

DOPPLER SPLITTING OF ACOUSTIC CYCLOTRON RESONANCE LINES IN AN OBLIQUE MAGNETIC FIELD IN ANTIMONY

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An investigation of the sound absorption coefficient in antimony at helium temperatures and with the vectors \vec{k} and \vec{H} not mutually perpendicular (\vec{k} - wave vector of sound, \vec{H} - magnetic field vector), which we have undertaken recently, has disclosed several new phenomena, one of which was reported earlier [1]. We are referring to oscillations on the extremal electron trajectories. A similar effect occurs at relatively low sound frequencies ω satisfying the inequality $2\pi s/v_F \leq \omega\tau \leq 1$ (s = speed of sound, v_F = characteristic Fermi velocity, τ = electron relaxation time).

According to Kaner's theory [2], the resonance bursts from both extremal points split at high frequencies ($\omega\tau \geq 1$) and yield two systems of resonance peaks. Their positions and periods are different:

$$(\Delta H^{\pm})_{\pm} = \frac{e}{m^*c |\vec{k} \cdot \vec{v} \pm \omega|} ; \quad |\vec{k} \cdot \vec{v} \pm \omega| = n\Omega. \quad (1)$$

Here c is the speed of light, e the electron charge, m^* the effective mass, Ω the cyclotron frequency, and $n = 1, 2, 3, \dots$. The relative splitting $\Delta H/H$ does not depend on the magnetic field intensity and is determined by the relation between the electron drift velocity along the field v_H and the speed of sound:

$$\frac{\Delta H}{H} = \frac{2s}{v_H \cos\theta}. \quad (2)$$

θ is the angle between \vec{k} and \vec{H} .

To observe the effect we have grown single crystals of brand Su-000 antimony, which was subjected to supplementary 20-fold zone recrystallization. Owing to the purification and to the lowering of the temperature to 1.4°K, the electron mean free path time increased to such an extent, that even at a sound frequency $\omega/2\pi = 5.0 \times 10^8$ cps it was able to reach the region of acoustic cyclotron resonance (ACR) already.

Figure 1 shows a plot of the ACR spectrum against the reciprocal magnetic field for $\theta = 35^\circ$ in the plane of the binary axes of the crystal; the wave vector \vec{k} is directed along the binary axis. The better resolution of the individual lines is obtained in a stronger magnetic field and is most markedly seen in the plot of the second derivative $d^2\Gamma/dH^2$ of the absorption coefficient with respect to the magnetic field (second harmonic of the magnetic-field modulation frequency).

Measurements of the periods and of the splitting of the ACR lines allow us, in contrast to the case described in [1], to measure separately the cyclotron mass and the velocity of the electron on the extremal section. We emphasize that the measured quantities pertain just

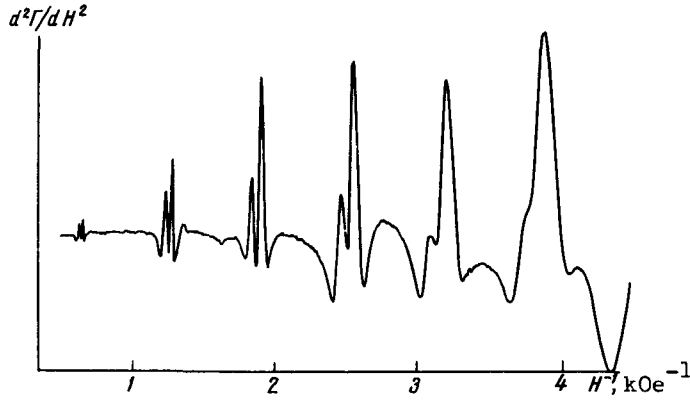


Fig. 1. Plot of the second derivative $d^2\Gamma/dH^2$ of the longitudinal sound absorption coefficient.

to the extremal section and the obtained velocity of electron drift along the field

$$v_d = \frac{1}{2\pi m^*} \frac{\partial S(p_H)}{\partial p_H}$$

is in general different from the Fermi velocity v_F at the limit point.

For the case of quadratic energy dispersion $\epsilon(\vec{p}) = (1/2m_0)\vec{p}\alpha\vec{p}$ it is easy to obtain a general expression for the angular dependence of the ACR periods on the extremal trajectories. The formula is

$$\Delta H_{\text{extr}}^{-1} = \frac{e\lambda}{2\pi c(\vec{n} \cdot \vec{k})} \left\{ \frac{2m_0\epsilon_F}{\det \alpha (\vec{n} \frac{1}{\alpha} \vec{n})^2} \left[1 - \frac{(\vec{n} \cdot \vec{k})^2}{(\vec{n} \frac{1}{\alpha} \vec{n})(\vec{k} \alpha \vec{k})} \right] \right\}^{-\frac{1}{2}} \quad (3)$$

Here λ is the length of the sound wave, $\vec{n} = \vec{H}/|\vec{H}|$ a unit vector along \vec{H} , $\vec{k} = \vec{k}/|\vec{k}|$ a unit vector along \vec{k} , ϵ_F the Fermi energy, and α and $1/\alpha$ the reciprocal and direct mass tensors.

