Microwave absorption in $YBa_2Cu_3O_{7-\delta}$ single crystals in a magnetic field

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The absorption of microwave power in $YBa_2Cu_3O_{7-\delta}$ single crystals in a magnetic field has been measured for the first time. An anisotropy in the microwave-absorption field dependences has been detected. The ESR signal from Cu^{2+} is absent.

The study of high-temperature metal-oxide superconductors by the ESR methods[1–7] has yielded interesting information on the presence and the position in the crystal lattice of paramagnetic centers, including the Cu^{2+} ions, and on the particular features of the interaction of microwave radiation with superconductor in the normal and superconducting states. The results of the ESR measurements, however, have until now involved polycrystalline ceramic samples, in which the strong anisotropy of the properties due to the layered perovskite structure of such materials is canceled out.[8,9] Accordingly, we are reporting here the preliminary results of an experimental study of the $YBa_2Cu_3O_{7-\delta}$ single crystals by the ESR method.

The samples were parallel-face plates with the *a,b* plane measuring (1.8–0.8) × (1–0.4) mm and 60–40 μm thick along the crystallographic axis $c \perp (a,b)$. The single crystals were grown by slow cooling of a partially molten mixture of the Y_2O_3, CuO, and BaO oxides. The crystals are characterized by the presence of twins which were formed in accordance with the {110} / {110} system.[10]

The composition and its distribution along the *a,b* surfaces of the plates and along the cleavage face in the direction of the *c* axis were controlled by means of an x-ray spectral microanalysis using the "Camebax" apparatus (with a resolution of $\sim 1\ \mu$m). It was established that the single crystals studied correspond in Y:Ba:C to the ratio 1:2:3 in all directions, along the *a,b* surfaces and in the transverse direction. The oxygen content, which was determined by the complementary method, was found to be 6.7, i.e., $YBa_2Cu_3O_{6.7}$, after averaging over several tens of points. The structure of perovskite, which was studied in $YBa_2Cu_3O_x$, as a function of x, is known to be stable[9] at $6 < x < 7$. A transition from an orthorhombic structure to a tetragonal structure is accompanied by a decrease in x at $x = 6.5$, when both phases can coexist at room temperature. Our samples with $x > 6.5$ were orthorhombic with $a = 3.86$ Å, $b = 3.92$ Å, and $c = 11.59$ Å.

The ESR measurements were carried out over the *X* range with a "Radiopan" SE/*x*-2543 spectrometer (with a frequency of ~9.15 GHz).

The ESR response of the Cu^{2+} copper ions in the metal oxide single crystals

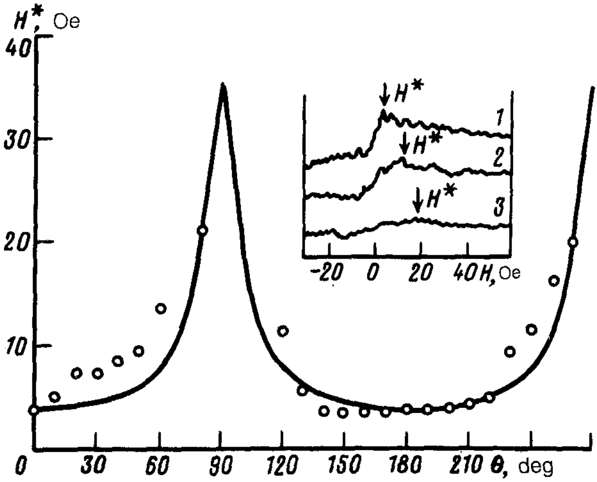

FIG. 1. H^* versus the angle θ between the magnetic field direction and the c axis of the crystal. Inset—The shape of the signal dr/dH for three orientations of the sample (1—$\theta = 0°$; 2—$\theta = 50°$; 3—$\theta = 70°$).

studied was found to be absent both in the normal state ($T = 290$ K) and in the superconducting state ($T = 78$ K). The certified sensitivity of the apparatus was 10^{11} spins. The signal received from bivalent copper, which was detected at $T > T_c$ in polycrystalline metal oxides Y-Ba-Cu-O and which was especially strong in the nonsuperconducting "green" ceramic of the composition Y_2BaCuO_5 (Refs. 1 and 4) and slightly weaker in the superconducting "black" ceramic characterized by the g-tensor components $g_{\parallel} \approx 2.03$–$2.06$ and $g_{\perp} \approx 2.2$, is thus apparently due to the phase and structure inhomogeneities of the ceramic samples and is not related to copper in the regular positions of the superconducting $YBa_2Cu_3O_{7-\delta}$ phase, as was assumed in Refs. 1, 5, and 7.

