Changes in the spectrum of acoustic resonances in metal plates

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Qualitative changes in the spectrum of acoustic resonances have been observed in a study of the temperature dependence of the amplitudes of standing sound waves excited by a contactless method in indium and tin plates.

An electromagnetic wave incident on the surface of a metal excites acoustic oscillations in the metal with an amplitude proportional to the alternating magnetic field h. If the sound is generated by a Lorentz interaction of the current in the skin layer with a static magnetic field H_0, the magnitude of the effect is described by

$$u = H_0 h / 4\pi\rho S\omega, \tag{1}$$

where u is the amplitude of the sound which is excited, ρ and S are the mass density and sound velocity of the metal, and ω is the frequency of the electromagnetic field. This expression applies when the skin layer is thin in comparison with the sound wavelength λ. When standing sound waves are excited in plates, the sound amplitude is again described by expression (1), but the frequency ω in the denominator must be replaced by the sound attenuation coefficient γ. The effect of this replacement is to increase u by a factor of Q, the quality factor of the plate as an acoustic resonator. The excitation of standing sound waves is accompanied by a resonant change in the surface impedance of the plate.[1] In the case of antisymmetric excitation[2] the velocity and attenuation of the sound are related by simple expressions to the parameters of the acoustic resonances:

$$\omega_r = \frac{\pi S}{d}(2n+1), \qquad \gamma = \omega_r / Q, \tag{2}$$

where $n = 0, 1, \ldots, d$ is the plate thickness. Strictly speaking, however, these expressions apply only to the hypothetical case of an infinitely long plate, in which the excitation of sound can be described by resonant lines spaced uniformly along the frequency scale.

In this letter we report a study of indium and tin single crystals grown in polished quartz forms. The indium crystals are disks 2.0 cm in diameter and 0.2 cm thick, and the corresponding dimensions of the tin crystals are 1.8 and 0.135 cm. The sound propagation direction **q** coincides with the normal to the plane of the disk, which is near (within 2–3° of) one of the high-symmetry crystallographic directions in each case. In the experiments we found it possible to excite both longitudinal and transverse sound of any given polarization $\vec{e}$. The measurements were taken over the temperature interval 4–300 K in magnetic fields up to 80 kOe. The experimental procedure is described in Ref. 3.

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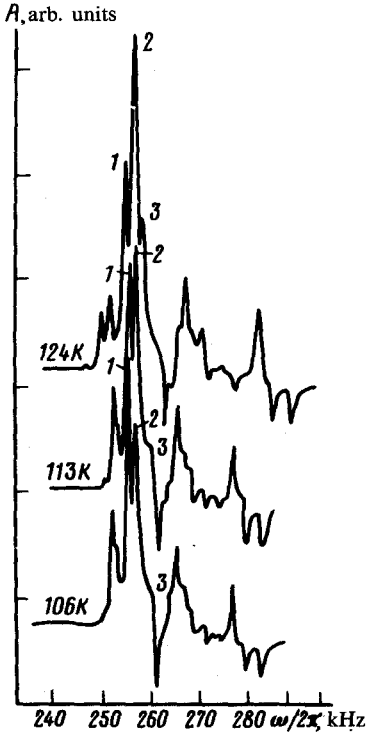

FIG. 1. Acoustic resonances observed in indium at three temperatures ($H_0 = 50$ kOe, $\mathbf{q} \| [001], \vec{e} \| [010]$.

The spectrum of acoustic oscillations in a plate of bounded dimensions is extremely complicated. As a result, resonant features in the surface impedance are observed for each value of n at all frequencies at which the displacements of the elastic medium in the plate satisfy the conditions for the excitation of standing waves in the plate. In the present experiments, the measurements were taken at the frequencies of the fundamental ($n = 0$) acoustic resonances, for which $\lambda/2$ was comparable to the plate thickness. Figure 1 shows the spectrum of acoustic resonances in indium which corresponds to the excitation of transverse sound. At a fixed temperature, the resonant group includes one relatively high-amplitude resonance (less commonly, two or three) and a set of small resonant peaks whose amplitudes fall off with distance from the fundamental resonance. As the temperature is varied, the spectrum of acoustic oscillations changes qualitatively (Fig. 1). The general behavior can be summarized as follows: Each of the resonances becomes observable at a certain temperature, goes through a maximum, and then decreases monotonically. As the amplitude of the largest resonance decreases, the small resonance nearest this large resonance grows simultaneously (the nearest small resonance on the high-frequency side in the case of transverse sound or on the low-frequency side in the case of longitudinal sound). This resonance then undergoes a similar evolution with the temperature. It is replaced by the next peak, etc. These changes observed in the spectrum are not due to the tempera-

