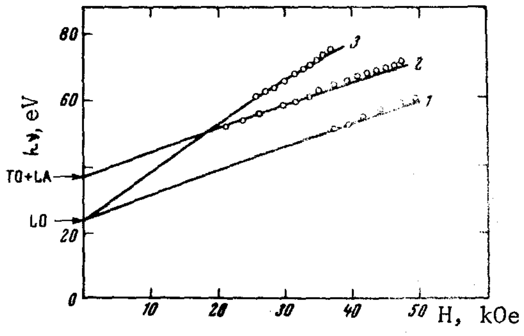

Fig. 2. Resonance energies vs magnetic field. The curve numbers correspond to the peak numbers in Fig. 1.

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_{max}^4 = 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).

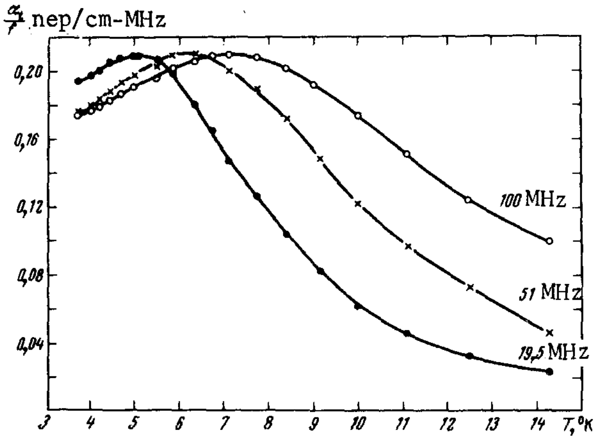

Fig. 1

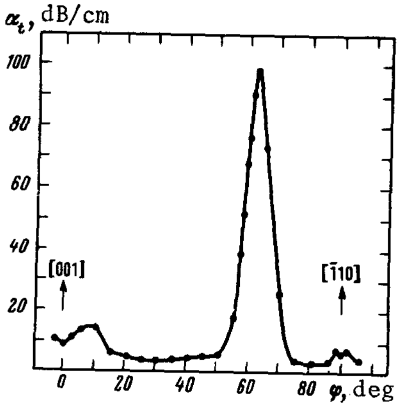

Fig. 2

Fig. 1. Temperature dependence of α_t at $q \parallel [110]$ and $\vec{\varepsilon} \parallel [\bar{1}10]$ for different sound frequencies.

Fig. 2. Dependence of α_t on the orientation of the magnetic field $\vec{H}$ relative to the [001] axis.

Mention should be made of a number of additional features observed for transverse sound propagating along the [110] axis and polarized along [$\bar{1}$10]. 1) The absorption coefficient is extremely large. Thus, at 51.4 MHz and T = 4.2°K we have at the indicated polarization direction α_t = 80 - 100 dB/cm, whereas at $\vec{q} \parallel [110]$ and $\vec{\varepsilon} \parallel [001]$ the absorption coefficient amounts to only 14 dB/cm. 2) A relatively large role is played in the observed variation of the sound absorption coefficient by the electromagnetic part of the absorption in the superconducting transition. Thus, at $\vec{q} \parallel [110]$ and $\vec{\varepsilon} \parallel [\bar{1}10]$ the electromagnetic part of the absorption in the superconducting transition is 70%, whereas at other orientations of $\vec{q}$ and $\vec{\varepsilon}$ this value drops to 35 - 40%.

An attempt to identify the electron group responsible for the indicated effects, by varying the oscillations of the geometric resonance, did not lead to a definite conclusion. However, experiments performed in strong transverse magnetic fields ($H \sim 8$ kOe) on the dependence of the absorption coefficient α_t on the orientation of the vector relative to the [001] axis proved to be very interesting1). Indeed, from the diagram in Fig. 2 we see that the absorption coefficient has a sharp maximum when the vector $\vec{H}$ makes an angle ϕ = 62.5° with the [001] axis.

At this orientation of the strong magnetic field, the absorption coefficient exhibits also an unusual temperature dependence, viz., α_t increases with decreasing temperature down to its lowest experimentally attained values. To emphasize the peculiar character of the temperature dependence of α_t at ϕ = 62.5°, the same figure shows an $\alpha_t(T)$ plot typical of all other magnetic-field orientations. We note that at the lowest attained temperature (T = 1.5°K) the sound absorption times wavelength (ϕ = 62.5° and H = 8 kOe) is $\alpha_t\lambda = 0.08$ neper, seemingly a record value for metals.

Since the sound absorption coefficient in a strong magnetic field is proportional to the mean free path ℓ [4], and $\ell^{-1} \sim T^3$, the experimental points plotted in the coordinates α_t^{-1} and T^3 should lie on a straight line, as is observed with good accuracy. The results of Fig. 3 show that in this case the ratio of the impurity and phonon contributions to the mean free path, for the electron group responsible for the observed phenomena, deviate appreciably from the mean.

