Electron spin resonance and electromagnetic effects in systems of the type Me-Ba(Sr)-Cu-O

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At temperatures below the superconducting transition temperature T_c the ESR spectrum of the system Me-Ba(Sr)-Cu-O reveals a line in a weak magnetic field. At temperatures well below T_c this line has an additional structure in the form of aperiodic fluctuations of the ESR signal in the magnetic field. In contrast with the noise fluctuations, the observed structure can be fully reproduced by repeatedly recording the signal.

Systems of the type Me-Ba-Cu-O are known[1] to be superconductors whose superconducting properties and transition temperature T_c depend on the relative content of the various components of the composition. It is assumed that in the compounds under consideration copper is in a state with a valence of 2 and that the d electrons form, as a result of aggregation, a band with a high state density. Structural irregularities of the material can clearly lead to the appearance of single Cu^{2+} ions which can be used as a spin marker in the study of the homogeneity of a composition in the normal state and in the study of a mixed state of a superconductor at $T < T_c$. The electron spin resonance is an effective research method in this case.

In the present letter we report the results of an experimental study of various superconductors by the electron spin resonance (ESR) method and we show that a conclusion concerning the homogeneity of the composition can be drawn from the intensity of the ESR signal. At $T < T_c$ we observed a magnetic-field-induced nonresonance effect which we call an electromagnetic effect. We have also observed effects which are attributed to the mesoscopic structure of the superconducting state.

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We studied the ceramics $MeBa_2Cu_3O_{6+\delta}$ (Me = Y, Ho, Eu) and $ScSr_2Cu_3O_{6+\delta}$ with Bruker ER-220 D-LR and Radiopan SE/X-2543 ESR spectrometers at frequencies of 9.5 GHz and 9.1 GHz over a temperature interval of 3.7–300 K. The point at which these ceramics undergo a transition to the superconducting state was determined from the temperature dependences of the resistivity and from the static magnetic susceptibility.

At temperatures below T_c the microwave power absorption spectrum of the superconducting ceramics reveals an additional line in the weak magnetic fields, whose intensity is three orders of magnitude higher than that of the Cu^{2+} ion line which is observed at temperatures above the phase-transition point of the samples studied. In weak fields the intensity of the signal increases with decreasing temperature and the line shifts up the field scale.

Figure 1 is a typical example of a field dependence of the first derivative of the

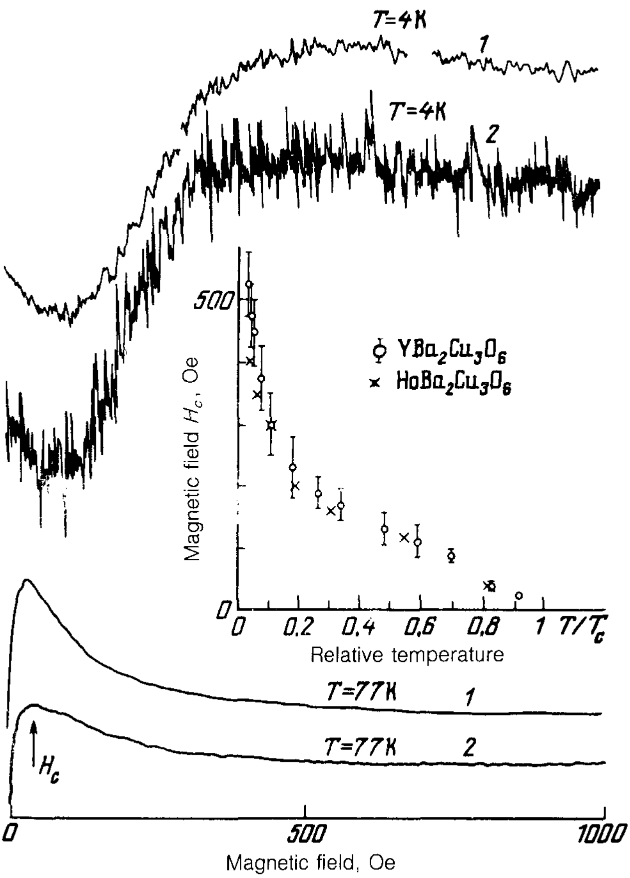

FIG. 1. Line produced by the electromagnetic effect in the ceramics (1) $YBa_2Cu_3O_{6+\delta}$ and (2) $HoBa_2Cu_3O_{6+\delta}$ for various ratios T/T_c. Inset—temperature dependence of H_c; the mesostructure of the line and the dependence of its amplitude on the external field and temperature are clearly evident.

