Peaks in electromagnetic absorption of ultrasound near a Doppler-shifted cyclotron resonance

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The absorption of circularly polarized ultrasonic waves in tungsten has been studied experimentally near a Doppler-shifted cyclotron resonance. The absorption peaks observed in both cases of the circular polarization are interpreted as resulting from a field interaction of the elastic subsystem with conduction electrons.

The Doppler-shifted cyclotron resonance of conduction electrons gives rise to peaks, antiresonances, and Kjeldaas edges on the curve of ultrasonic absorption versus the magnetic field (see the review by Mertsching[1]). It has been assumed that the absorption peaks result from a deformation interaction of the elastic and electron subsystems of the metal. These peaks, which had been predicted by Kaner *et al.*,[2] are observed in both senses of the circular polarization. If temporal dispersion is ignored, they occur in the same field (at a fixed frequency) and are equal in magnitude. Also seen as an absorption peak, but in only one sense of the circular polarization, is a doppleron-phonon resonance,[3] which is the result of a field (electromagnetic) interaction of subsystems.

We have studied the absorption of circularly polarized ultrasonic waves in tungsten in the region of the *G*-doppleron-phonon resonance.[4] The experiments are carried out at a temperature of 4.2 K with a tungsten sample with a resistance ratio $\rho 300/\rho 4.2\ \mathrm{K} \gtrsim 1.5\times 10^5$. The procedure for determining the absorption of the circularly polarized waves is described in Ref. 5. The experimental results are shown in Fig. 1. We see that, in addition to the main maximum of the doppleron-phonon resonance in the minus polarization (we denote the resonant field at the frequency $f = 119$ MHz by H_R^-), there are additional maxima at the fields H_r^- and H_r^+, in both polarizations. The values of H_r^- and H_r^+ for these additional peaks are typically unequal at a given frequency, and there is typically a slight deviation from a linear dependence of the position along the magnetic-field scale as f is varied. These circumstances rule out an assignment of these structural features to peaks in the deformation absorption.

To determine the nature of these additional peaks, we consider a model. Specifically, we consider the electron sheet of the Fermi surface to have the shape of a "truncated sphere,"[4] while the hole sheet is a cylinder of the same volume. For this model, the components of the nonlocal-conductivity tensor σ_{11} and σ_{21} vary with the magnetic field as shown in Fig. 2. The maximum ultrasonic absorption in the vicinity of the doppleron-phonon resonance corresponds to the equation

$$\frac{k_0^2 c^2}{4\pi\omega} + (\operatorname{sgn} p)\sigma_{21} = 0, \qquad (1)$$

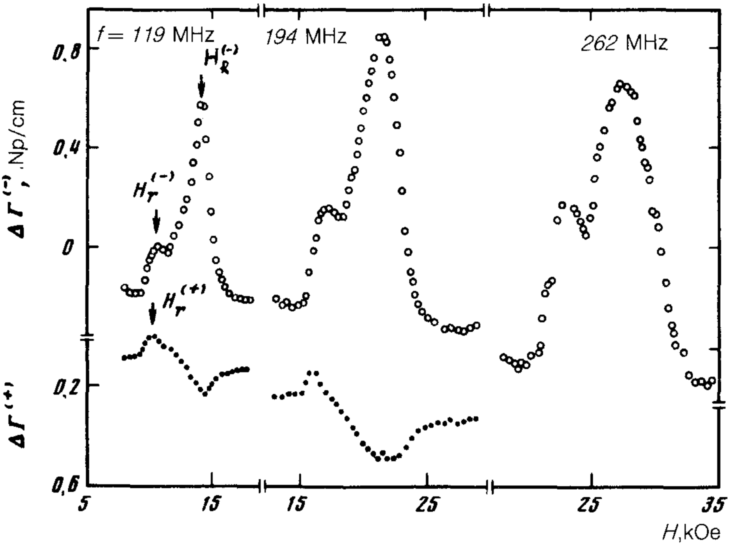

FIG. 1. Absorption of circularly polarized ultrasonic waves versus the magnetic field in tungsten. $\Delta\Gamma^{\pm} = \Gamma^{\pm}(H) - \Gamma^{\pm}(0)$. The propagation direction of the ultrasound and the direction of the magnetic field coincide with the [001] crystallographic axis.

where $\text{sgn}p = \pm 1$ for the ($\pm$) polarizations, $\omega = 2\pi f$, $k_0 = \omega/v$, v is the transverse ultrasonic velocity at $H = 0$, and c is the velocity of light. The graphical solution of Eq. (1) is the intersection of the curve $\sigma_{21}(H)$ with the lines $\pm k_0^2c^2/4\pi\omega$. It can be seen from Fig. 2 that this intersection occurs in the field H_R^-, where

$$|\sigma_{21}/\sigma_{11}| \gg 1. \tag{2}$$

Inequality (2) means that there can be a solution of the dispersion relation corresponding to a slightly damped electromagnetic mode (doppleron), so that the resonance is a doppleron-phonon resonance. In addition, $\sigma_{21}(H)$ intersects the lines $\pm k_0^2c^2/4\pi\omega$ in the region of the Doppler-shifted cyclotron resonance ($H < H_1$). Analysis of the solution of the dispersion relation for elastic waves in the linear ap-

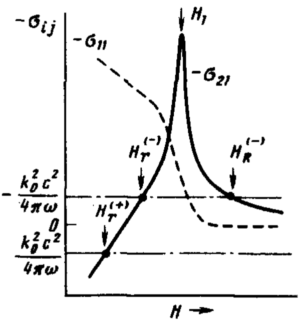

FIG. 2. Components of the nonlocal-conductivity tensor versus the magnetic field for a fixed value of the wave number, $k = k_0$.

proximation in the coefficient of the coupling of the elastic and electromagnetic subsystems of the metal, for quite general (not model-based) representations regarding the behavior of the tensor components which appear in this relation, shows that when Eq. (1) holds, a resonant increase in electromagnetic absorption will be observed in the cyclotron absorption region. The relative half-width of this structural feature can be estimated from

$$\frac{\Delta H}{H} \simeq \left| \frac{\sigma_{11}}{H \dfrac{\partial \sigma_{21}}{\partial H}} \right| \tag{3}$$

From this expression it follows that if there is a rapid change in the nondissipative Hall component σ_{21} as a function of the magnetic field, one will observe peaks on the curves of the ultrasonic absorption which are superficially reminiscent of a doppleron-phonon resonance but which are seen in both circular polarizations. In addition, they will be observed under the condition $|\sigma_{21}| \lesssim |\sigma_{11}|$, which is not characteristic of a doppleron-phonon resonance.

In summary, the structural features observed in tungsten near the doppleron-phonon resonance can be explained in a noncontradictory way in a phenomenological theory as peaks of the electromagnetic absorption of ultrasound in the region of a ultrasound Doppler-shifted cyclotron resonance. Their position along the magnetic-field scale makes it possible to reconstruct the Hall component of the nonlocal-conductivity tensor by the method proposed by Butenko *et al.*,[4] not only beyond the edge but also in the region of cyclotron absorption. The effect is to substantially expand the capabilities of ultrasonic spectroscopy.

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