Possible stimulation of superconductivity in Bi–Sr–Ca–Cu–O by electromagnetic radiation

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A lowering of the surface resistance of a Bi–Sr–Ca–Cu–O ceramic in the superconducting state has been observed during the application of microwave radiation. The effect is observed in a certain temperture interval (60 K $< T < T_c$) at the frequency $\omega = 2\pi \times 3.6 \times 10^{10}\,\text{s}^{-1}$.

Despite the large number of published studies of the impedance properties of the high-T_c superconductors, the research interest in this topic is not weakening. The reasons are both purely scientific and applied aspects of high-T_c superconductivity. Significantly, many of the measurements have been carried out on materials with the composition $YBa_2Cu_3O_{7-x}$, so our understanding of the microwave properties of the high T_c superconductors is based primarily on the results of measurements on these materials (see, for example, Ref. 1).

In this letter we are reporting a study of the impedance properties of a Bi–Sr–Ca–Cu–O ceramic over the temperature interval $T = 300$–10 K. The results indicate a possible stimulation of superconductivity in the high T_c superconductors by electromagnetic radiation.

The Bi–Sr–Ca–Cu–O ceramic was synthesized from oxides of bismuth and copper and carbonates of strontium and calcium. The starting material, in the proportions Bi:Sr:Ca:Cu = 2.2:2:0.8:2, was carefully mixed in an aluminum oxide crucible and smelted at ~1000 °C. The melt was held at this temperature for 12 h and then cooled to 700 °C at a rate of 4 k/h. At 700 °C the furnace cooling rate was increased to 50 K/h. From the crystallized material which resulted, we prepared a sample with dimensions of 20×20×5 mm, which was annealed in air for 10 h at ~760 °C and cooled at 25 K/h.

Measurements were taken at the frequency $\omega = 2\pi \times 3.6 \times 10^{10}\,\text{s}^{-1}$ by a method involving a perturbation of a quasioptical dielectric resonator by the superconducting sample.[2] The radiation power in the waveguide did not exceed $P = 1$ mW and could be varied over two or three orders of magnitude with the help of a measuring attenuator. In the experiments we measured the width ($\Delta\omega$) of the resonance of the perturbed dielectric resonator as a function of the radiation power in the waveguide, P, and the sample temperature T. The sample interacted with the field of an EH_{n11} traveling azimuthal wave. The magnetic component of the field was oriented perpendicular to the plane of the sample, and the electric component parallel to it. The sample was not screened from external magnetic fields. A possible effect of the nonlinearity of the detector on the experimental results was eliminated.

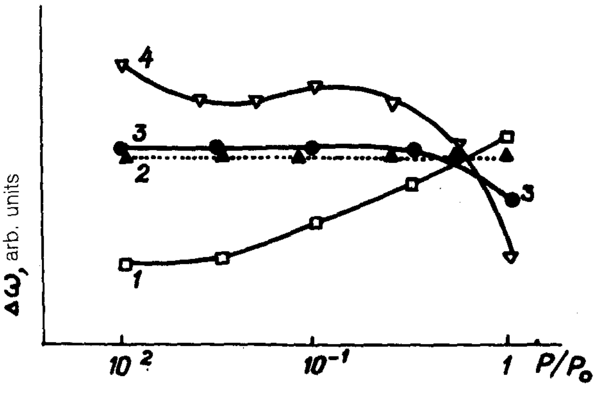

FIG. 1. The resonance width $\Delta\omega$ of a quasioptical resonator perturbed by the high-T_c sample versus the power P. 1 – $T = 30$ K; 2 – $T = 50$ K; 3 – $T = 67$ K; 4 – $T = 74$ K.

Figure 1 shows the resonance width $\Delta\omega$ of the quasioptical resonator perturbed by the sample versus the power P; the parameter of these $\Delta\omega(P)$ curves is T. At the minimum values of P used in the experiments, an increase in T is naturally accompanied by an increase in the resonance width $\Delta\omega$, which is proportional to the increase in the surface resistance. At $T = 30$ K, the width $\Delta\omega$ in a weak field does not depend on P; when P is raised above a certain value, it begins to increase monotonically (curve 1). This behavior prevails over the temperature interval $T = 10$–35 K. As T is raised to 50 K, we find no effect of P on $\Delta\omega$, within the measurement error (curve 2). With a further increase in T, the dependence $\Delta\omega(P)$ changes the sign of the derivative $\partial(\Delta\omega)/\partial P$ at elevated P (curve 3, for $T = 67$ K). When T is raised to 74 K (curve 4), the dependence $\Delta\omega(P)$ becomes nonmonotonic, and another descending region appears on the curve (in this interval of P).

