Magnetic-field-induced breakdown of correlation between spins and momenta of photoexcited electrons in GaAs crystals

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(Submitted July 21 1982)
Pis'ma Zh. Eksp. Teor. Fiz. **36**, No. 5, 155–157 (5 September 1982)

The effect of a longitudinal magnetic field on the circular polarization of recombination photoluminescence of hot electrons is observed. This effect is related to the change in the mutual orientation of correlated momenta and spins of photoexcited electrons.

PACS numbers: 78.55.Ds, 78.20.Ls

It was established in Ref. 1 that circular polarization ρ_c of hot photoluminescence (HPL) greatly exceeds the polarization of thermalized luminescence in the presence of circular pumping in GaAs. This result was interpreted in Ref. 2 as the manifestation of correlation between momenta and spins of photoexcited electrons. Until now, however, there was no direct experimental proof of this interpretation. In this work, we observed a decrease in the magnitude of ρ_c in a longitudinal magnetic field (Faraday geometry), because of the breakdown of spin-momentum correlation.

At first glance, it appears that a magnetic field **B**, which is parallel to the exciting light beam, should not decrease the circular polarization of HPL due to the axial symmetry of the system. However, since the precession frequencies of the spin and momentum of an electron in a magnetic field are different, their mutual orientation varies with time. A change in ρ_c is attributable to the fact that the selection rule for radiative recombination depends only on the orientations of the momentum and spin of the recombining electron separately but also on their mutual orientation. For electrons in GaAs, the Larmor frequency is much smaller than the cyclotron frequency, so that spin precession can be ignored.

The term in the electron density matrix, which describes the correlation is proportional to the expression[2]:

$$3(\mathbf{n},\vec{\nu})\,(\vec{\sigma},\,\vec{\nu}) - (\vec{\sigma},\,\mathbf{n}).$$

Here $\vec{\sigma}$ are the Pauli matrices, while the unit vectors **n** and $\vec{\nu}$ are oriented along the light beam and along the momentum, respectively. A longitudinal magnetic field only affects the matrix $(\sigma,\vec{\nu})$. The inclusion of the cyclotron motion of electron reduces in this case to the substitution $\nu_\pm \to \nu_\pm \exp(\mp i\omega_c t)$, where $\nu_\pm$ are the circular components of the vector $\vec{\nu}$, while ω_c is the cyclotron frequency. After the usual averaging over time,[1] the nondiagonal part of the matrix $(\vec{\sigma},\vec{\nu})$ approaches 0 with increasing parameter $\omega_c\tau$ (τ is the lifetime of electrons in the initial state relative to the inelastic scattering).

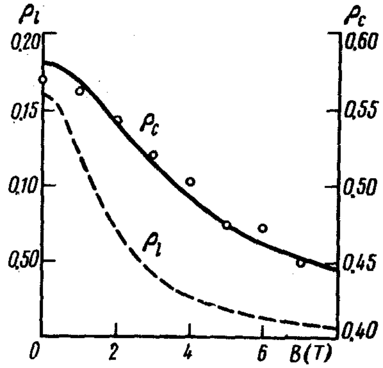

FIG. 1. Curves showing the degree of circular $\rho_c(B)$ and linear $\rho_L(B)$ polarization for GaAs (Zn), $\mathbf{B}\|[111]$, $N_A = 9\times10^{16}$ cm^{-3}, $T = 20$ K. The continuous curve represents $\rho_c = A + [C/(1+x^2)]$, where $A = 0.43$ and $C = 0.15$. The dashed curve represents $\rho_L = [C/(1+(2x)^2)]$.

