

It is possible to separate the cases of two-neutron decay from the background of the simple successive evaporation of two neutrons by using the correlation between the energies of the two neutrons in the double decay. A study of the process of two-neutron decay will make it possible to investigate in detail the neutron stability limit. The behavior of this limit, unlike the proton stability limit, which is determined by the Coulomb interaction of the protons, depends on a number of factors, which can lead, in particular, to the existence of neutron nuclei [5] and distort this limit considerably.

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OPTICAL ORIENTATION OF CARRIERS IN INTERBAND TRANSITIONS IN SEMICONDUCTORS

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Optical orientation, meaning the preferred orientation of the electron spin upon absorption of polarized light, is one of the most fruitful methods of spectroscopy, and is extensively used for the investigation of atoms and ions [1]. Observation of optical orientation in a semiconducting crystal would make it possible to use the methods developed in atomic spectroscopy to investigate semiconductors, and particularly to perform accurate measurements of the lifetime, the spin-relaxation time, the carrier g-factors, etc. So far, however, only one communication was published reporting such investigations in semiconducting crystals [2].

We report here observation of optical orientation of free carriers in $\text{Ga}_x\text{Al}_{1-x}$ crystals upon excitation of the electrons by circularly-polarized light (σ^\pm) from the valence band into the conduction band. The degree of orientation was determined from the polarization of the recombination radiation. The investigations were performed on n- and p-type material at 4.2 and 77°K. In particular, an appreciable degree of electron orientation (0.46 ± 0.06) was obtained for the p-type material, and the lifetime of the electrons in the conduction band, $\tau = (1.2 \pm 0.2) \times 10^{-10}$ sec, was determined from the depolarization of the luminescence in a transverse magnetic field.

The luminescence was excited with an He-Ne laser ($h\nu = 1.959$ eV). The composition of the mixed crystals ($x \approx 0.7$) was chosen such as to make the laser radiation fall in the region of the interband transitions near the intrinsic-absorption edge. The degree of luminescence polarization, $S = |(I_{\sigma^+} - I_{\sigma^-}) / (I_{\sigma^+} + I_{\sigma^-})|$, (where I_{σ^\pm} is the radiation intensity for the polarization σ^+ or σ^-) was measured with the aid of special modulator, namely a rotating quarter-wave plate. In all the experiments a value $S \neq 0$ was observed only when the excitation was by circularly-polarized light. In the differential spectrum ($I_{\sigma^+} - I_{\sigma^-}$), the sign of the signal changed in this case when the polarization of the exciting light changed from σ^+ to σ^- .

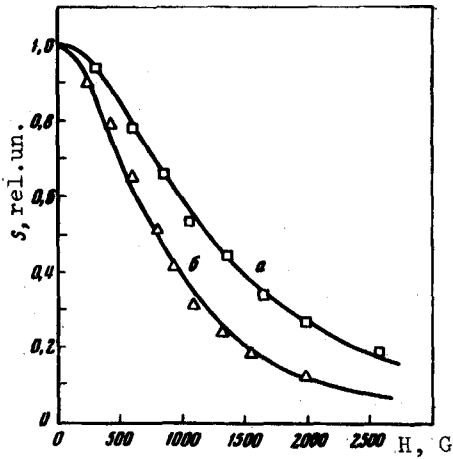


Fig. 1

Fig. 1. Dependence of the degree of luminescence polarization S on the transverse field in a p-type crystal at 77°K (a) and 4.2°K (b). The solid curves represent Lorentz contours with widths 1200 G (a) and 800 G (b).

