PROC. 15TH INT. CONF. PHYSICS OF SEMICONDUCTORS, KYOTO, 1980
J. PHYS. SOC. JAPAN 49 (1980) SUPPL. A p. 125-128

# EXPERIMENTAL INVESTIGATION OF THE NON-PARABOLICITY OF LIGHT HOLE BAND IN GERMANIUM

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Extrinsic photoconductivity of p-Ge with shallow acceptors concentration in the range $(1\sim7)10^{14}$ $cm^{-3}$ was measured at 1.6K in magnetic fields up to 85kOe. Photon- and optical phonon-assisted resonant processes of photoionization and recombination were observed. From the resonant spectra light hole band parameters and g-factors in energy range 25-130 meV were determined and, besides, an information concerning Coulomb shift of the free hole levels in the vicinity of the ionized acceptor was obtained.

When magnetic field H changes and quasi-classical Landau levels $E_n$ pass through some fixed energy level E the periodicity P of this process in the inverse field scale is related to the k-space area S of the extremal section of the isoenergetic surface by a plane perpendicular to H by

$$P = 2\pi e/c\hbar S. \tag{1}$$

We have registrated the passage of light hole Landau levels in Ge through fixed energy levels

$$E = \hbar\omega - E^{(i)} \tag{2}$$

Here $E^{(i)}$ is the energy of a hole bound with acceptor and $\hbar\omega$ is the energy of either a photon or an optical phonon depending on the type of the experiment.

Under monochromatic illumination the light absorbtion coefficient, and photocurrent J as well, rose steeply whenever the photocarriers were produced near the bottom of a magnetic subband [1] (Fig. 1). By changing the photon energy $\hbar\omega$ it was possible to fix E value in the range 40-130 meV. Under non-monochromatic illumination the generation rate did not oscillate with H but the recombination rate did. It rose whenever

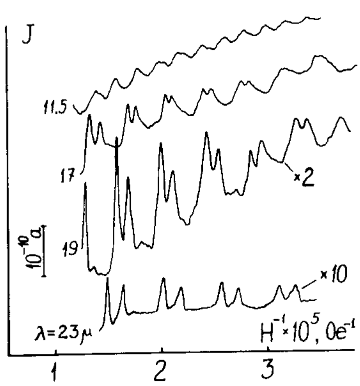



Fig. 1 The dependencies $J(H^{-1})$ at different illumination wavelength values $\lambda$ in the sample with $N_{Ga}=2x10^{14}$ $cm^{-3}$, H // [100]

the photocarriers were captured from the bottom of a magnetic subband with an optical phonon emission. As a result photocurrent decreased but these changes were much weaker than in the first case and could be detected with field modulation technique only. Several series of resonances in Fig. 2 correspond to resonant capture of the holes in the ground and different excited states of Ga acceptor. Capture in the ground state corresponded to E=26,7 meV in (2).

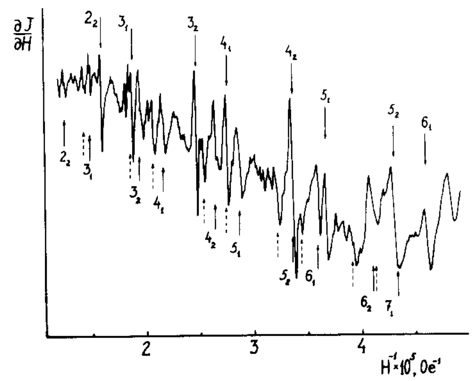



Fig. 2 The dependence $\partial J/\partial H$ $(H^{-1})$ in the sample with $N_{Ga}=2x10^{14}cm^{-3}$, H//[100]: The arrows mark the extrema corresponding to transitions from magnetic subbands to the ground acceptor state (over the curve) and to the first and the second excited ones (under the curve). The system of Landau level notation is the same as in [5].

The amplitudes of the resonances of the different series were of the same order of magnitude. At this point the optical phonon -assisted capture processes differ significantly from the acoustic phonon-assisted ones. The reason is that an increase of the volume $\alpha_i^3$ occupied by the wave function of an excited bound state is compensated by a decrease of phase volume $\alpha_i^{-3}$ of the optical phonons involved.

By measuring periods P for different E values we have obtained S(E) dependencies for the extremal sections of light hole isoenergetic surfaces by (100), (110) and (111) planes. They were interpolated by a polynomial $S(E)=S_{par}+AE^2 + BE^3$, where $S_{par}= =(2\pi m/\hbar^2)E$ is the section area in the parabolic band, cyclotron masses m values are taken from [3]. The derived coefficients A and B are presented in Table I. Since $m=(\hbar^2/2\pi)\partial S/\partial E$ from S(E) the functions m(E) were obtained for three field directions. They are presented in Fig. 3. The non-parabolicity defined as $(S-S_{par})/S_{par}$ amounts approximately 30% for E=100 meV. That is 1.5 times larger than that given by the Kane's formulas [4].

