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GIANT QUANTUM OSCILLATIONS OF SECOND HARMONIC OF SOUND IN BISMUTH

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Generation of the second harmonic of sound in bismuth was observed, as well as giant quantum oscillations of the second harmonic of sound under the condition $\varepsilon_F \gg \hbar\Omega \gg kT$ (ε_F is the Fermi energy, Ω the cyclotron frequency, and T the absolute temperature). The dependence of the second-harmonic power on the power of the sound at the fundamental frequency is determined.

Nonlinear phenomena in piezo-semiconductors, produced by propagation of acoustic waves of finite intensity, have been the subject of an appreciable number of investigations (e.g.[1 - 3]). The mechanism of these phenomena is associated with the so-called concentration nonlinearity - the capture of the carriers by deep potential wells connected with the motion of the sound wave and the depletion of carriers from the remainder of the volume. As a result, both the sound velocity and its absorption depend on the intensity of the acoustic waves.

Such a mechanism can apparently not be realized in pure metals and semimetals if $K\ell \gg 1$ (K is the wave vector of the sound and ℓ is the electron mean free path), since the Fermi energy of the electrons is much larger than the depth of the potential wells produced by the sound wave. When a wave with $K\ell \ll 1$ passes through the metal, the interaction between the acoustic waves and the electrons, which has a deformation nature in metals, decreases strongly and the conditions for the existence of the nonlinearity are not realized. The possible existence of a nonlinearity mechanism connected with the distortion of the electron distribution function by the sound wave was discussed in [4 - 6]. Such a mechanism, as shown in [6], should lead to a number of phenomena of clearly pronounced nonlinear character in metals and semimetals, such as the generation of the second harmonic of the acoustic wave, the dependence of the intensity of this harmonic on the magnetic field, the onset of combination frequencies, and also giant quantum oscillations of the second harmonic when the condition

$$\varepsilon_F \gg \hbar\Omega \gg kT$$

is satisfied (ε_F is the Fermi energy, Ω the cyclotron frequency, and T the absolute temperature).

The purpose of our experiments was to observe these phenomena in pure bismuth. The samples were cut by the electric spark method from a bulky single crystal and were in the form of disks 6 - 8 mm in diameter and 1 - 2 mm thick. The plane of the cut was perpendicular to the X or Y axis of the crystal (X - binary, Y - bisector). The resistance ratio characterizing the purity of the sample was R(300°K)/R(4.2°K) = 300.

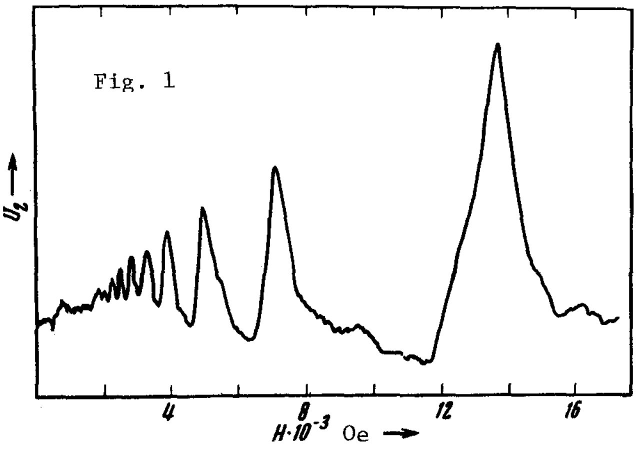
Fig. 1

The sound was excited and registered by a pulsed method using longitudinal-type sound converters with single-crystal $LiNbO_3$. To obtain maximum sound power in the sample at a given generator power, the coaxial-line and converter impedances were matched with the aid of lumped capacitors. The generated first harmonic frequency of the sound was 235 MHz, and reception was at 470 MHz.

Figure 1 shows the second-harmonic signal amplitude (in arbitrary units) against the magnetic field intensity, at the output section of the sample, for the orientation

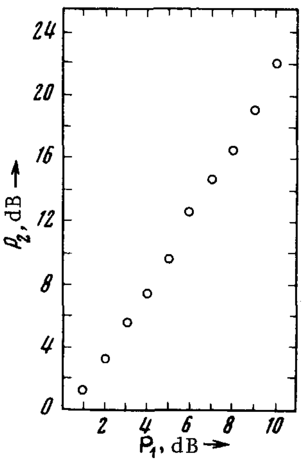

Fig. 2

$K \parallel H \parallel Y$. The periods of the giant quantum oscillations of second-harmonic absorption agree well with the periods of the first-harmonic sound oscillations in the bismuth. Figure 2 shows, in relative units, the dependence of the second-harmonic power P_2 on the fundamental power P_1, measured in a 7-kOe field, at which the giant oscillation absorption has a peak. It is seen from the figure that P_2 (dB) = $2P_1$ (dB), and hence $u_2 = \chi u_1^2$ (where u_2 is the amplitude of the second-harmonic wave, u_1 the amplitude of the first harmonic, and χ the coefficient of conversion of the first harmonic into the second). A similar relation was obtained theoretically in [4, 6]. On the basis of the first results it is still impossible to identify uniquely the mechanism that produces the nonlinearity in semimetals. It is clear, however, that the observed nonlinearity has an electronic character, since it becomes manifest in an effect that is connected with conduction electrons.

It was not our purpose to measure the parameter χ, and quantitative measurements will be reported in our next communication.

In conclusion, we consider it our pleasant duty to thank E.A. Kaner for useful discussions of the present work.

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INFLUENCE OF MULTIPLE SCATTERING ON TRANSITION RADIATION

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We present the results of the measurement of the spectrum of the transition radiation produced when 680-MeV electrons pass through a layered paper radiator. It is shown that multiple scattering of the electrons does not affect the intensity of the transition radiation.

Transition radiation in the x-ray band, in layered and porous radiators, has been the subject of many investigations [1 - 9]. The investigations were performed in the main at electron energies ≥ 1 GeV. At energies ≤ 1 GeV, The intensity of the transition radiation is low and the use of this phenomenon for particle identification entails certain difficulties. Obviously, this makes the phenomenon less interesting to physicists.

X-ray transition radiation in the region ≤ 1 GeV, however, is of definite interest from the point of view of the physics of this phenomenon.

X-ray transition radiation at electron energies 250 - 600 MeV was investigated in various layered radiators in [1, 2], where the experimental results exceeded appreciably (by more than one order of magnitude in some cases) the theoretical values calculated from the theory of transition radiation [10]. Moreover, the results obtained at different distances between the layers and with different numbers of layers could not be understood from the point of view of the ordinary theory of transition radiation or explained from the point of view of the known mechanisms whereby the photons are absorbed in the radiator itself.

A theory of transition (resonant) radiation was developed in [11] with account taken of multiple scattering, and the spectral distributions predicted by this theory coincided with striking accuracy with the experimental data of [1, 2].