LONGITUDINAL MAGNETORESISTANCE OF SEMICONDUCTIVE FILM WITH THE PARABOLIC POTENTIAL IN QUANTIZING MAGNETIC FIELD

Kh.A. GASANOV
Scientific-technical complex "Informatika"

In this work longitudinal magnetoresistance in semiconductive films with parabolic potential in strong magnetic field are investigated. It is shown that longitudinal magnetoresistance is nedative at certain value of the magnetic field. Its magnitude is determined by spin splitting.

The account of quantiation the electron motion in the magnetic field unlike the classic theory leads to different from zero the longitudinal magnetoresistance. The change of the longitudinal magnetoresistance is caused by the fact that in the quantum magnetic field the possibility of the charge carriers scattering and Fermi level depend essentially on the magnetic field [1-3]. The longitudinal magnetoresistance in some region of the magnetic field may be negative, it has been experimentally observed in the wide range of semiconductors [4, 5]. The magnetoresistance sign, its value, the nature of the temperature and field dependence have been determined by m any factors, the band structure, the relaxation mechanism and size of sample. In paper [6] the existence of the negative magnetoresistance in the multilinear semiconductors in the fixed region of the magnetic field both for three and two-dimensional electron gas when has been theoretically predicted, the sample thickness has been compared with the diffusion length, which is connected with the account of the spin-orbit scattering of the current carriers on the impurities. It has been also noted, that in the same region of the magnetic fields in the non-degenerate case the main contribution in to the anomaly magnetoresistance gives the quantum correction to the magnetoresistance without the account of the electron interaction, caused by the spin-orbit interaction. Suggested in the present paper theoretically research gives the alternative explanation to the negative magnetoresistance of the semiconductive film with the parabolic potential in the strong magnetic field, placed in the film plane with the account of the spin-orbit interaction. It has been established, that in some region of the magnetic fields, the magnetoresistance of the non-degenerated electron gas has the negative values. Besides the behavior of the electron gas depends essentially on the spin splitting.

The electron energy spectrum of the conductivity in the parabolic quantum well in the longitudinal quantizing magnetic field has the form [7]:

$$\varepsilon_{N,k_y,k_Z,\sigma} = \left(N+\frac{1}{2}\right)\hbar\omega + \frac{\hbar^2 k_Z^2}{2m} + \frac{\omega_0^2}{\omega^2}\frac{\hbar^2 k_y^2}{2m} + \sigma g\mu_B H \qquad (1)$$

Here Landaus gauge is chosen for the vector-potential $\overline{A}(0, x\cdot H, 0)$; ω_0 characterizes the parabolic potential of the film:

$$U = \frac{m\omega_0^2 x^2}{2}$$

$$\omega = \sqrt{\omega_o{}^2 + \omega_C{}^2},\ \omega_c = \frac{eH}{mc}$$

is the cyclotron frequency, μ_B is Bohr magneton, g is the factor of the spin splitting, $\sigma = \pm\frac{1}{2}$, N is the number of the quantum level. The coordinate wave function, corresponding to the energy eigenvalue (1) has the form:

$$\varphi_{N,k_y,k_z}(r) = \varphi_N(x-x_0)\exp(ik_y\cdot y + ik_z\cdot z) \qquad (2)$$

where

$$\varphi_N(x-x_0) = \frac{1}{\pi^{\frac{1}{4}} a_0^{\frac{1}{2}}\sqrt{2^N N!}}\exp\left(-\frac{(x-x_0)^2}{2a_0^2}\right)H_N\left(\frac{x-x_0}{a_0}\right)$$

where

$a_0 = \sqrt{\frac{\hbar}{m\omega}}$; $x_0 = -\frac{\omega_c}{\omega}\frac{\hbar k_y}{m\omega} = -\frac{\omega_c}{\omega}a_0^2 k_y$, H_N is the Ermitte polynomial.

