should be limited by the relaxation time of the employed absorber. Consequently, dye No. 3955 has a saturated-state relaxation time on the order of 10^{-12} sec.

The authors thank S.A. Churilova, A.N. Zherikhin, and E.V. Kurganova for help with the experiment.

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OSCILLATION OF THE RADIATION OF AN ELECTRON-HOLE FERMI LIQUID IN GERMANIUM IN A STRONG MAGNETIC FIELD

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Submitted 9 July 1972
ZhETF Pis. Red. 16, No. 3, 120 - 124 (5 August 1972)

When a magnetic field is applied to a solid, a number of resonant effects are produced (cyclotron resonance, the Shubnikov - de Haas effect, oscillations of magneto-absorption, and others), and these yield the most complete information concerning the band spectrum of the solid.

We have observed a new resonance effect, namely the oscillation of the recombination radiation of germanium under the phase-transition conditions when electron-hole drops are produced [1] from the gas of free excitons.

We investigated the recombination radiation of pure germanium crystals ($N_A + N_D \sim 10^{12}$ cm^{-3}) with the <100>, <110>, and <111> axes along the magnetic field direction. A cryostat especially constructed for optical measurements, on the basis of the "Solenoid" apparatus of our Institute[1)], has made it possible to employ high-transmission optics both to excite the recombination radiation (He-Ne laser) and to gather the radiation. As a result, the spectral width of the slit used when registering the emission spectra was 5×10^{-4} eV. An x-y automatic recorder was used to plot the integrated radiation intensity as a function of the magnetic field.

Just as in the case of the <100> orientation [2], we obtained a splitting of the emission line E_d of the electron-hole drops also for two other orientations of the samples, and the magnitude of the splitting Δ greatly exceeded kT in all cases (e.g., $\Delta \approx 1.5$ meV at 60 kG and H || <110>).

When registering the integrated radiation intensity, when the spectral width of the slit covered completely the E_d line with allowance for the change of its energy position, we observed oscillations of this radiation as a function

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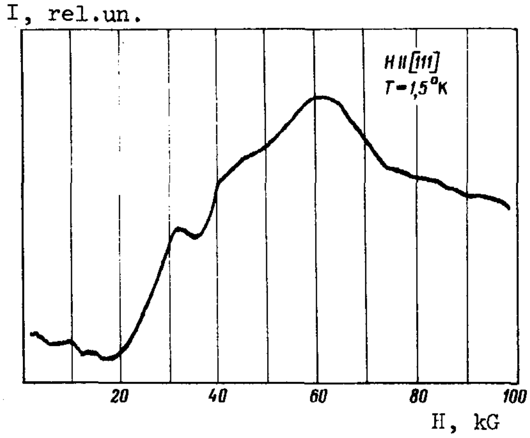
[1)] We take the opportunity to thank V.G. Veselago for the possibility of working with the "Solenoid" apparatus.



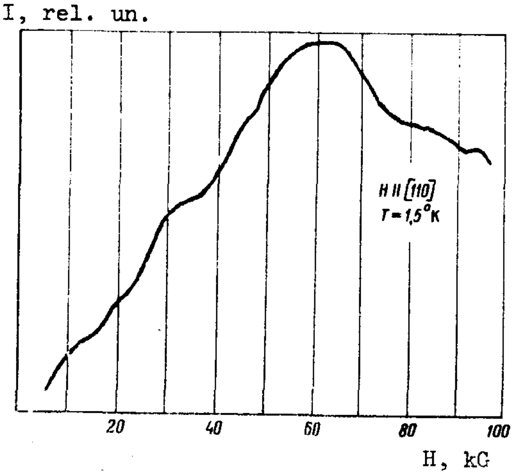


Fig. 1. Dependence of the integrated radiation intensity on the magnetic field at H || <111> and T = 1.5°K.