At temperatures $T < T_c \approx 90$ K the $YBa_2Cu_3O_{7-\delta}$ single crystals exhibit peculiarities in the microwave power absorption which are particularly sharply defined in the region of zero static magnetic field. A similar effect in ceramic samples was described in Refs. 2–6. This effect is strongly anisotropic in single crystals, in contrast with ceramics. Figure 1 is a typical example of the field dependences of the first derivative of the microwave absorption signal, $dR/dH = f(H)$. These dependences were obtained by slowly sweeping and strongly modulating ($H_m = 4$ Oe) H at the frequency $f = 100$ kHz and at different values of the angle θ between H and the c axis. The shape of the signal changes systematically as a result of the variation of θ: The strongest signal with a minimum width occurs when $H \parallel c$ and the relation between the amplitude and the width of the signal is the reverse when $H \perp c$. If the static magnetic field H^*, which corresponds to the inflection point on the curve for the microwave power absorption, is chosen as a parameter, the orientational dependence can be approximated by the expression

$$H^*(\theta) = H_{\parallel}(\cos^2\theta + \epsilon^2 \sin^2\theta)^{-1/2},$$

where $H^*_{\parallel} \approx 4$ Oe, $H^*_{\perp} \approx 35$ Oe, and $\epsilon = H^*_{\parallel}/H^*_{\perp}$. The observable anisotropy is not caused by the shape of the crystal, since the width and strength of the signal from the ceramic samples, which are similar to the single crystals, do not depend on the orien-

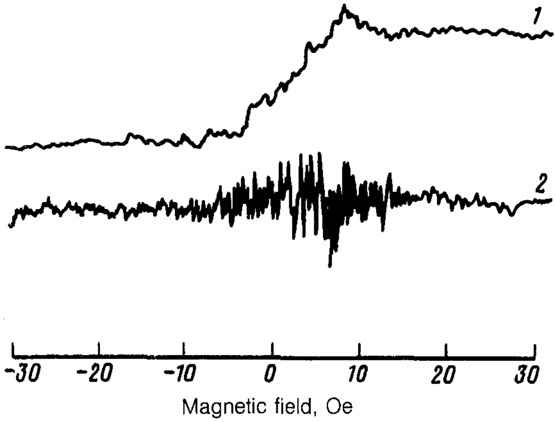

FIG. 2. The shape of the dR/dH signal for the orientation $\theta = 50°$ (the modulation amplitudes are: 1—4 Oe; 2—0.125 Oe).

taion of the sample relative to H.

The distinguishing feature of the $YBa_2Cu_3O_{7-\delta}$ single crystals is the strong oscillatory nature of the dependence $(dR/dH) = f(H)$ in the region of weak static fields, which manifests itself at low modulation amplitudes. The field range in which the large-amplitude oscillations are seen correlates with the width of the "remodulated" signal dR/dH (Fig. 2). Upon repeated scanning the oscillatory pattern is stably reproduced in the magnetic field interval near the ero field, but the particular features of its structure differ in this case.

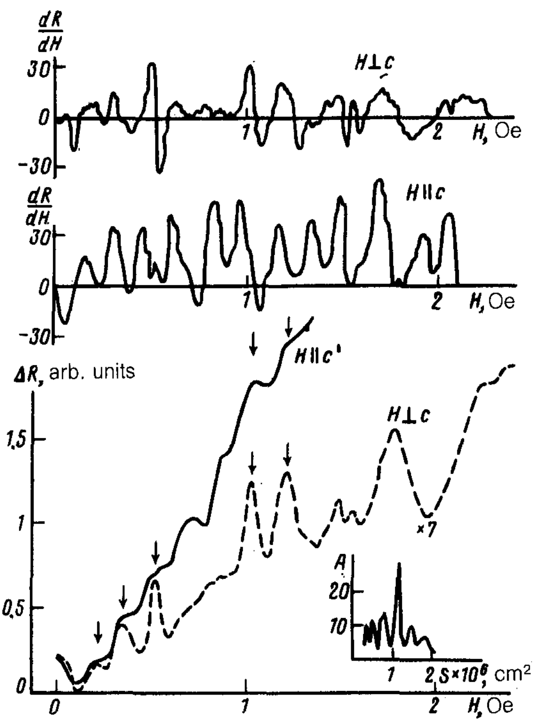

FIG. 3. Oscillations of dR/dH and ΔR in the region of zero magnetic field for the orientations $H\|c$ and $H\perp c$. Inset—The Fourier transform of dR/dH for the orientation $H\|c$.

Figure 3 shows the results of the measurements in small fields ($H = 0$–2 Oe) with slight modulation ($H_m = 0.125$ Oe) for $H \| c$ and $H \perp c$. In the case of each orientation we see a clear agreement in the position of the oscillatory features along the H axis, which is particularly obvious for the integral curves. These features beome more acute on going from $H \| c$ to $H \perp c$, but the field periodicity remains essentially constant. The Fourier transform of dR/dH reveals a sharp peak at $\Delta H = 0.176$ Oe, which is close to the distance between the first maxima on the $R(H)$ curve and which corresponds to an area $S = \Phi_0/\Delta H \approx 1.14 \times 10^{-6}$ cm^2. The result which we have obtained clearly confirms the presence of processes of a Josephson nature, which are possibly related to the presence of the twins and to the nonuniform distribution of oxygen in the crystal. Further studies along this line are necessary.

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