The current density in the direction of the magnetic and electric fields (H//j) is given by the following expression:

$$j_z = -e\frac{L_y L_z}{(2\pi)^2}\sum_{N,\sigma}\int\int_{-\infty}^{\infty}\frac{\hbar k_z}{m}f_1(\varepsilon)dk_y dk_z \qquad (3)$$

where $f_1(\varepsilon)$ is the non-equilibrium addition to the Fermi Derek spreading function, $f_1(\varepsilon)$ is presented in the form:

$$f_1(\varepsilon) = \frac{\hbar k_z}{m}\tau_H(\varepsilon)\left(\frac{\partial f_0}{\partial\varepsilon}\right)eE_z \qquad (4)$$

where $\tau_H(\varepsilon)$ is relaxation time in the quantizing magnetic field. In the case of the scattering in the short-acting potential, the relaxation time m ay be present ed in the form [1]:

$$\tau_H^{-1}(\varepsilon)=\tau_0^{-1}g_H(\varepsilon) \qquad (5)$$

where $g_H(\varepsilon)$ is the density of states, which for the charge carriers in the parabolic well in the longitudinal quantizing magnetic field has the form:

$$g_H(\varepsilon)=\frac{L_yL_z}{2\pi\hbar^2}\cdot\frac{m\omega}{\omega_0}\sum_{N,\sigma}\Phi(\varepsilon-\varepsilon_{N,\sigma})\Phi(-\varepsilon+\varepsilon_{N,\sigma}+\frac{\beta L_x^2}{4}) \qquad (6)$$

Here $\varepsilon_{N,\sigma}=\hbar\omega\left(N+\frac{1}{2}\right)+\sigma g\mu_B H$

$\Phi(x)$ is the Heaviside function, $\beta=\frac{m\omega_0^2}{2\omega_c^2}\cdot\omega^2$

At the real concentration Fermi levels are located much below $\frac{\beta L_x^2}{4}$, therefore in the case of the weak filling in the expression for the density of states (6) $\Phi\left(-\varepsilon+\varepsilon_{N,\sigma}+\frac{\beta L_x^2}{4}\right)$ may be considered equal to 1.

Applying formulae (3-6) and passing to the polar coordinates for the conductivity σ_{zz} we obtain

$$\sigma_{zz}=\frac{e^2L_yL_z}{2\pi\hbar^2}\cdot\frac{\omega}{\omega_0}\sum_{N,\sigma}\int_{\varepsilon_{N,\sigma}}^{\infty}(\varepsilon-\varepsilon_{N,\sigma})\tau_H(\varepsilon)\left(-\frac{\partial f_0}{\partial\varepsilon}\right)d\varepsilon \qquad (7)$$

In order to calculate y_{zz} we should divide the integration region on the energy from the region $\frac{\hbar\omega}{\kappa_0 T}r$ to $\frac{\hbar\omega}{\kappa_0 T}(r+1)$ and then performing the summation over r from 0 to ∞. Thus, after the integration on the energy and the summation on the spin we obtain:

$$\begin{aligned}\sigma_{zz}=\frac{\sigma_0}{2}\sum_{N=0}^{\infty}\sum_{r=0}^{\infty}\Bigg\{&\frac{1}{N+r+1/2}\Bigg[arf_0\left(a\left(N+r+1/2\right)-\frac{b}{2}\right)-(ar+b)f_0\left(a\left(N+r+1/2\right)+\frac{b}{2}\right)+\\&+\ln\frac{1+e^{\eta-a(N+r+1/2)+\frac{b}{2}}}{1+e^{\eta-a(N+r+1/2)-\frac{b}{2}}}\Bigg]+\frac{1}{N+r+1}\Bigg[(2ar+b)f_0\left(a\left(N+r+1/2\right)+\frac{b}{2}\right)-\\&-(2a(r+1)+b)f_0\left(a\left(N+r+3/2\right)-\frac{b}{2}\right)+\ln\frac{1+e^{\eta-a(N+r+1/2)-b/2}}{1+e^{\eta-a(N+r+3/2)+b/2}}+\\&+\ln\frac{1+e^{\eta-a(N+r+1/2)-b/2}}{1+e^{\eta-a(N+r+3/2)+b/2}}\Bigg]+\frac{1}{N+r+3/2}\Bigg[a(r+1)f_0\left(a\left(N+r+3/2\right)+\frac{b}{2}\right)-\\&-(a(r+1)-b)f_0\left(a\left(N+r+3/2\right)-\frac{b}{2}\right)+\ln\frac{1+e^{\eta-a(N+r+3/2)+b/2}}{1+e^{\eta-a(N+r+3/2)-b/2}}\Bigg]\Bigg\}\end{aligned} \qquad (8)$$

where

$$a=\frac{\hbar\omega}{k_0T},\ b=\frac{g\mu_B H}{k_0T},\ \eta=\frac{\xi}{k_0T},\ \sigma_0=\frac{e^2n\tau_0}{m} \qquad (9)$$

here n is the two-dimensional concentration.