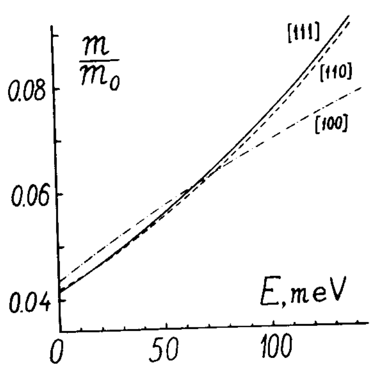



Fig. 3 Dependence on E of light holes cyclotron masses

The resonant lines were in most cases spin-splitted. This made it possible to derive energy dependence of the effective g-factor since in the experiment reduced g-factor $g^{*}=g(m/m_0)$ was easily measured. The latter was found to be well approximated

Table I The coefficients in dependencies of S and $g^*$ values on the energy E

| Field direction | A, $10^{15} cm^{-2} eV^{-2}$ | B, $10^{15}$ $cm^{-2}, eV^{-3}$ | C, $eV^{-1}$ | $g^*(0)$ [5] |
|---|---|---|---|---|
| [100] | 1.2 | -0.96 | 4.7 | 1.21 |
| [110] | 0.9 | 2.6 | 5.2 | 1.47 |
| [111] | 1.0 | 2.4 | 6.4 | 1.57 |

by a linear function $g^*(E)=g^*(0)+CE$ (for H // [100] the measurements were made up to $E \approx 100$ meV, for H // [110] and H // [111] up to $E \approx 40$ meV). The coefficients C are presented in Table I along with calculated [5] $g^*(0)$ values.

Estimates show that dependence $E^{(i)}$ on H due to Zeeman effect as well as Coulomb binding between the hole and the ionized acceptor (see below) when taken into account would give only 1-2% corrections that don't exceed experimental errors.

The free holes that participate in the ionization and recombination processes are affected by the electric field of the ionized centre. This field removes the Larmor orbit centre degeneracy of the free carriers levels and chips off a discrete level from the bottom of the magnetic subband [6]. Transitions we have investigated involve just these discrete levels and not the magnetic subbands bottoms themselves. This can be easily seen from Fig. 4: extrapolation of the experimental dependencies to E=0 shows a noticeable shift as compared with the low-energy levels "ladders" known for an undoped crystal from the cyclotron resonance experiments [3]. A rough estimate of Coulomb correction value made from Fig. 4 gives, for instance, approximately 2 meV for the level $2_2$ in the field 60 kOe.

In Fig. 5 two comparatively isolated lines are shown which correspond to capture of light holes in the ground acceptor states. It can be seen from the lines shape that the photocurrent J has minimum in resonant field $H_{res}$. Probably the additional broad $\partial J/\partial H$ maximum at the low field side of the line is not occasional. Estimates show that the resonant condition $E_n=E$ is valid for the true bottom of the magnetic subband $2_2$ just at the maximum position. So, this maximum may be conditioned by the passage of the magnetic subband bottom through the level E.

Our magnetic field is too weak to produce discrete levels in the heavy holes band. This probably may be the

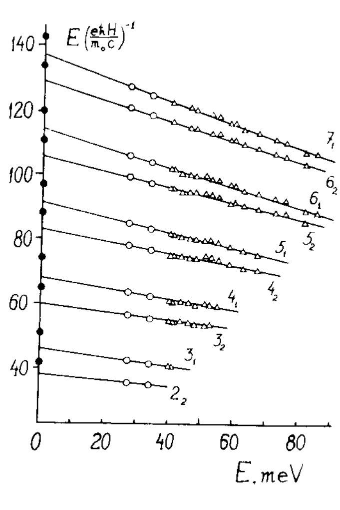
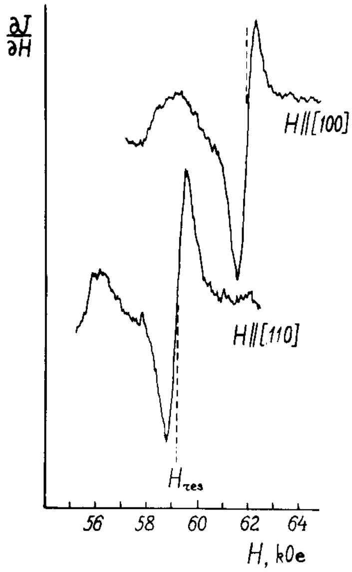



Fig. 4 Positions in scale proportional to $H^{-1}$ of extrema corresponding to resonant photoionization (triangles) and recombination (circles) processes at different E values: Black points are taken from [3]




reason why even a trace of heavy holes in all our resonance spectra is absent.

Fig. 5 Resonant lines corresponding to light hole capture in the ground acceptor state from Landau level $2_2$

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