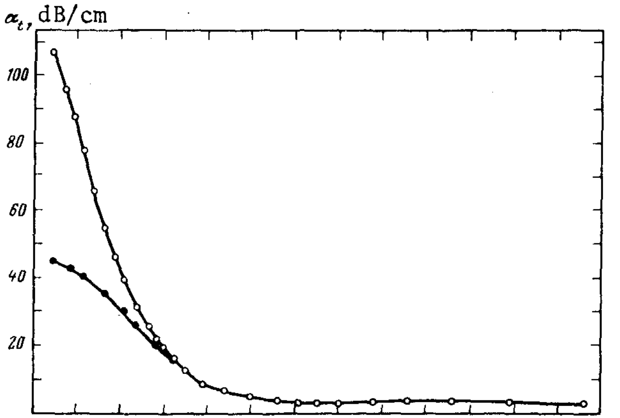

Fig. 3. Temperature dependence of α_t in a strong magnetic field: o - $\vec{q} \parallel [110]$, $\varepsilon \parallel [\bar{1}10]$. The angle between $\vec{H}$ and [001] is 62.5°. o - $\vec{q} \parallel [100]$ and $\vec{\varepsilon} \parallel [010]$.

We recall that considerable anomalies are observed near the superconducting transition at the given orientations of $\vec{q}$ and $\vec{\varepsilon}$ [5]. These anomalies have in our opinion the same nature as the effects described here.

The reasons for the observed phenomena are not clear at present. It can be assumed, however, as already stated earlier in [5], that in multiband metals such as tin there can exist weakly bound Fermi surfaces, with essentially different characteristics and different carrier relaxation times, pertaining to different bands. By introducing in addition the interband relaxation time it becomes possible to describe the observed anomalous phenomena with the aid of three parameters. The distinctive role of sound waves in this case is that it becomes possible to realize selective interaction of the sound with different electron groups because of the peculiarities of the deformation-potential components. This hypothesis is favored, e.g., by the fact that the singularity in the behavior of α_t in a strong magnetic field takes place at an orientation (ϕ = 62.5°) such that contact is produced between the central sections of the 4-th electron and 4-th hole bands of tin in the "neck" region [6].

In conclusion, we are sincerely grateful to I. O. Kulik, V. M. Kontorovich, and N. A. Sapogovaya for useful discussions.

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1) The vector $\vec{H}$ is rotated in the plane of the axes [001] and [110].

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STRUCTURE OF NONLINEAR WAVES PRODUCED WHEN INSTABILITY DEVELOPS IN ION-ION OR ELECTRON-BEAM PLASMA

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The electric field of a nonlinear wave excited in a synthesized ion-ion or electron-beam plasma and connected with the bunching of the charged particles and their capture by the wave field has been measured directly for the first time.

The question of the amplitude and waveform of the waves during the nonlinear stage of the instabilities developed in a two-beam or plasma-beam system was considered in a large number of theoretical papers [1 - 5]. We have measured directly, for the first time, the electric field of a wave excited in a synthesized ion-ion [6] and electron-beam plasma [7]. We used a probing electron beam (Fig. 1) that passed through the investigated system at right angle without perturbing it. The time of flight of the probing electrons was much shorter than the period of the investigated oscillations. Beam 5 was deflected in the plasma-oscillation field, which was directed along the z axis, and in the sinusoidal field between plates 7, which was directed along the x axis, and traced on the screen 8 a figure from which the time dependence of the electric field of the wave was determined.

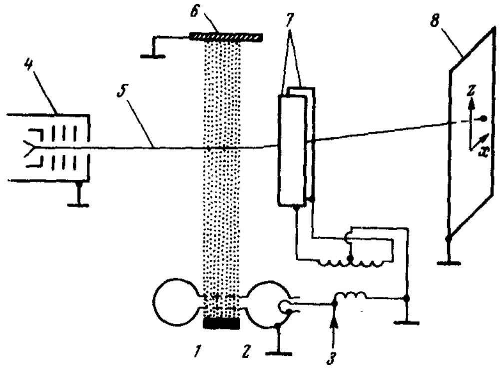

Fig. 1. Experimental setup for electron-beam plasma: 1 - cathode, 3 - microwave power input, 4 - electron gun, 5 - collector.

The synthesized ion-ion plasma was obtained in the manner described in [6]; the energy of the interacting beams of positive and negative hydrogen ions making up the plasma was W_0 = 13 keV, and the current in each component reached mA. The beams were velocity-modulated with amplitude $\tilde{v}_0$ on entering the interaction chamber and propagated along the z axis with a low adjustable relative velocity $2\Delta v$ ($\tilde{v}_0 \ll \Delta v$).

The electron-beam plasma was produced in argon by an electron beam of energy on the order of 100 eV and