CYCLOTRON COMBINATION PHONON RESONANCE

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A new type of cyclotron phonon resonance was observed, namely, cyclotron resonance with participation of two phonons in indium antimonide at 4.2°K.

Cyclotron phonon resonance, or direct transitions between Landau levels with participation of longitudinal optical phonons, was predicted by Bass and Levinson [1] and was observed by a number of workers [2, 3]. While two-particle interaction of an electron with longitudinal optical phonons has by now been sufficiently well investigated in semiconductors, there has been little study of many-particle interaction.

We present here the results of observation of a new absorption line of indium antimonide in a magnetic field at 4.2°K. This line can be interpreted as cyclotron resonance with participation of two phonons. We measured the transmission of unpolarized radiation by an n-InSb crystal ($n = 1.5\times10^{16}$ cm^{-3}, $\mu = 1.5\times10^{5}$ cm^2/V-sec) 2.4 mm thick, placed in a superconducting solenoid in a Faraday geometry. The measurements were made in the wavelength interval 15 - 25 μ with an IKS-21 monochromator with a KBr prism, having a spectral resolution $\sim 1.4\times10^{-3}$ eV at a resonable signal amplitude. The radiation was registered with a receiver of zinc-doped germanium.

Figure 1 shows experimental plots of the transmission against the magnetic field at two wavelengths. It reveals absorption peaks pertaining to the fundamental, first, and second harmonics of the cyclotron phonon resonance (CPR) with participation of longitudinal optical phonons. Between the fundamental and the first harmonics there is a distinct transmission minimum that shifts towards the stronger magnetic fields with decreasing wavelength. From the point of view of absorption intensity, this line is weaker by about one order of magnitude than the CPR fundamneteal harmonic, and is comparable with the intensity of the first harmonic.

The circles in Fig. 2 show the experimental energies of the observed lines as functions of the magnetic field.

Extrapolation of the experimental data to zero magnetic field reveals the difference between the natures of the observed absorption lines. The energies of the absorption peaks identified by us as the fundamental and first harmonics of the CPR have a tendency to cross the ordinate axis at $\hbar\omega_{LO} = 2.4\times10^{-2}$ eV, in good agreement with the earlier investigations [2, 3]. The solid lines show the energies of the transitions between the ground (n = 0) and respectively the first (n = 1) and second (n = 2) Landau levels, as functions of the magnetic field, calculated on the basis of [3]. Good agreement is observed between the CPR theory and the experimental data.

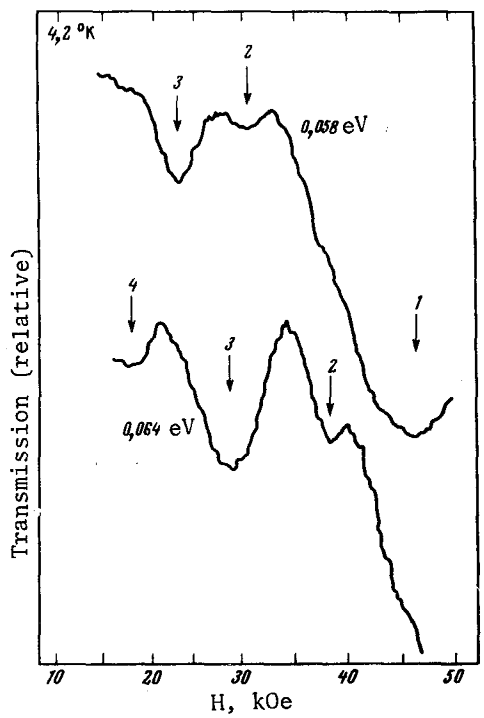

Fig. 1. Experimental transmission of InSb vs the magnetic field. The arrows indicate the transitions $\hbar\omega_c + \hbar\omega_{LO}$ (1), $\hbar\omega_c + \hbar\omega_{TO} + \hbar\omega_{LA}$ (2), $2\hbar\omega_c + \hbar\omega_{LO}$ (3), and $3\hbar\omega_c + \hbar\omega_{LO}$ (4)

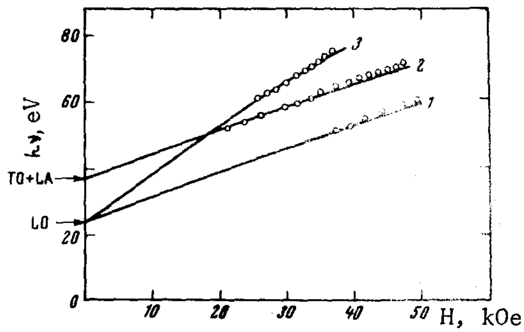

Fig. 2. Resonance energies vs magnetic field. The curve numbers correspond to the peak numbers in Fig. 1.

The second group of absorption peaks coincides with the theoretical energy of the transition between the ground and first Landau level plus the TO(L) + LA(L) phonon combination energy (0.037 eV), which is clearly seen in the infrared absorption spectra of indium antimonide [4].

The presented data give grounds for interpreting the cyclotron-absorption peaks observed by us as cyclotron resonance with participation of two phonons. The combination phonon resonance may be due to the nonlinear electron-phonon interaction considered in [5].

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ANOMALIES IN THE ABSORPTION OF TRANSVERSE SOUND IN TIN

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Results are reported of an experimental study of electron absorption of transverse sound in pure tin under the conditions $\vec{q} \parallel [110]$ and $\vec{\varepsilon} \parallel [\bar{1}10]$ ($\vec{q}$ is the wave vector of the sound and $\vec{\varepsilon}$ is the polarization vector). Ideas are expressed concerning the nature of the observed anomalies.

It is by now regarded as well established that the coefficient α_t of absorption of transverse ultrasonic waves in metals, which is due to the conduction electrons, is proportional to the mean free path ℓ if $q\ell << 1$ and is independent of ℓ if $q\ell >> 1$, and the transition from the first limiting case to the second is accompanied by a monotonic increase of the sound absorption coefficient. A general expression for α_t at arbitrary values of $q\ell$, derived in the free-electron approximation, is given in [1]. Allowance for the anisotropy of the electron spectrum of the metal [2, 3] does not lead to significant changes in the dependence of α_t on $q\ell$.

We have registered a qualitative difference from such a behavior of α_t at sound frequencies 20 - 100 MHz in single-crystal tin prepared from an ingot with $R(4.2°K)/R(300°K) = (3 - 4) \times 10^{-5}$, under conditions when $\vec{q} \parallel [110]$ and $\vec{\varepsilon} \parallel [\bar{1}10]$. A study of the temperature dependence of the absorption coefficient has revealed that the $\alpha_t(T)$ curves go through a maximum whose position depends on the frequency of the sound (Fig. 1). Within the limits of the available experimental data, the temperature T_{max} corresponding to the maximum absorption coefficient is connected with the sound frequency f by the relation f/T^4_{max} = constant, although the branches of the curves to the right of the maxima agree satisfactorily with the relation $\alpha_t \sim T^{-3}$.

The presence of maxima in the $\alpha_t(T)$ dependence and their variation with frequency cannot be attributed to the interaction of the sound with the dislocations, since the heights and positions of the maxima turned out to be the same for a number of samples investigated at the same frequency. This point of view is confirmed also by investigations performed on samples with impurities. Addition of small amounts of impurities did not lower the absorption coefficient at T = 4.2°K but, to the contrary, increased it in spite of the decrease in the electron mean free path. Thus, by varying the electron mean free path (by introducing impurities) one can obtain a plot of α_t against the impurity concentration of the same form as when the temperature is varied (see Fig. 1).