Figure 2 shows preliminary results of an investigation of the angular dependence of the periods and the splitting of the ACR lines in the plane of the binary axes of antimony, for $\omega/2\pi = 5.0 \times 10^8$ cps. The vector \vec{k} is parallel to the binary axis. The solid lines a, b, and c represent the result of calculation of the periods by means of formula (3) for one of the groups of carriers (holes, according to [3]). The spectrum parameters used for the calculations were taken from [4].

All the resonant peaks observed in the experiment are split. In the figure, the series of lines a_1 and a_2 , b_1 and b_2 , and f_1 and f_2 , which have the largest splitting, have been plotted separately. Two other groups of lines, c_1 and g_1 , are also split into two lines each, but in view of the noticeably smaller effect, the corresponding periods have been drawn without splitting.

It is not clear at present how good the quadratic approximation is for antimony, and whether the available spectral constants are reliable. Therefore the qualitative agreement

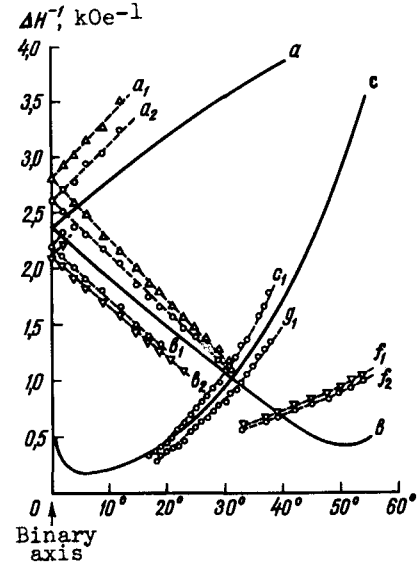


Fig. 2. Dependence of the periods and splittings of acoustic cyclotron resonances on the angle in the plane of the binary axes.

between the calculated and measured quantities can be regarded as fully satisfactory.

The obtained effective masses of the carriers are in sufficiently good agreement with the masses measured by the method of "ordinary" cyclotron resonance. From Fig. 1 we get $m^*v_\alpha = 3.86 \times 10^{-21}$ g-cm/sec, $v_\alpha = 2.7 \times 10^7$ cm/sec, and $m^* = 0.15 m_0$. According to Datars [5] $m^* = 0.14 m_0$ for $\theta = 35^\circ$.

In conclusion, we sincerely thank E. A. Kaner for fruitful discussions.

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RESOLUTION OF THE SPECTRUM OF AN OPEN RESONATOR WITH THE AID OF AN ECHELETTE GRATING

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It is known that a decrease in the number of natural frequencies in the generation band of an open laser resonator increases the stability of the generated oscillations. In this communication ¹⁾ we report a method of thinning out the longitudinal wave-number spectrum of open resonators. This method is based on the use of a reflecting diffraction grating of the echelette type as one of the reflecting mirrors of the open resonator (see also [1]). A distinguishing feature of such an open resonator is that the grating has angular dispersion, so that emission at a wavelength that does not correspond to the chosen grating parameter is scattered aside and the corresponding oscillation has low Q. This causes additional thinning out of the spectrum, as compared with an ordinary open resonator with flat mirrors.

We investigated experimentally a resonator operating in the 8-mm band. The diffraction grating had 11 elements and operated in the second order of the diffraction spectrum; the grating parameters were as follows: period 18.29 ± 0.02 mm, blaze angle $27^\circ 43' \pm 2'$, width of working face 15.72 ± 0.02 mm, and height of steps 8.52 ± 0.02 mm. The power reflection coefficient at $\lambda = 8.52$ mm was 0.945. The resonator consisted of a plane mirror measuring 178×178 mm and a grating having the same transverse dimensions, both made of copper. The oscillations were excited through a coupling aperture in the grating, using a 7.2×3.4 mm rectangular waveguide oriented so that the vector \vec{E} was perpendicular to the grooves of the grating. The measurement procedure was analogous to that used in [2].

At a fixed angle of inclination of the grating and at a fixed distance between the grating and the mirror, three oscillations were observed in the 27.7 - 40 Gcs band, with the same longitudinal index and with different field distributions in the transverse direction (see the table).