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EXPERIMENTAL INVESTIGATION OF THE FREQUENCY DEPENDENCE OF ELECTRON ABSORPTION OF ULTRASOUND IN TIN SINGLE CRYSTALS OF VARIOUS CRYSTALLOGRAPHIC ORIENTATIONS

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The temperature dependence of the electron absorption of ultrasound has been measured by the pulse technique in the frequency range from 90–280 MHz and for temperatures between 1 and 4° K in pure tin single crystals. The sound wave vector was perpendicular to the (101), (111), (301), (112), (211), (113) and (311) planes in the different experiments. In accordance with theory, the electron absorption frequency dependences are linear and strongly anisotropic.

IN a well known review devoted to the electronic properties of metals, Pippard[1] pointed out the significant interest which has been attached to the investigation of the electron absorption of ultrasound in single crystals for various crystallographic directions. The electronic part of the sound absorption is a direct criterion of the electron–phonon interaction, which up to now has been studied principally by means of transport phenomena (thermal and electrical conductivity). A complicating property of these phenomena is that the entire phonon spectrum and the whole electron distribution of metals takes part in them, which makes difficult the interpretation of the details of the electron–phonon interaction. Since the high frequency ultrasonic oscillations can be regarded as beams of coherent phonons that interact with definite portions of the Fermi surface (the line $\mathbf{k}\cdot\mathbf{v}_F = 0$, where $\mathbf{k}$ is the wave vector of the sound and $\mathbf{v}_F$ is the velocity of the electron),[1,2] then the data on the electron absorption of ultrasound can be used in the interpretation of the complex transport phenomena in metals. Here, of course, even for energies $\hbar\omega \sim kT$ (for $T \ll \Theta_D$), the phonon frequencies are much greater than those used in ultrasonic experiments. However, thanks to the linearity of the phonon dispersion law, it can be assumed that the ultrasonic measurements have a direct relation to the electron–phonon interaction, corresponding to a macrophenomenon. Unforunately a direct relation to the electron–phonon interaction, corresponding to a macrophenomenon. Unfortunately, such detailed experimental data on the frequency dependence of the electronic absorption of sound for different orientations are lacking in the literature at the present time, even for a single metal. There is also a similar lack of detailed theoretical representations of the possible treatment of similar experiments.

To carry out the experiments, it is necessary to satisfy the condition $kl \gg 1$ (l is the mean free path of the electron) which is satisfied in pure metals at the temperature of liquid helium. For an exact determination of the electronic part of the sound absorption, it is natural to use the phenomenon of superconductivity for which the electron absorption in a pure metal vanishes on approaching 0° K.[3] In the present note, the results are given of the investigation of the frequency dependence of the electron absorption of ultrasound in the frequency range 90–280 MHz in tin single crystals (impurity content $< 10^{-4}\%$) of different orientations, for which the sound wave vector was perpendicular to the crystallographic planes (101), (301), (111), (112), (113), (311). The measurements were made by a pulse technique in the temperature range from 4.2 to 1.0° K on apparatus described previously.[4] As a high-frequency transducer for the ultrasound, thin plates of X-cut quartz were used, which underwent longitudinal vibrations under the action of radio pulses. It should be noted that complicated ultrasonic vibrations could arise in the general case in the orientations of the specimens that we studied.

Figure 1 shows a typical temperature dependence of the coefficient of electron absorption of ultrasound of frequency of 276 MHz in one of the tin single crystals for an orientation $\mathbf{k} \perp (211)$. After

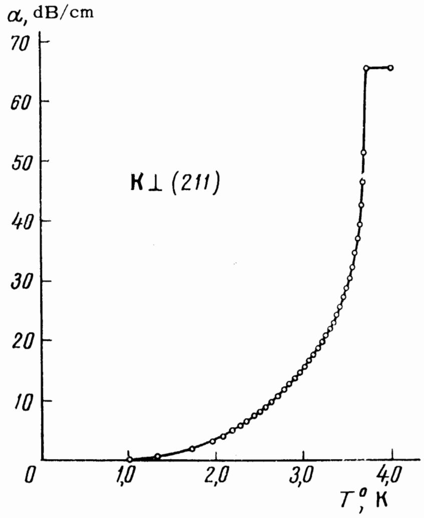

FIG. 1. Temperature dependence of the coefficient of electron absorption of ultrasound of frequency 276 MHz for the orientation of the sound wave vector k⊥(211) in pure superconducting tin.

extrapolation of this dependence to 0°K (for details on the extrapolation, see [5]), the values of the coefficient of electron absorption in the normal state, which was measured by us over a wide range of frequencies for different orientations of **k** relative to the crystallographic axes of tin, can be represented as a function of the sound frequency in Fig. 2 (curves 1–8). It is seen that for all the orientations studied, the frequency dependence of the coefficient of electron absorption in tin has a linear character, in correspondence with the theory for the case $kl \gg 1$.[1,2] Figure 2 also shows the data of investigations on the electron absorption of longitudinal ultrasonic frequencies up to 80 MHz, obtained by Olsen[6] for three orientations of **k** in tin single crystals (curves A–C).

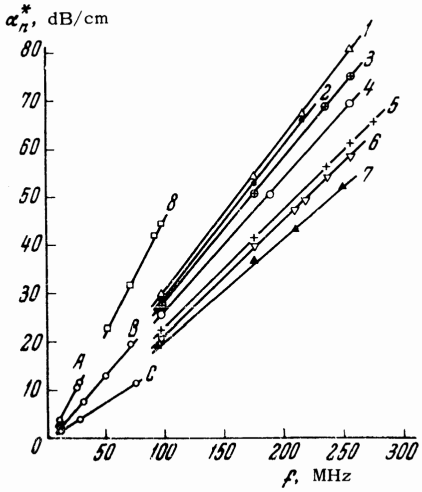

FIG. 2. Frequency dependence of the coefficient of electron absorption of ultrasound in the normal state of tin. The curve 1–k⊥(301; 2–k⊥(311); 3–k⊥(113); 4–k⊥(112); 5–k⊥(211); 6–k⊥(101); 7–k⊥(111); 8–k∥(100). Data of Olsen[6]: curve A–k∥[100]; B–k∥[001]; C–k∥[110].

The experimental results obtained are a confirmation of the severe anisotropy of the Fermi surface of tin and can make possible, following appropriate theoretical consideration, the determination of the detailed energy spectrum of electrons and the interaction of electrons with phonons in this metal. For the known Fermi surface, one can find the anisotropy of the parameter of electron–phonon interaction from similar measurements; however, the Fermi surface of tin is not so well known that one can immediately obtain such information. We note that the assumption made in [6] in the analysis of the data, that the parameter of electron–phonon interaction is constant on all Fermi surfaces, is evidently not satisfied. An additional argument in favor of this viewpoint is the significant anisotropy of the energy gap (> 50%) in the spectrum of superconducting tin, recently discovered in the study of ultrasonic absorption[5] and the tunnel effect.[7]

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Note added in proof (August 3, 1966). Jones and Raine (Phys. Lett. 21, 510 (1966) draw a conclusion from data on the study of three orientations of single crystals of rhenium as to the presence of a direct connection between the slope of the curves of the frequency dependence of the coefficient of electron absorption of ultrasound in the normal state of a metal and the value of the energy gap in the superconducting state. More detailed investigation of tin[5] and the present research) have not revealed a similar simple correlation.

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