Magnetoplasma resonance in electron-hole drops germanium at submillimeter wavelengths

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(Submitted May 15, 1976)
Pis'ma Zh. Eksp. Teor. Fiz. **23**, No. 12, 701–704 (20 June 1976)

We investigated the magnetoplasma resonance spectra in electron-hole drops (EHD) in germanium in the submillimeter wavelength band 440–770 μ in magnetic fields up to 35 kOe. The renormalized carrier masses in the EHD we determined experimentally.

PACS numbers: 72.30.+q

In the first investigations of magnetoplasma resonance (MPR) in electron-hole drops (EHD) in germanium, performed in the far IR region,[1] splitting of the resonance absorption band of the EHD in a magnetic field was observe together with the appearance of singularities on the long-wave absorption edg These changes were explained on the basis of the developed model of MPR in EHD,[1–3] according to which, when a magnetic field is applied, a splitting o the plasma resonance of the EHD should occur, together with hybrid magnet plasma oscillations in the region of the cyclotron frequencies of the free carriers. In the investigations of [1,2], owing to the insufficient spectral resolution, it was impossible to study the long-wave part of the MPR in EHD. This region of the MPR in EHD in Ge was investigated later at several discrete points of the spectrum.[4–6]

In this study, using the methods of monochromatic submillimeter spectroscopy based on backward wave tubes (BWT),[7,8] we investigated for the first time the long-wave part of MPR in EHD in germanium with smooth scanning over the spectrum in the region 1.6—2.8 meV ($\lambda = 440 - 770\ \mu$), that is, both the exciton-absorption region [8] and beyond its limits. We studied the chang in the parameters of the MPR lines as functions of the photon energy and showed experimentally that the effective mass of the carriers in the EHD differs from the mass of the free carriers in Ge.

Measurements of the change in the transmission of samples of pure Ge ($N_A \approx 10^{12}$ cm^{-3}) at submillimeter wavelengths following optical generation of non-equilibrium carriers was carried out by the BWT method [8] at temperature 4.2—1.9 °K in a light-pipe cryostat used earlier to study a MPR in EHD

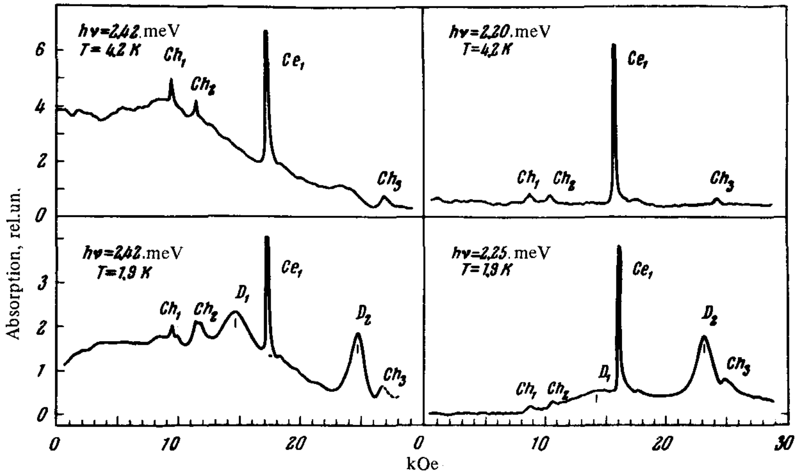

Fig. 1. MPR spectra in EHD in germanium.

Ge in the region of the EHD plasma resonance.[1] The investigations were rried out at the orientation **H** ∥ [111] in fields up to 35 kOe at the Faraday nfiguration $E_\omega \perp \mathbf{H}$.

Figure 1 shows typical spectra measured at 4.2 and 1.9 °K in the region of exciton absorption ($\hbar\omega = 2.42$ meV) [8] and beyond its limits ($\hbar\omega = 2.25$ meV). e spectra show the nonequilibrium-electron CR lines Ce_1, the energy ellip- d of which is elongated along H, and the lines Ch_1, Ch_2, and Ch_3 correspond- to transitions between the Landau levels of the valence band deformed in magnetic field.[5,9] The absorption at 2.42 meV in weak magnetic fields is to photoexcitation of free excitons [7,8] and decreases with increasing field, ce the exciton spectrum shifts towards higher energies.

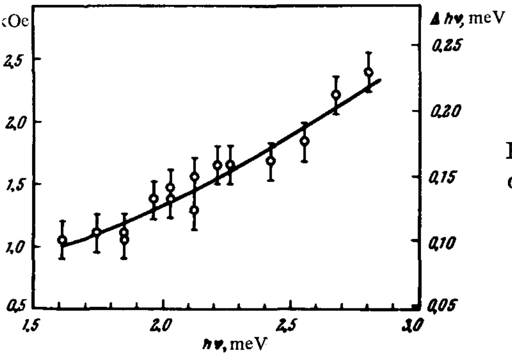

Fig. 2. Dependence of the half-width of the D_2 line on the photon energy.

