Nonlinear Response of a Superconductor of the Bi-Sr-Ca-Cu-O System to an Alternating Magnetic Field in the Superconducting Transition Temperature Range

Alexander Sergeev[1,*], *Igor* Golev[2], *Victoria* Gvozdevskaya[1] and *Anastasia* Barkalova[1]

[1]Voronezh State Technical University, 394026 Moscow Avenue 14, Voronezh, Russia
[2]The Military Educational and Training Center of Air Forces «The Air Force Academy, named after Prof. N.E. Zhukovsky and Y.A. Gagarin», 394064 ul. Old Bolsheviks 54 "A", Voronezh, Russia

Abstract. The nonlinear response of the superconductor of the Bi-Sr-Ca-Cu-O system in the temperature range of the superconducting transition under the action of a harmonic alternating magnetic field is experimentally studied. For multiphase superconductors having in their volume regions with distinct critical temperatures, the effect of odd harmonics in the response signal is observed. The contribution of crystallites and the system of weak bonds between the crystallites in the nonlinear response is singled out. It was found that the nonlinear properties of the investigated samples in the resistive state are determined mainly by the nonlinear current-voltage characteristics of the system of weak bonds between the crystallites.

1 Introduction

The study of the behavior of high-temperature superconductors (HTSC) under the influence of alternating magnetic fields of different amplitudes still raises an increased practical interest. The results obtained can be a source of additional information on physical processes occurring in high-temperature superconductors with a complex real crystal structure, including regions with different chemical composition, crystallites, and intercrystalline media [1-4].

This paper presents the results of experimental studies of the nonlinear properties of ceramic HTSC Bi-Sr-Ca-Cu-O systems during their transition from the normal to the superconducting state, when the volume of the superconductor has an electrical resistance to a constant electric current.

2 Samples and experimental procedure

Samples of the Bi-Sr-Ca-Cu-O system measuring 3.2 × 3.2 × 20 mm^3, obtained by solid-phase synthesis, were studied. The X-ray photograph is shown in fig.1. The fig. 2 presents the photograph of the sample surface microstructure, obtained using an electronic scanning microscope with a detector of inversely scattered electrons (BEI). The phase composition of samples was determined by the Rietveld method. The samples consisted of two phases: Bi-2223 – 47.6 % (a = 5.411 Å, b = 5.411 Å, c = 37,21 Å) and Bi-2212 – 52.3 % (a = 5.397 Å, b = 5.4 Å, c = 30.783 Å). The temperature of the onset of the superconducting transition of the sample is T = 103 K, the temperature of the end of the superconducting transition is T = 94 K, the sample density was 4.1 g / cm^3.

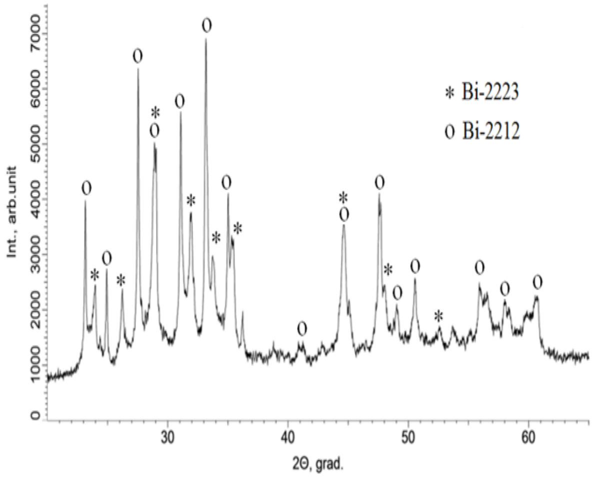


Fig. 1. The X-ray photograph of a sample

In the experiments we measured the voltages of odd (n = 1, 3, 5, 7) harmonics from a measuring single-layer coil wound around the sample under the action of a low-frequency alternating magnetic field. The alternating magnetic field was directed along the principal axis of symmetry of the superconductor sample. Harmonic components from the response signal of a superconductor sample were isolated using a selective microvoltmeter. In Fig. 3 is a schematic diagram of the measuring stand.