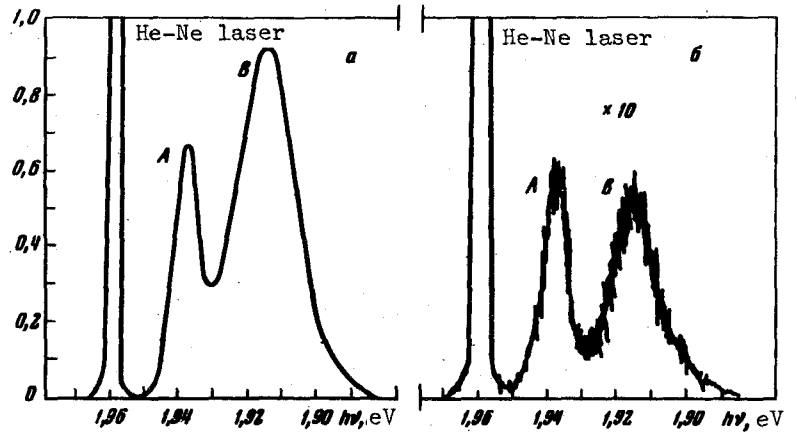


Fig. 2

Fig. 2. Polarized luminescence in n-type crystals at 4.2°K: a - luminescence spectrum, b - differential ($I_{\sigma^+} - I_{\sigma^-}$) spectrum of the radiation polarization of the same sample upon excitation with circularly polarized light σ^+ .

In the spectrum of the p-type crystals ($Zn \sim 10^{17} \text{ cm}^{-3}$) at 4.2 and 77°K there is observed one luminescence band due to transitions to the shallow acceptor ($E_1 \approx 0.03 \text{ eV}$). The position of the band in mixed crystals changed in accordance with the change of the composition, and was at 1.89 and 1.91 eV in the investigated samples. It was observed that the luminescence was strongly polarized following excitation with circularly polarized light, the degree of polarization remaining constant over the entire band. At 77°K, the degree of polarization for both samples was $S = 0.23 \pm 0.03$.

The appreciable luminescence polarization shows that in this case the free electrons produced by the light were effectively oriented. The effect of optical polarization of the holes can be neglected, since the total number of holes in p-type material is much larger than the number of holes produced by the light. The degree of orientation (P) is defined as $P = |(n_{+1/2} - n_{-1/2}) / (n_{+1/2} + n_{-1/2})|$, where $n_{\pm 1/2}$ is the number of electrons with spin parallel or antiparallel to the propagation direction of the exciting light. In the presence of relaxation we have

$$P = \frac{1}{1 + \tau / T_1} P_0 [1],$$

where τ is the lifetime of the electron, T_1 is the relaxation time of the electron spin, and P_0 is the maximum degree of orientation and is determined by the probability of transitions in which electrons with spin +1/2 or -1/2 are produced upon absorption of circularly polarized light. The band structure of the $Ga_{0.7}Al_{0.3}As$ crystal is the same as that of the GaAs crystal. $P_0 = 0.5$ for the interband transitions ($\Gamma^{3/2} - \Gamma^{1/2}$), in accordance with the known selection rules. In the effective mass approximation, the probabilities of recombination transitions in which shallow impurities take part are equal to those of the interband transitions. In this case the degree of luminescence polarization in the recombination of oriented electrons should equal $S = 0.5P$.

It follows from the measured values of the degree of polarization that the electron orientation reached in our experiments, $P = 0.46 \pm 0.06$, is close to the maximal degree $P_0 = 0.5$. This shows that $\tau/T_1 \ll 1$ in the investigated crystals, i.e., the spin relaxation time T_1 greatly exceeds (by at least 3 - 4 times) the lifetime τ .

For the investigated samples, the quantum energy of the exciting light exceeded the width of the forbidden band by 0.02 and 0.04 eV. Consequently, the oriented electrons produced by the light relaxed to the bottom of the conduction band. The observed high degree of polarization indicates that in this case the relaxation of the electron energy was not accompanied by spin relaxation.

The electron lifetime τ can be determined from the depolarization of the luminescence in a transverse magnetic field [1]. The dependence of the degree of polarization on the magnetic field has a Lorentz form

$$S \sim \frac{1}{1 + (\omega_L g T_{1M})^2},$$

where ω_L is the frequency of the classical Larmor precession, g is the electron g -factor, T_{1M} is the lifetime of the magnetic moment, $1/T_{1M} = 1/T_1 + 1/\tau$. Inasmuch as in our case $\tau/T_1 \ll 1$, the time T_{1M} determined from the magnetic measurements is practically equal to τ . The value of the electron g -factor in GaAs is 0.5 [3], and for the mixed $\text{Ga}_{0.7}\text{Al}_{0.3}\text{As}$ crystal, with account taken of the band parameters [4], we can estimate that $g = 1.0$.