absorption line for the two systems Y-Ba-Cu-O and Ho-Ba-Cu-O in weak fields. The temperature interval over which the signal increases in intensity is related to the abruptness of the transition to the superconducting state, i.e., it depends on the properties of the ceramic. This temperature interval is different in each ceramic which has the same composition but which is fabricated under different technological conditions. We believe that this line is not related to the resonant absorption in the samples, but stems from the change in the macroscopic properties of the sample as a result of transition of the disordered system to the superconducting state—the electromagnetic effect. This effect occurs as a result of absorption of microwave power in a Josephson medium. At temperatures below T_c the superconducting ceramics, like the metal-oxide superconductors $BaPb_{1-x}Bi_xO_3$, are, in our view, such a medium.[2] This effect increases as the external magnetic field is increased to a critical value H_c, and then it falls off. The temperature dependence of H_c for the two systems is shown in the inset in Fig. 1.

Upon return of the external field to zero, the signal relaxes, at $H = 0$, to the initial value over a time (on the order of a minute or more) which characterizes the time scale for the existence of ring currents in the superconducting grid of the ceramic.

The mesostructure of the superconducting state is another intriguing manifestation of the electromagnetic effect. The "fluctuations" of the signal increase sharply as the temperature is lowered. Multiple magnetic-field traversals have no effect on the structure of the signal (Fig. 2). The structure of the signal changes sharply, however, when the sample is rotated in the magnetic field. As can be seen in Fig. 2, the structure requires some time to become established. The structure of the signal in the ceramic Y-Ba-Cu-O is distinct from that in the ceramic Ho-Ba-Cu-O. As the temperature is

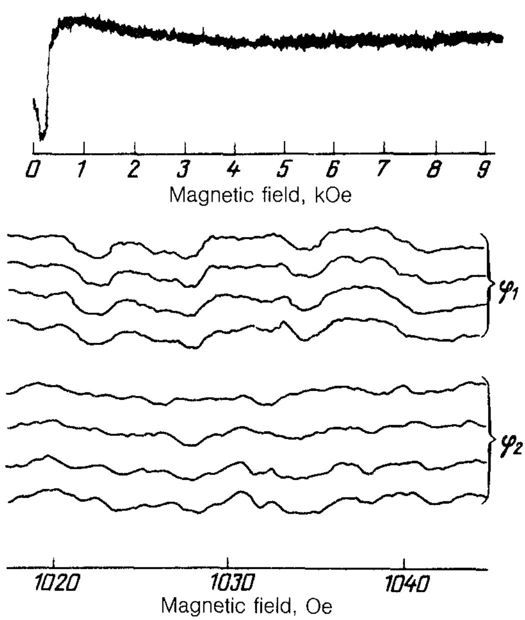

FIG. 2. The mesostructure of the line of the electromagnetic effect produced as a result of multiple traversals of the magnetic field for two different orientations of the sample relative to the external magnetic field at $T = 4$ K. The top part of the figure shows the general view of the line for the electromagnetic effect.

lowered below T_c, the amplitude of the "mesoscopic signal" first increases and then levels off to essentially constant value at $T < 15$ K. Such a behavior is typical for the occurrence of mesoscopic effects.[3] Although this effect clearly must be studied in greater detail, we can now assert, nonetheless, that it offers additional opportunities to determine the organization of the superconducting state of disordered systems.

More detailed results of the experimental studies of the electromagnetic effect in the inhomogeneous superconductors and of the field and time dependences of the mesoscopic structure of this effect will be published in a separate paper.

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