Depolarization of hot photoluminescence in GaAs crystals in a magnetic field

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The rotation of the momentum distribution function of hot electrons was recorded in *p*-GaAs crystals from the variation of the polarization characteristics of hot photoluminescence in the magnetic field. This made it possible to measure the lifetime of hot electrons in the 0.4-eV state. For an acceptor concentration of 1.2×10^{18} cm^{-3} the lifetime was 5×10^{-14} sec.

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It was shown earlier that anisotropic distribution (alignment) of momenta of photoexcited electrons occurs as a result of interband absorption of light in GaAs semiconductors with a band structure.[1] Thus, for example, excitation of the band of heavy holes by a linearly polarized light produces electrons with a preferential direction of momenta, which is perpendicular to the electric vector of the exciting light. The anisotropy of the momentum distribution occurs in the linear polarization of hot photoluminescence (HPL). Isotropization of the distribution function and hence depolarization of the luminescence occur during the energy relaxation.

It can be expected that in a sufficiently strong magnetic field H, a rotation of the anisotropic part of the momentum distribution function occurs due to cyclotron motion of electrons. This rotation can be determined from the variation of HPL polarization characteristics. Such effect can be observed if the cyclotron frequency ω_c is not too small in comparison with the reciprocal time of the energy relaxation. This gives rise to a nontrivial possibility of direct measurement of the energy relaxation time of hot electrons and of the energy dependence of these times.

Below we give the results of measurements of the HPL polarization in the (111) plane of a *p*-GaAs sample with an acceptor concentration $N_A(\mathrm{Zn}) = 1.2\times10^{18}$ cm^{-3} in $\leqslant$60-kg magnetic fields. The measurements were made in the Faraday geometry (**H** is parallel to the exciting beam). The excitation was accomplished by a He-Ne laser emission (1.96 eV), so that the energy of the hot electrons at the time of their generation was $\epsilon_c = 0.4$ eV.

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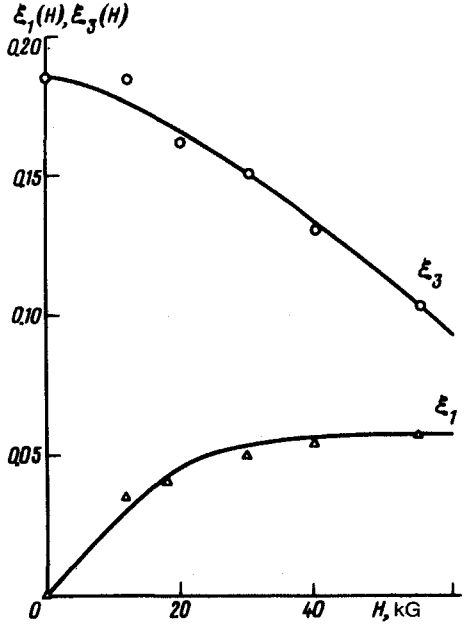

FIG. 1. Variation of the HPL Stokes parameters in the magnetic field ($\hbar\omega_L = 1.893$ eV).

At temperature of the experiment (1.5 K) the luminescence spectrum was generated by band-acceptor transitions. The maximum energy in the spectrum, 1.89 eV, corresponds to recombination of the electrons that have not undergone energy relaxation. The luminescence polarization for this energy is characterized by two Stokes parameters.[2] One of them, ξ_3, coincides with the polarization of the form $(I_{\|} - I_{\perp})/(I_{\|} + I_{\perp})$, where $I_{\|,\perp}$ are the intensities of the luminescence that is polarized parallel (perpendicular) to the excitation polarization. The other Stokes parameter, ξ_1, characterizes the polarization of the form $(I_{\pi/4} - I_{-\pi/4})/(I_{\pi/4} + I_{-\pi/4})$, where $I_{\pm\pi/4}$ are the intensities of the radiation that is polarized at the corresponding angles to the excitation polarization.