Figure 1a shows that the observed decrease of the polarization with increasing magnetic field is well described by a Lorentz contour with half-width 1200 G, yielding a lifetime $\tau = (1.2 \pm 0.2) \times 10^{-10}$ sec. This value agrees with the estimates of the lifetime of the minority carriers ($10^{-10} - 10^{-12}$ sec) obtained in the investigation of transport phenomena in such crystals as p-GaAs [5].

Thus, observation of optical orientation makes it possible to measure relatively simple short carrier lifetimes, something impossible to do with sufficient accuracy by other methods.

At 4.2°K, a lower degree of polarization was observed in the same crystals, $S = 0.10 \pm 0.02$, and measurements in the magnetic field (Fig. 1b) yielded $T_{1M} = (1.8 \pm 0.03) \times 10^{-10}$ sec. The decrease of the degree of orientation of the electrons at 4.2°K can be due either to an increase of the ratio τ/T_1 , or to the fact that at 4.2°K the recombination proceeds not from the bottom of the conduction band, but from the donor level, and in the case of band-level relaxation the electron orientation is partially lost.

In n-type material at 4.2°K, we also obtained an appreciable carrier orientation. The spectrum of these crystals at 4.2°K shows two emission bands (Fig. 2a): band A lies near the absorption edge and is due to transitions in which a shallow donor or exciton takes place, and band B is connected with transition to a shallow acceptor. The degrees of polarization for these bands (Fig. 2) differ greatly: $S = 0.11 \pm 0.03$ for band A and $S = 0.06 \pm 0.03$ for band B. We also observed for these crystals depolarization of the luminescence in a transverse magnetic field ($T_{1M} \approx 10^{-10}$ sec), but in view of the weakness of the signals, the lifetime was not measured accurately.

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INSTABILITIES ARISING IN A FORCE-FREE CURRENT FLOW IN THE SUPERCONDUCTING ALLOY Ti - 22 at.% Nb

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In investigations of the critical currents of wire made of the alloy Ti - 22 at.% Nb, we observed an interesting phenomenon - a sharp dip on the plot of the critical current against the external magnetic field parallel to the wire axis.

Typical results are shown in Fig. 1a. We see that when I is parallel to H_0 the current first increases, then decreases by a factor of 1.5 and $H_0 \approx 2$ kOe, goes through a minimum, after which it doubles at $H_0 \approx 5$ kOe.

At $H_0 > 10$ kOe, the experimental data are described with good accuracy by the expression

$$i_k(H_0) = i_0 \exp(-H_0/H_{cr}). \quad (1)$$

Here $j_c = I_c/\pi R^2$, where R is the wire radius, H_{cr} and j_0 are parameters that depend on the structure of the sample (on the dimensions and concentration of the ω -phase particles) [1].

For comparison, Fig. 1a shows the dependence of j_c on the magnetic field directed perpendicular to the sample axis. The $j_{c\perp}$ curve has no dip.

The behavior of the critical current in the region of the dip is characterized by two singularities: a) the value of j_c at the first destruction of the superconductivity is always higher than at the second and all the succeeding ones; b) the value of j_c stabilizes and becomes reproducible only after the first two or three transitions of the sample to the normal state.

Figure 1 shows the steady state values of j_c . In Fig. 1b, where the temperature dependence of $j_c(H)$ is demonstrated, are shown additionally points obtained at 4.2°K following the first transition of the sample into the normal state.

The dip on the $j_{c\parallel}$ curves is observed for samples subjected to aging after prior recrystallization. In such samples, the ω particles destroyed upon decay of the solid solution, which stabilize the Abrikosov vortex lattice, have a uniform and isotropic distribution.