We shall present results of a calculation of the degree of polarization of HPL for electron recombination to the ground state of a shallow acceptor. In the spherical approximation (neglecting the undulations of the valence band),

$$\rho_c = \frac{2}{20-a}\left(10S + 2\beta + \frac{3\beta}{1+x^2}\right), \quad x = \omega_c \tau,$$

where α, S, and β are parameters of the electron density matrix: the quantity α describes the anisotropy of the momentum distribution, S describes the spin anisotropy, and β describes the correlation between the momentum and spin distributions. For $S = 1/4$, $\beta = 1$ and $\alpha = -1$, which correspond to excitation from the heavy-hole band,[2] we obtain $\rho_c \approx 0.71$ for $x = 0$ and $\rho_c \approx 0.43$ for $x \gg 1$. If the undulations are included by separating the diagonal orientations of the momenta $v\|\{111\}$,[1] then for different magnetic field orientations relative to the crystallograhic axes we find

$$\begin{aligned}
&\mathbf{B}\|[100] \qquad \rho_c = \frac{1}{2}\left(2S + \frac{\beta}{1+x^2}\right),\\
&\mathbf{B}\|[110] \qquad \rho_c = \frac{1}{4}\left(4S + \beta + \frac{\beta}{1+x^2}\right), \qquad (1)\\
&\mathbf{B}\|[111] \qquad \rho_c = \frac{2}{12-a}\left(6S + 2\beta + \frac{\beta}{1+x^2}\right).
\end{aligned}$$

It is evident that the largest effect is expected for $\mathbf{B}\|[100]$, where for values of S and β presented above the quantity ρ_c decreases with increasing B by a factor of 3: $\rho_c = 0.75$ for $x = 0$ and 0.25 for $x \gg 1$.

Figure 1 shows the experimental dependence $\rho_c(B)$ for $\mathbf{B}\|[111]$. The smaller value of $\rho_c(0)$ as compared with the theoretical value (according to (1), for this geometry $\rho_c(0) \approx 0.69$) is apparently a result of the action of the precession mechanism for spin relaxation.[3] The experimental dependence $\rho_c(B)$ is well described by a curve of the

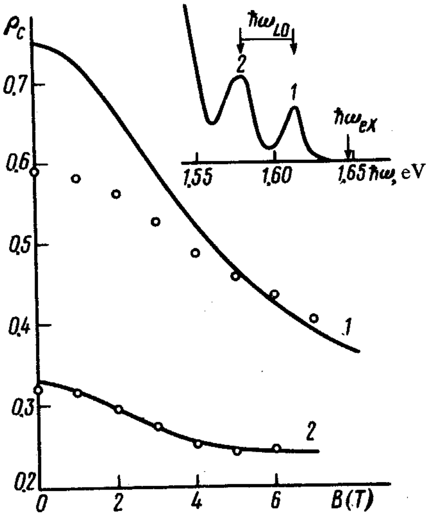

FIG. 2. The curves $\rho_c(B)$ for GaAs (Zn), B$\|$[100], $N_A = 2\times10^{16}$ cm^{-3}, $T = 20$ K. Curve 1 shows the luminescence from the point of creation and curve 2 shows luminescence after emission of an optical phonon. The continuous curves show the calculations and the points show the experimental values. The insert shows the HPL spectrum with excitation $\hbar\omega_{ex} = 1.65$ eV.

form $A + \dfrac{C}{1+x^2}$ with the half-width of the Lorentz term double the corresponding half-width of the curve for linear polarization $\rho_L(B)$, also shown in Fig. 1.[1)] This relation follows from (1) and the dependence $\rho_L(B)/\rho_L(0) = (1+4x^2)^{-1}$.[1] The total change in ρ_c is equal to the theoretical value $\rho_c(0) - \rho_c(\infty) \approx 0.15$.

Analogous dependences for the orientation B$\|$[100] are presented in Fig. 2, together with theoretical curves for recombination of electrons from the point of creation (curve 1), as well as after emission of a single optical phonon (curve 2). It is evident that the change in ρ_c is larger for this geometry, while in case 2 the limiting theoretical value $\rho_c = 0.25$ is attained in the experiment.

We thank B. P. Zakharchenya and V. I. Perel' for useful discussions.

[1)]The appearance of linear polarization with linearly polarized excitation is a result of the increase in the electron momenta, while the decrease in ρ_L in a longitudinal magnetic field is a result of their rotation under the action of the Lorentz force.[1]

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Translated by M. E. Alferieff
Edited by S. J. Amoretty