# Rotation of plane of polarization and ellipticity of ultrasonic waves in indium

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The ellipticity and angle of rotation of the polarization plane of ultrasound were measured as functions of the magnetic field. The character of the obtained plots is attributed both to the Doppler-shifted acoustic cyclotron resonance and to interaction of the elastic waves with multiple dopplerons.

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The measurements were made at $T = 4.2$ K on single-crystal indium samples with resistivity ratio $\rho_{293\,\mathrm{K}}/\rho_{3.4\mathrm{K}} = 80\,000$, grown at the Institute of Solid State Physics of the USSR Academy of Sciences. The magnetic field of intensity up to 70 kOe and the wave vector of the elastic wave were directed along the [001] crystallographic axis. Transverse ultrasound was excited and registered by piezoconverters of $x$-cut lithium niobate placed at right angles to each other. Frequencies 28–74 MHz were used. A pulsed photosensitive installation based on the acoustic-bridge principle[1] was used to measure the changes in the power and in the phase shift of the elastic wave, which occur when a magnetic field $H$ is applied (first parallel and then antiparallel to the propagation direction), relative to the level and phase shift of the signal in a zero field,. As shown in Ref. 2, this makes it possible to determine the changes of the real $k^{(\pm)'}$ and imaginary $k^{(\pm)''}$ components of the wave vectors $k^{(\pm)} = k^{(\pm)'} \mp ik^{(\pm)''}$ of the right ( + ) and left ( − ) polarized elastic waves, and from them the ellipiticity $\epsilon$ and the polarization-time rotation angle $\phi$, which appear when ultrasound passes through the sample.

The experimental data on the dependence of the relative change of the real parts of the wave vectors $\Delta k^{(-)'}/k_0$ (curve 1) and $\Delta k^{(+)'}/k_0$ (curve 2) are shown in Fig. 1

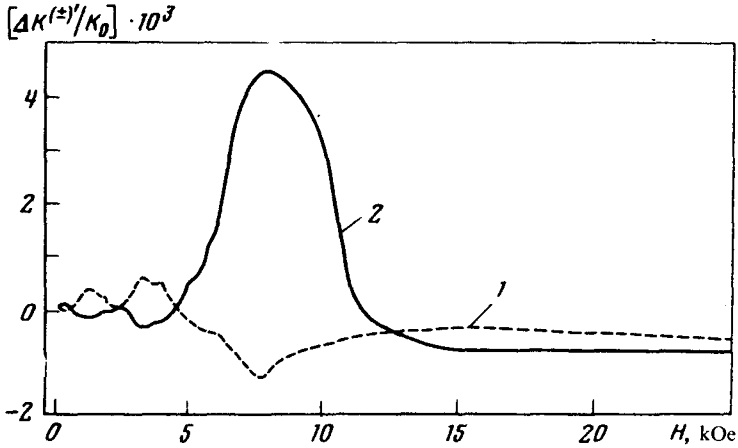


FIG. 1.

  

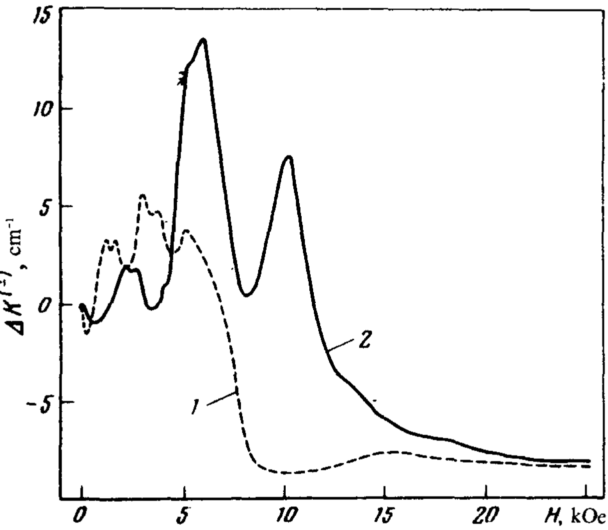


FIG. 2.