This formula is true for the arbitrary degree of the electron gas degeneracy.

It is possible to sum N and r for the non-degenerated electron gas, and this formula (8) can be presented the form

$$\sigma_{zz}=\sigma_0\frac{e^{-\frac{a}{2}}}{4}\frac{sh\frac{a}{2}}{ch\frac{b}{2}}\left[(2-b)+a\,sh\frac{b}{2}+\frac{a\,ch\frac{b}{2}}{(1-e^a)}+\frac{1}{2}(2b-a)e^{\frac{a}{2}}\,sh\frac{b}{2}\ln cth\frac{a}{4}\right] \qquad (10)$$

From the formula (10) it is possible to show, that the region of the magnetic field and temperature exist, where $\rho(H)<\rho(0)$, ($\rho(0)$) is the resistance in the absence of the magnetic field, i.e it has been establish negative magnetoresistivity, magnitude of which depend on the value of the spin splitting, unlike the negative magnetoresistance, revealed for the three-dimensional case in the paper [3], where the spin splitting can not done into account. It is shown that longitudinal magnetoresistance is negative at certain value of the magnetic field.

Supposing $a>1$, $a>b$, $b<1$, for the magnetoresistance $\frac{\Delta\rho}{\rho}=\frac{\rho(H)-\rho(0)}{\rho(0)}$, we receive from (10):

$$\frac{\Delta\rho}{\rho}=-\frac{b^2(H)}{4}=-\left(\frac{g\mu_B H}{2k_0 T}\right)^2 \tag{11}$$

Using the above-indicated formulae and numerous calculations, it is possible to determine such physical characteristics as the factor of the spin split, the parameter of the quantum well ω_0.

[1] *B.M.Askerov*. Kinetic effects in semiconductors, L. Nauka ,1970, p.303.
[2] *P.N. Argyres, E.N.Adams*. Phys.Rev, 104, 900 (1956)
[3] *L.S.Dubinskaya*. FTT, 1965, 7, 2821.
[4] *A.I.Dmitriev, Z.D.Kovalev, V.I.Lazorenko and G.V.Lashkarev* Phys. Stat. Sol.(b), 1990, 162,213.
[5] *E.G.Gwinn, R.M.Westervelt, P.F. Hopkins, A.J.Rimberg, M.Sundaram, and A.C.Gossard*. Phys. Rev. B 39, 1989, 6260.
[6] *V.L. Altshuler, A.G. Aronov, A.I.Larkin, D.E.Khmelnitskiy*. JETP, 1981, v.81, issue2, 768.
[7] *F.M. Gashimzade, A.M.Babayev, Kh.A.Gasanov* FTT,2001, 43, 1776.

X.A.Həsənov

KVANTLAYIJI MAQNİT SAHƏSİNDƏ PARABOLİK POTENSİALLI YARIMKEÇİRİCİ TƏBƏQƏNİN UZUNUNA MAQNİT MÜQAVİMƏTİ

Bu işdə güclü maqnit sahəsində parabolik potensiallı yarımkeçirici təbəqənin uzununa maqnit müqaviməti tədqiq edilmişdir. Təyin edilmişdir ki, maqnit sahəsinin müəyyən oblastında maqnit müqavimətinin dəyişməsi mənfi olur və bu spin parçalanması ilə bağlıdır.

Х.А. Гасанов

ПРОДОЛЬНОЕ МАГНИТОСОПРОТИВЛЕНИЕ ПОЛУПРОВОДНИКОВОЙ ПЛЕНКИ С ПАРАБОЛИЧЕСКИМ ПОТЕНЦИАЛОМ В КВАНТУЮЩЕМ МАГНИТНОМ ПОЛЕ

В работе исследовано продольное магнитосопротивление полупроводниковой пленки с параболическим потенциалом в сильном магнитном поле. Установлено, что существует область магнитного поля, где магнитосопротивление отрицательно, причем величина магнитосопротивления определяется спиновым расщеплением.

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