Nonlinear absorption of sound in gallium in the superconducting state

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Singularities in the behavior of absorption and velocity sound were observed in the region of the superconducting state near T_c under conditions when the sample was acted upon by an additional high-power ultrasonic field. These singularities seem to indicate a restructuring of the energy spectrum of the superconductor.

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We have previously reported[1] unusual behavior of the absorption of sound in tin in the vicinity of the superconducting transition, namely, the existence of an exponential "tail" in the absorption above the critical temperature. The hypothesis was advanced that one of the possible causes of the observed phenomenon may be the presence of multiple bands. This assumption, and also the results of[2], which offer evidence of strong paraconductivity in isotopically pure gallium, have dictated the choice of gallium (which has a complicated Fermi surface[3]) as the subject of further research.

We investigated samples cut from single-crystal gallium of very high purity (mean free path $l \gtrsim 1$ cm), and also samples grown from the metal of grade GL-0 (purity 99.999%). The measurement apparatus is described in[4]. The magnetic fields were screened with Permalloy and superconducting shields. We used lithium-niobate pickups for longitudinal and transverse sound. The temperature was measured with an Allen-Bradley carbon resistor.

The results of the experiments are analogous to those of[1].

1. An exponential "tail" is observed ahead of the region of the steep decrease of absorption above T_c. The size of the tail depends on the crystallography of the sample and on the polarization of the sound.

2. In the dirtier samples, the temperature over which the tail extends is smaller (see curves 1 and 2 of Fig. 1).

At the same time, we have observed nonlinear effects consisting of strong deformation of the absorption curve with increasing amplitude of the sound field, in a direction opposite to that observed in[5]. To decrease the influence of overheating, further experiments were performed with two pulses of different frequencies applied to the sample, a weak measuring pulse and a high-power pump pulse. The pump pulse could either coincide with the measuring pulse or be shifted relative to it. The repetition frequency did not exceed 100 Hz.

Curves 1 and 2 of Fig. 1, for pure and dirty samples, respectively, correspond to the case when the pump pulse was applied 20 μsec after the measuring pulse (the pulsed heating of the sample was then completely dissipated prior to the arrival of the next measuring pulse). Curves 1′ and 2′ correspond to simultaneous propagation of the pulses. A characteristic feature of the latter case is the increase of the slope of the initial section of the sound-absorption curve, an increase which is stronger for the pure sample. Curve 2′ exhibits also symptoms of pulsed overheating, and possibly also the influence of relaxation of the order parameter.[5] Since the pump power was the same in both cases (as was also the length of the samples), it is reasonable to introduce the same correction also in the temperature position of curve 1′, and this suggests that the superconducting transition is shifted upward in temperature under the influence of the pump. The small difference between curves 1 and 1′ in the region of the normal state is connected with the appearance of pulsed nonlinearity.[6]

Figure 2 shows curves characterizing the change in the velocity of the transverse sound following the superconducting transition. In addition to the temperature shift corresponding to the minimum $(\Delta V/V)_{min}$, an appreciable change is observed also in the amplitude of this minimum under the influence of the pump, indicating apparently a restructuring of the energy spectrum of the superconductor.

The foregoing singularities appear in the behavior of the absorption also in the case of longitudinal sound. One other characteristic feature of these singularities is the decrease of the "tail" under the influence of the pump, which is particularly noticeable at higher pump frequencies (~150 MHz), at which the amplitudes needed for the given deformation of the absorption curve also decrease.

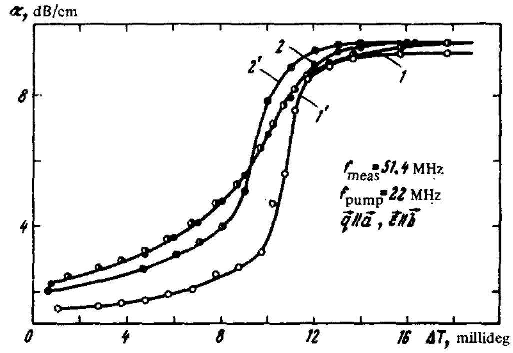

FIG. 1. Dependence of the absorption α on the temperature near T_c for pure (1 and 1′) and dirty (2 and 2′) samples: ◑, ●—absorption without pumping, ○, ⊙—absorption with pumping. Pump power 0.3 W/cm^2.

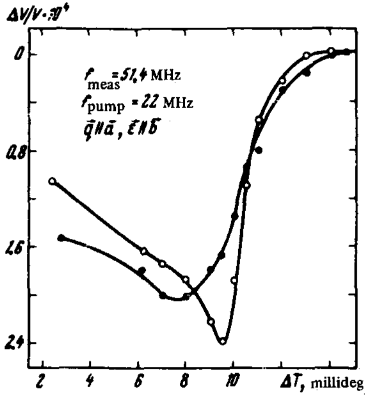

FIG. 2. Temperature dependence of the relative change of the velocity, $\Delta V/V$, near T_c. Pump power 0.3 W/cm^2. ○—with pumping, ●—without pumping.

In conclusion, we list certain factors that must be taken into account when it comes to explaining the observed phenomenon.

1. Overheating cannot be very influential for the following reasons: a) It should shift the curves towards lower temperatures. Deformation of the absorption curve is then possible in principle because of the decrease of the specific heat below T_c, but the deformed curve must not drop below the undeformed one; b) The quantity $(\Delta V/V)_{min}$ must not change in this case.

2. Effects such as gap relaxation[5] can likewise not explain the observed phenomena, since they increase rather than decrease the absorption.

3. There is no reason for expecting a significant change in the dislocation of absorption at values $(T_c - T)/T_c \ll 1$.

4. It is not very likely that effects such as pulsed nonlinearity can explain the observed phenomenon since: a) They are so small at the employed pump power; b) they do not appear at all in dirty samples (cf. curves 2 and 2′ of Fig. 1); c) it is shown in[6] that no specific singularities in the superconducting state are observed in the case of pulsed nonlinearity, i. e., one should not expect a strong deformation of the absorption curve in this narrow temperature interval; d) the pulsed nonlinearity does not influence the speed of sound significantly.

5. On the whole, the effect is reminiscent of stimulated "superconductivity,"[7] and this may more readily be the cause of the observed phenomena.

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