($k_0 = k^{(\pm)'}(0)$). Figure 2 shows the measured changes of the imaginary components of the wave vectors $\Delta k^{(-)''}$ (curve 1) and $\Delta k^{(+)''}$ (curve 2). The resultant ellipticity and rotation of the plane of polarization are shown in Fig. 3 ($\phi$—dark circles, $\epsilon$—light

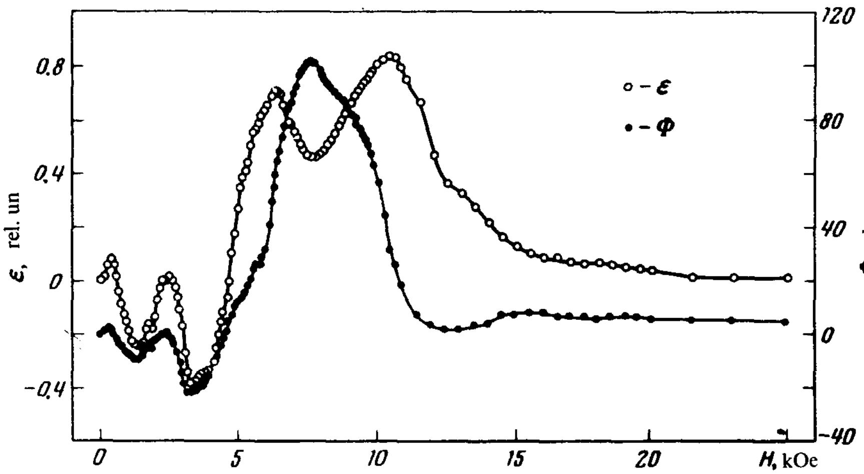


FIG. 3.

circles). All the plots were obtained at 64.2 MHz and at a sample length 1.5 mm.

It is seen from Fig. 1 that magnetoacoustic effects that differ in character are superimposed in the investigated region. First, Doppler-shifted acoustic cyclotron resonance is observed, characterized by increments of equal absolute value but of opposite sign to the real parts of the wave vectors of the ( + ) and ( – ) polarized waves (which cause the rotation of the plane of polarization) and by practically identical increments to the imaginary parts of these vectors in both polarizations (absence of ellipticity). Second, magnetoacoustic effects occur, due to the interaction of the elastic wave with the weakly damped circularly polarized electromagnetic waves in the metal in the magnetic field. This conclusion is based on the fact that peaks were observed on the plot of the imaginary components of the wave vectors of the elastic waves against $H$ for both circular polarizations, and their positions do not coincide for waves of different polarization. This gives rise to an appreciable ellipticity. Taking into account the information on the character of the helicon and doppleron spectra for indium and for aluminum, whose Fermi-surface topology is similar to that of indium, as obtained in Refs. 3 and 4, we can conclude that the observed effects are due to the interaction of the elastic waves with multiple dopplerons (doppleron–phonon resonances). As expected, the ultrasound-absorption peaks have pairwise alternating-sign polarization due to the interaction with the dopplerons of the corresponding polarizations, caused (in the notation of Ref. 4) by the $nm$ and $(n+2)M$ multiple harmonics of the Doppler-shifted resonance (in the general case $n = 1,3,5\cdots$). Resonances of the $nm$ type are due to holes with $p_z = 0.48p_0$ ($p_z$ is the momentum component along the magnetic field and $2p_0$ is the dimension of the Brillouin zone in the [100] direction, while the resonances $(n+2)M$ are due to holes located near the central section of the Fermi surface. Favoring these arguments is the fact that the second peak (reckoned from the direction of stronger fields) shifts with increasing frequency $\omega$ towards stronger magnetic fields more slowly than linearly, while the first peak shifts more rapidly.

The unusual character of the dependences of $k^{(+)\prime}$ and $\phi$ on $H$ (the absence of distinctly pronounced minimum followed by a maximum) can be understood if it is recognized that at the $nm$ harmonic the doppleron has $\partial\omega/\partial k > 0$ and when it interacts with the elastic wave the doppleron-phonon branches of the dispersions should move apart, while at the $(n+2)M$ harmonic the doppleron with $k > 0$ has $\partial\omega/\partial k < 0$ and when it interacts with the elastic wave a gap should be produced (in terms of $\omega$, and consequently also in terms of $H$). Therefore, if the phonon-doppleron coupling is weak, the minimum of the $\phi(H)$ curve at the $(n+2)M$ harmonic should be followed by a maximum, whereas at the $nm$ harmonic, conversely, the maximum should be followed by a minimum. If the distance between the $(n+2)M$ and $nm$ resonances is commensurate with the width of their lines, then the resultant plot of $\phi(H)$ should have two minima separated by a broad maximum, as is in fact observed in experiment.

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