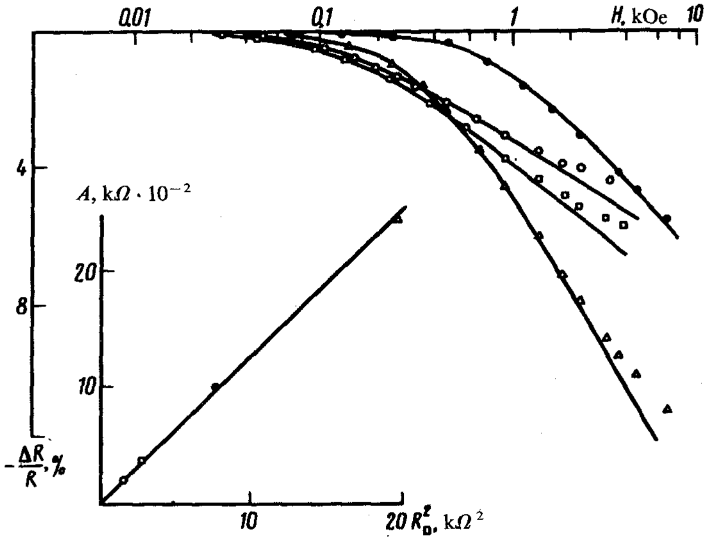

FIG. 1. Negative magnetoresistance of a GaAs film with $d \sim 500$ Å with different levels of bias lighting ($T = 4.2$ K, $R_\square = 4.5$ kΩ is the dark resistance).

allowed performing several measurements on a single specimen, having a different resistance depending on the level of bias illumination switched-on for a short time.

Figure 1 shows the curves $\Delta R(H)$ at $T = 4.2$ K for specimen No. 5 with thickness $d \sim 500$ Å (electron concentration $\sim 9 \times 10^{17}$ cm^{-3} and mobility ~ 200 cm^{-2}/V·s), whose resistance was varied with the help of the light in the range $R_\square = 4.5 - 1.2$ kΩ ($R_\square$ is the resistance of the film "on a square," and the first value corresponds to the dark resistance). The curves show the theoretical dependences describing the effect of weak localization of electrons in the two-dimensional case[1]:

$$\Delta R_\square(H) = -A\left(\ln x + \Psi\left(\frac{1}{2} + \frac{1}{x}\right)\right),$$

where $A = \alpha \dfrac{R_\square^2 e^2}{2\pi^2 h}$, α is a coefficient whose theoretical value is $\alpha = 1$, Ψ is the digamma function, $x = 4\dfrac{L_{\phi e} H}{c\hbar}$, $L_\phi = \sqrt{D\tau_\phi}$ is the diffusion length over the interruption time of the phase of the electron wave τ_ϕ, and D is the diffusion constant. The theoretical curves contain two adjustable parameters A and L_ϕ, which were determined from the best fit with experimental data. The insert in Fig. 1 shows the curve $A(R_\square^2)$, which is linear, in agreement with theory; the value $\alpha = 0.96$ is determined from the slope of the straight line.

We note that a measurement of the dependence $\Delta R(H)$ for different angles γ between the directions of the magnetic field and the film showed that the NMR depends only on the normal component of the field: the curves $\Delta R_\gamma(\lg H)$ are displaced relative to the curve $\Delta R_{90°}(\lg H)$ along the abscissa axis by an amount $-\lg \sin\gamma$. This

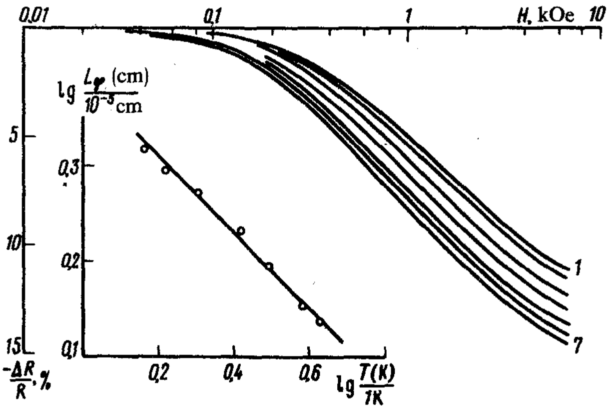

FIG. 2. Magnetoresistance of a specimen at different temperatures [$T = 4.2$ K (1) and 1.5 K (7)].

confirms the two-dimensional nature of the magnetoresistance of the specimens studied.