Fig. 2. Dependence of the integrated radiation intensity on the magnetic field at H || <110> and T = 1.5°K.

of the magnetic field (Figs. 1, 2, and 3). For the <100> orientation, where the electron motion in all four valleys is described by a single cyclotron mass $m_c = 0.13\ m_0$, we were able to determine from the period of the reciprocal field $(\Delta(1/H))$, the Fermi energy $\mathcal{E}_F^{\ell}$ and the corresponding equilibrium carrier concentration in the drop $n_0 = p_0 \approx 2 \times 10^{17}\ cm^{-3}$. The results were in good agreement with other experimental data [3] and theoretical calculations [4]. Figure 2 shows the experimental I = f(H) plot in conjunction with the theoretical values of the Landau quantization for the electrons and holes. The "fan" of the Landau hole levels was constructed in accordance with [5].

The observed minima of the I = f(H) dependence are due to oscillations of the electron Fermi energy, which are caused in turn by the quantization of the Landau degenerate plasma in the electron-hole drops.

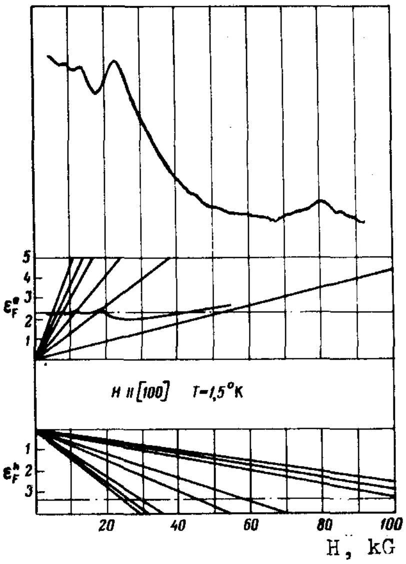


Fig. 3. Oscillations of the integrated radiation intensity as a function of the magnetic field for the case H || <100> at T = 1.5°K. In the lower part of the figure is shown the Landau energy quantization diagram in the conduction band and in the valence band (in accordance with [5]), and also the oscillations of $\mathcal{E}_F^{\ell}$ at $n_0 \approx 2 \times 10^{17}\ cm^{-3}$, which explains the minima of the radiation intensity. $\mathcal{E}_F^{\ell}$ (at H = 0) = 2.3 meV.

Indeed, when the Fermi level crosses the Landau level, the Fermi energy increases, and this should lead to evaporation of the electron-hole drops, since the effective "work function" for the release of free excitons from the drop to the gas decreases.

It is obvious that in weak fields the oscillations of the integrated intensity are connected precisely with the electrons and not with the holes, since for holes in weak fields the Fermi level crosses Landau levels with larger quantum numbers n.

The oscillations of the integrated radiation intensity cannot be attributed to radiative recombination of free carriers located in allowed bands: a) the line E_d is shifted relative to the edge of the band by 8 meV, b) when the Landau levels cross the Fermi level, the total number of particles remains unchanged; thus, the integrated radiation intensity of an indirect semiconductor, for which there are no selection rules for interband transitions, should not oscillate as a function of the magnetic field.

For the orientations <110> and <111>, the picture becomes more complicated because of the existence of two families of Landau subbands in the conduction band, described by two different cyclotron masses for the electrons.

It is seen from Figs. 1 and 2 that a decrease in the radiation intensity is observed in the case <111> and <110> at $H \sim 60 - 65$ kG, and at $H \sim 30$ kG for the case <100>. It can be assumed that when the Fermi level approaches the zeroth Landau level the spin splitting becomes significant, and consequently also the spin orientation of the electrons. As a consequence, the density of states decreases, and this leads to a decrease of the equilibrium concentration in the drop [6], as a result of which the integrated radiation intensity decreases.

When we raise the temperature to 4.2°K, we do not obtain such a decrease of the intensity for the orientation <111>, since kT becomes of the order of $g\beta H \cong 10^{-3}$ eV, and the temperature hinders the spin orientation; the oscillatory structure also becomes smeared out at 4.2°K. We note also that if the temperature is raised to 6 - 8°K, when there is no E_d line at $H = 0$, application of the magnetic field leads to a "flaring up" of the E_d line, since the binding energy of the exciton increases with increasing H, and T_{crit} for the formation of the liquid phase increases accordingly.

The authors thank L.V. Keldysh for constant interest in the work and valuable advice, and S.P. Grishechkin for a useful discussion.

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