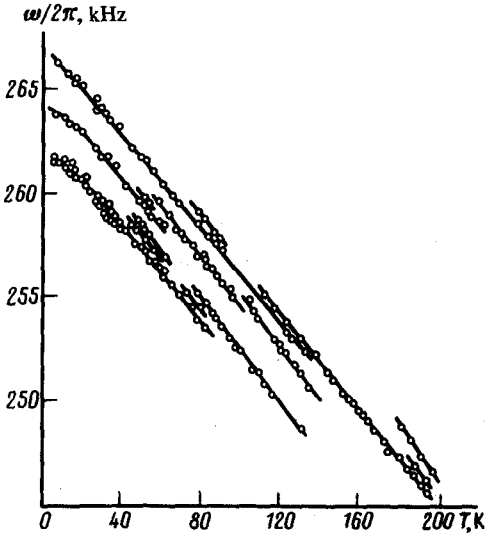

FIG. 2. Temperature dependence of the frequencies of acoustic resonances in indium ($H_0 = 50$ kOe, $\mathbf{q} \| [001], \vec{e} \| [010]$.

ture dependence of the attenuation of the sound; most of the resonances have essentially identical quality factors. As the temperature is varied, the entire resonant group shifts along the frequency scale, in accordance with a temperature-induced change in the elastic moduli. Figure 2 shows the temperature dependence of the frequencies of some of the acoustic resonances in indium. The length of each line connecting experimental points determines the temperature interval in which the given acoustic resonance is observed. The sound velocity calculated from the frequencies of the largest

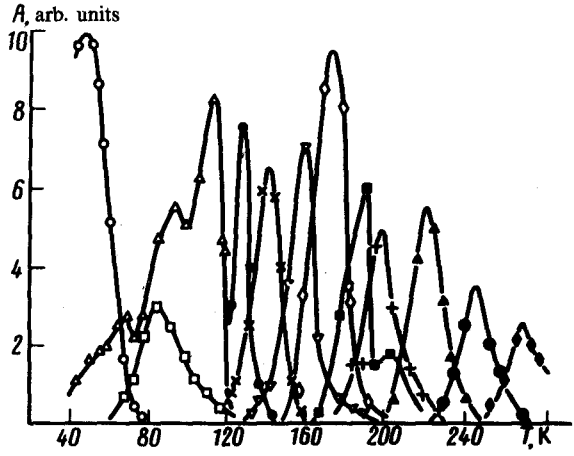

FIG. 3. Temperature dependence of the amplitude of the successive acoustic resonances (indicated by different symbols) in tin ($H_0 = 25$ kOe, $\mathbf{q} \| [110], \vec{e} \| [001]$.

resonances at each temperature agrees within 1–2% with the tabulated value of the velocity of the sound of the given polarization.[4] Evidently because of the changes in the spectrum, the temperature dependence of the frequencies of the individual resonances does not correspond to the temperature dependence of the velocity of sound.[4]

The changes in the spectrum of acoustic resonances can be seen most clearly in the tin plates. Figure 3 shows the temperature dependence of the amplitude of the acoustic resonances associated with the excitation of transverse sound. These resonances are packed in a small group along the frequency scale; the identity of the "maximum" resonance changes more than ten times over the temperature interval 4–300 K. The apparent reason for these pronounced changes in the spectrum is the choice of a less-symmetric sound propagation direction and the greater crystallographic anisotropy of tin (in comparison with indium).

Two features were found in the results for all the samples studied. At any temperature, the resonance having the largest amplitude is that whose frequency is closest to the value of ω_r given by (2), which corresponds to an infinite plate. The energy stored in the acoustic resonator represented by the sample—the integrated area under the resonance curves is a measure of this energy—remains essentially the same upon a change in the identity of the "maximum" resonance.

For a physical interpretation of the changes in the spectrum of acoustic resonances, we first need to determine what is responsible for the sharp differences in the amplitude of the various peaks. The existence of a large number of resonances undoubtedly means that elastic oscillations of various types are superimposed and are interacting. The most important of these elastic oscillations are compressional, shear, bending, and twisting waves. A complicated resonant spectrum is also observed in conventional piezoelectric resonators, but the latter do not exhibit a pronounced change in the resonance spectrum because of the low sensitivity to the temperature. Since the electromagnetic excitation of sound is used widely to study the attenuation and velocity of sound in metals[5] and also in practical applications[6] for contactless monitoring of materials at high and low temperatures, the change in the spectrum of acoustic resonances should be taken into account in interpreting temperature dependences.

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