A rotation of the distribution function should depolarize the luminescence along the initial axes (ξ_3 decreases) and polarize it along the rotated axes (ξ_1 increases). The curves in Fig. 1 have this shape. The behavior of ξ_3 and ξ_1 in Fig. 1 indicates that the plane of the maximum HPL polarization rotates with the field. In the absence of collisions, the rotation of the electron momentum distribution function would periodically change the polarization with the field: $\xi_3(H) \sim \cos 2\omega_c t$. Inelastic collisions release the electrons from the energy state ϵ_c. Averaging in the usual way over the lifetimes of the electrons in this state, we obtain

$$\xi_3(H) = \xi_3(0)\frac{\int_0^\infty \cos 2\omega_c t \exp(-t/\tau)\, dt}{\int_0^\infty \exp(-t/\tau)\, dt} = \frac{\xi_3(0)}{1 + 4\omega_c^2 \tau^2}, \quad (1)$$

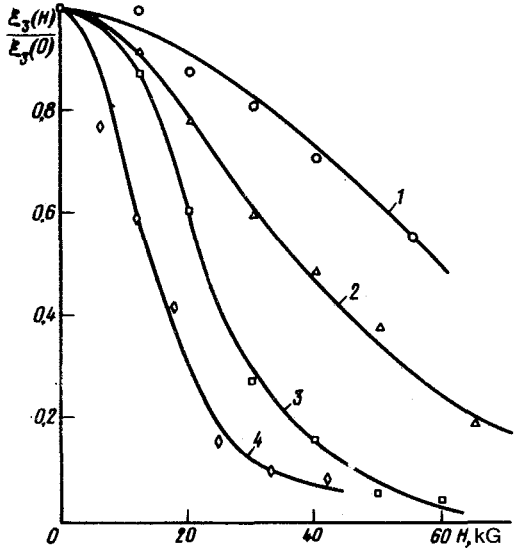

FIG. 2. Normalized Stokes parameter $\xi_3(H)/\xi_3(0)$ for different values of $\hbar\omega_L$: 1, 1.893 eV; 2, 1.85 eV; 3, 1.81 eV; 4, 1.771 eV.

where τ has the meaning of the average "lifetime" of the electrons in the state ϵ_c relative to all the processes that release them from this state. Equation (1) can be regarded only as a first approximation: specifically, it does not take into account the complications due to the nonsphericity of the isoenergetic surfaces in the valence band. Nevertheless, it describes rather well the experimental data for $\xi_3(H)$ (Fig. 1). The value of τ turns out to be 0.5×10^{-13} sec. Similar values of τ were obtained by using other samples with approximately the same doping. In calculating the cyclotron frequency ω_c in Eq. (1), we took into account the nonparabolicity of the conduction band in the framework of the Kane model.[3] At $H = 60$ kG ω_c is 1.0×10^{13} sec^{-1}.

Figure 2 shows a series of $\xi_3(H)$ dependences for different energies $\hbar\omega_L$ in the luminescence spectrum. The smaller values of $\hbar\omega_L$ correspond to longer residence times of the electrons in the conduction band from the moment of their formation with the energy $\epsilon_c = 0.4$ eV to the time the recombine with the release of a quantum $\hbar\omega_L$; hence the angles of rotation are larger in the given field. Because of this, the $\xi_3(H)$ dependences turn out to be steeper with decreasing $\hbar\omega_L$.

In our case (p-GaAs, $T = 1.5$ K, and $\epsilon_c = 0.4$ eV), the main mechanisms for the energy loss of hot electrons apparently are the emission of optical phonons (τ_{opt}^{-1} probability) and shock ionization of the acceptors (τ_i^{-1} probability). The measured value of τ is determined by both mechanisms: $\tau^{-1} = \tau_{opt}^{-1} + \tau_i^{-1}$. The estimate for GaAs at $\epsilon_c = 0.4$ eV and $T = 0$ K gives the value $\tau_{opt} \approx 2\times10^{-13}$ sec.[4] It can be assumed, therefore, that the measured value $\tau = 0.5\times10^{-13}$ sec is determined mainly by the second mechanism indicated above, i.e., shock ionization. From the results of this experiment and the estimate of τ_{opt} given above, we obtain $\tau_i = 0.7\times10^{-13}$ sec (at $N_A = 1.2\times10^{18}$ cm^{-3}). More precise values of τ_i and also of τ_{opt} can be obtained after performing similar experiments with less doped crystals in which the energy relaxation

occurs largely due to the emission of optical phonons. In similar studies of luminescence in the (100) plane, we observed a decrease of ξ_3 with H. However, unlike in the experiment described above, there was no rotation of the plane of the maximum luminescence polarization. This is attributable to the fact that for this orientation, as shown in Ref. 5, the direction of the maximum polarization of hot luminescence always coincides with [110].

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