The increase in $\Delta\omega$ with P indicates that the microwave field has a destructive effect on the superconductivity. The lowering of $\Delta\omega$ with increasing P may be a consequence of a stimulation of superconductivity by this field. The experimental results indicate that the superconductivity stimulation effect is manifested at temperatures above a certain value of T, and the effect becomes particularly noticeable near T_c.

A stimulation of superconductivity has been observed previously in low-T_c superconductors under other experimental conditions.[3,4] The microscopic theories which have been proposed[5,6] give a good description of the experimental results on these superconductors.[7]

Let us discuss at a qualitative level certain aspects of the observed effect, in the model of a granular sample of a high-T_c superconductor with nonuniform contacts between grains. The nonmonotonic $\Delta\omega(P)$ dependence (curve 4) may indicate that at a fixed temperature the radiation will destroy or stimulate the superconductivity, depending on the value of P. This nonmonotonic behavior follows from the theory of Ref. 6, which was derived for nonuniform contacts. This behavior may indicate that the length of the contacts, L, satisfies the inequality[6,7] $L < \xi(T)$, where $\xi(T)$ is the coherence length. In this case the superconducting properties are intensified only at power levels $P > (1/3v_F il^2/\Delta_0)$,[10,11] where v_F is the Fermi velocity, l is the mean free path of the electrons with respect to scattering by impurities, and Δ_0 is the energy gap

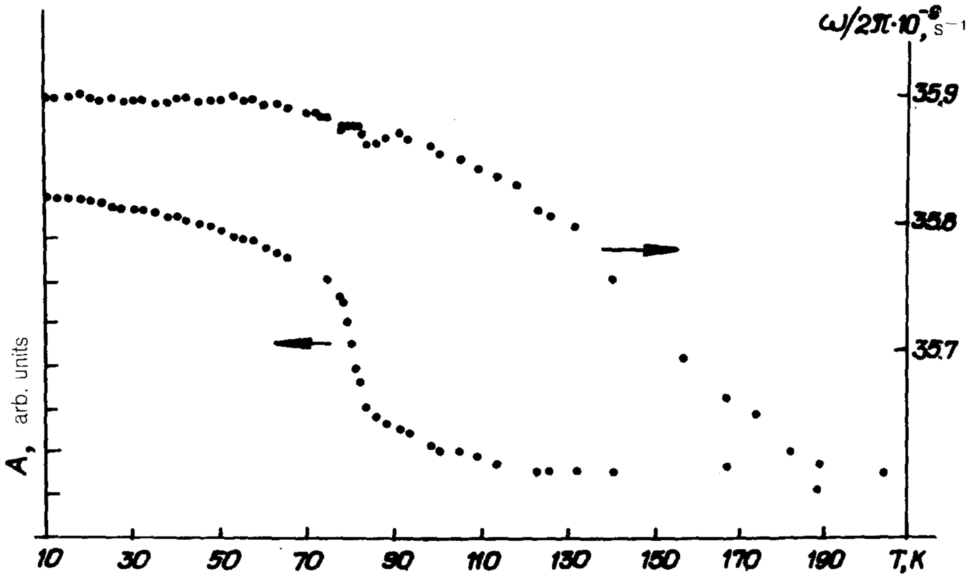

FIG. 2. Temperature dependence of the absorption coefficient for electromagnetic energy, A, and that of the resonant frequency $\omega/2\pi$ of the quasioptical resonator with the high-T_c sample.

in the interior of the sample, away from a contact. At lower power levels, the radiation suppresses the superconductivity at the contact.

The apparent reason for the two inflection points on the nonmonotonic $\Delta\omega(P)$ curve in this P interval is the presence of two superconducting phases in the sample. The presence of these two phases is confirmed by the temperature dependence of the absorption coefficient (A) for electromagnetic energy in the resonator with the sample. The coefficient A increases with decreasing surface resistance, i.e., with an increase in the intrinsic Q of the sample-loaded resonator. The $A(T)$ dependence correlates well with the temperature dependence of the resonant frequency, $\omega(T)$ (Fig. 2).

On the other hand, it is known[8] that the value of $\xi(T)$ in Bi–Sr–Ca–Cu–O is extremely small, on the order of interatomic distances in the crystal lattice of the high-T_c superconductor. For this reason, the validity of the model of Ref. 6 in this case comes under doubt and requires proof.

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