Measurement of the dependence $\Delta R(H)$ at different temperatures (Fig. 2) allowed finding the temperature dependence of the length L_ϕ and the exponent p in the temperature dependence τ_ϕ ($\tau_\phi \sim T^{-p}$). The insert in Fig. 2 shows the curve $\lg L_\phi$ ($\lg T$), whose slope angle gives $p = 0.82$. The magnitude obtained is close to unity. This permits assuming that the main mechanism for phase interruption is electron-electron scattering in the "dirty" limit.[2] In the temperature range investigated, the quantity L_ϕ varies in the range 1,000–3,000 Å, which agrees with the condition for two-dimensional localization: $L_\phi > d$.

Figure 3 shows the temperature dependences of the resistance of film No. 5 measured with $H = 0$ (1) and $H = 2$ kOe (2). The magnitude of the magnetic field indicated corresponds to the beginning of the logarithmic section of the curve $\Delta R(H)$; in addition, according to theory,[1] the magnetic field eliminates that part of the temperature dependence of the resistance that arises due to the localization effect. Curve 3 in Fig. 3 was obtained by subtracting (2) from (1) and must represent the localized behavior in $R(T)$. The dependence obtained was compared with the theoretical expression for two-dimensional localization[3]:

$$\Delta R_\square = -\alpha p \frac{R_\square^2 e^2}{2\pi^2 \hbar} \ln T,$$

from which the value $\alpha p = 0.71$ was determined. This quantity agrees with the quantities $\alpha = 0.96$ and $p = 0.82$ obtained from an analysis of the negative magnetoresistance. The contribution of electron-electron interaction[4] to $\Delta R(T)$ is apparently small in the specimens investigated, since measured temperature dependence of the Hall constant R_x showed a much smaller change in R_x with changing temperature than that which follows from the interaction theory:

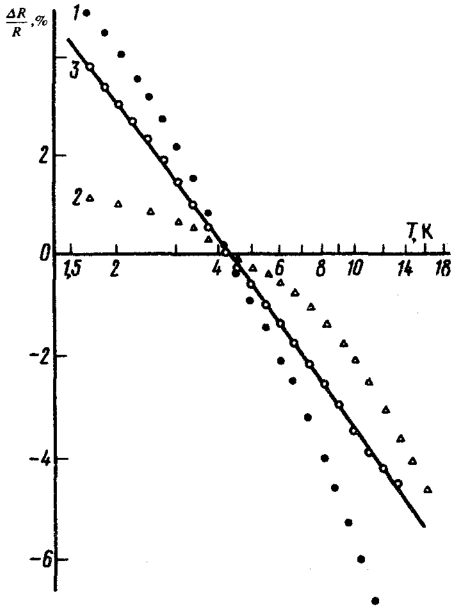

FIG. 3. Temperature dependence of the resistance of a GaAs film with $H = 0$ and $H = 2$ kOe.

$$\frac{\Delta R_x}{R_x} = 2\frac{\Delta R}{R}$$

We note that localization and electron interaction effect were observed on GaAs-GaAlAs heterojunctions,[5] but the analysis of the results in this system was greatly complicated due to the presenece of two dimensional sub-bands beneath the Fermi level. In the specimens studied by us, dimensional quantization was not manifested, greatly simplifying the analysis. The approximately equal values of the parameters α and p, obtained in Ref. 5 and in the present work, should be noted.

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