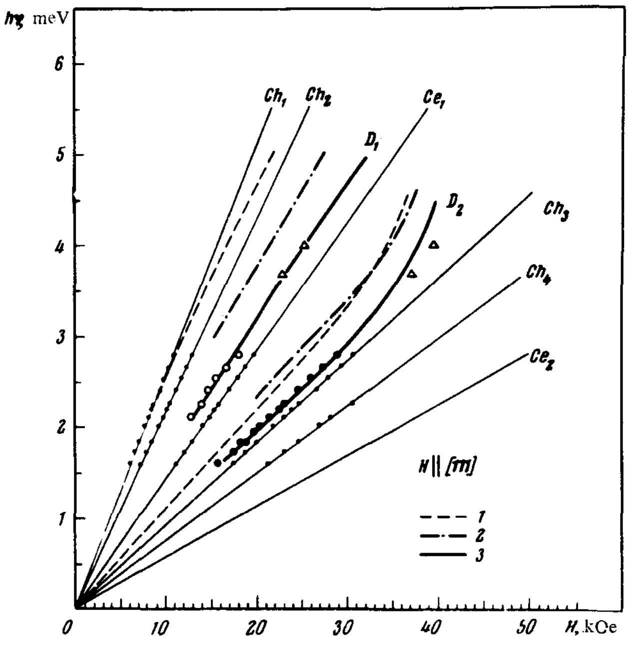

Fig. 3. Spectral positions of the CR lines of the free carriers and of the lines of the MPR in EHD in germanium (points and circles—our experimental data, triangles—data of [5]); calculated curves: 1—from the model of [3], 2—with allowance for the quantum deformations of the valence band of Ge, 3—the sam for the altered carrier masses.

When the temperature is lowered to 1.9 °K, a decrease of the intensity of the exciton absorption is observed, due to the exciton transition to the condensed state and to the appearance in the spectrum of new quite broad lines D_1 and D_2. The appearance of these lines, as well as their spectral position r lative to the CR lines of the free carriers, agree with the predictions of the m del of the MPR in EHD in germanium, developed in [1-3]. The intensity of the lines D_1 and D_2 decreases with increasing wavelength (the expression for the MPR intensity contains the factor [3] λ^{-1}) the line D_1 being broader and attenua ing more rapidly with the wavelength than the line D_2 (it is hardly seen in Fig. at 2.25 meV). The half-width of the line D_2, as seen from Fig. 2, is approximately 0.2 meV (damping constant $\gamma \approx 2.5 \cdot 10^{11}$ sec^{-1}), it differs by more than one order of magnitude from the half-width of the plasma resonance measure in the 9-meV region [1], and decreases with increasing wavelength. The possibility of such a frequency dependence of γ was noted in[1] in connection with a discussion of various mechanisms of the damping of plasma oscillations in EH in germanium.

Figure 3 shows the results of measurements of the spectral dependence of the MPR in EHD and of the quantum cyclotron resonance in a system of free carriers, and also the results of theoretical calculations of the MPR in EHD on the basis of the model of [3]. According to this model, a resonant MPR freency appears between any two CR frequencies of equal sign and circular .arization. Consequently the line D_1 is due to the presence of light and heavy .es, while the line D_2 is due to the presence, in the given orientation, of) groups of electrons with different cyclotron frequencies (Ce_1 and Ce_2). e positions of these lines in fields up to 20—30 kOe, as noted in [2,3] and as)wn by numerical calculations, differs little on the carrier density in the D, and is determined mainly by the carrier masses. This makes it possible principle to estimate from our measurement data the values of the effective .sses of the carriers in the EHD. As seen from Fig. 3, the calculation per- med on the basis the free-carrier parameters in Ge, even with allowance the quantum deformations of the valence band of Ge in the magnetic field.[9] ll does not make it possible to describe satisfactorily experimental results. is indicates that the effective carrier mass in the EHD differs from the mass the free carriers in Ge. Good agreement with experiment was obtained for ctron masses $m_{\rm I}^{\rm EHD}=1.1\, m_{\perp}$ and $m_{\rm II}^{\rm EHD}=m_{\parallel}$ and for valence-band hole masses ivier by 15%. This agrees with the theoretical estimates of the renormali- ion of the carrier masses in EHD as a result of multiparticle effects.[10] note that the theoretical dependence of the position of D_2, calculated for a ticle concentration $n_k = 2\cdot 10^{17}$ cm^{-3} in the EHD, differs from the experi- ntal value in fields $H \gtrsim 35$ Oe. This difference, due to the incipient emer- ice of the zero Landau level of the "light" electrons beyond the limits of the rmi level, shows that the concentration n_k in the EHD greatly increases in se fields.

Phe authors thank Dr. J.C. Hensel (Bell Laboratories, USA) for supplying calculated dispersion curves of the energy spectrum of the valence band Ge in magnetic fields H ∥ [111].

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