* Corresponding author: sergeev-av@bk.ru

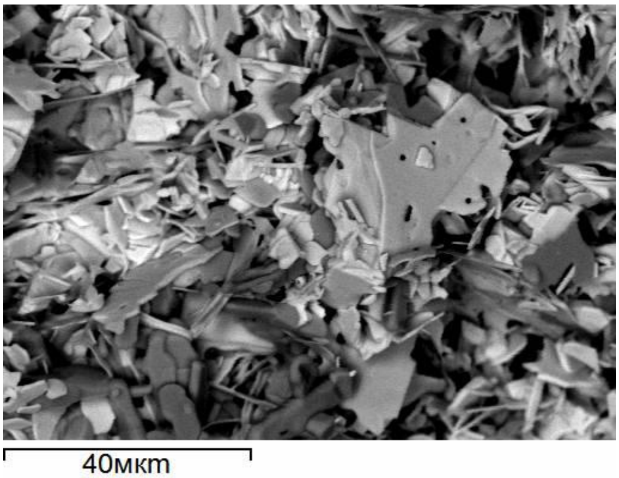
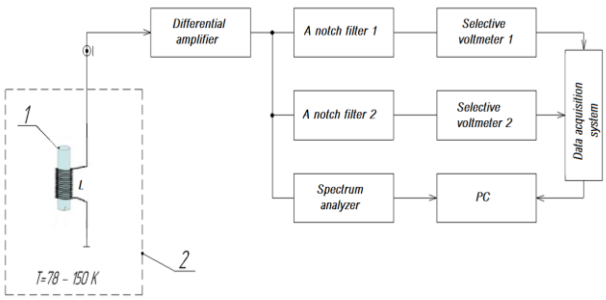


Fig. 2. The microstructure of a sample split



1 – sample, 2 – thermo-stabilized volume
Fig. 3. The circuit diagram of the measuring unit

3 Results and discussion

In Fig. 4 shows the temperature dependences of the first harmonic of the response signal of a superconductor on an alternating magnetic field and the resistivity. In Fig. 5 shows the temperature dependences of the odd harmonics (third, fifth, seventh) of the sample response signal to an alternating magnetic field.

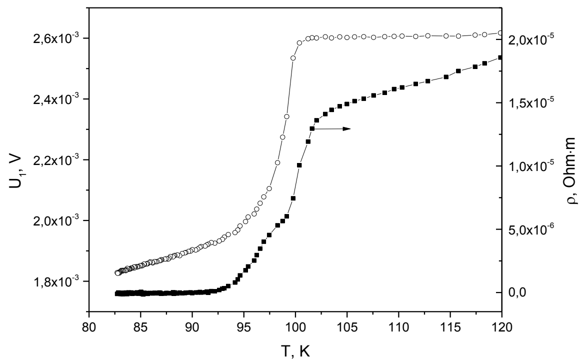


Fig. 4. Temperature dependences of the voltage of the first harmonic of the response signal and the resistivity at b = 5 G; f = 1000 Hz

As can be seen from the results of the experiments (Fig. 5), maxima are observed in the superconducting transition temperature range, with a specific electric resistance ρ > 0 on the dependences $U_3(T)$, $U_5(T)$, $U_7(T)$. In addition, the maximum value of the harmonic voltage ($U_3(T)$, $U_5(T)$, $U_7(T)$) decreases with decreasing ordinal number of the harmonic, and the temperature of realization of the maximum does not change.

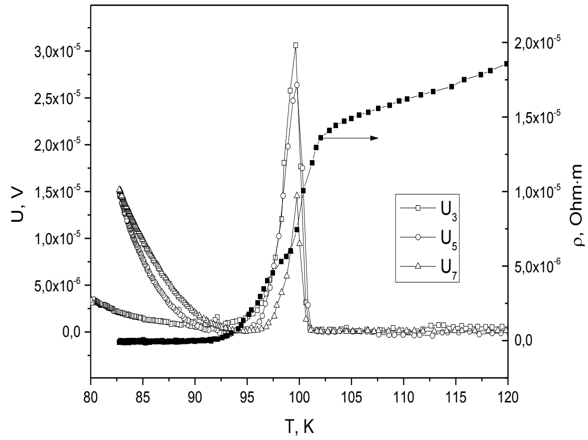


Fig. 5. Temperature dependences of the voltages of the third, fifth, seventh harmonics of the response signal at b = 5 G; f = 1000 Hz

In the future, only $U_3(T)$ dependences will be presented, characterizing the nonlinearity of the superconductor response to an alternating magnetic field. Even harmonics were not detected under the action of an alternating magnetic field of different amplitudes [5].

The effect of the amplitude of the alternating magnetic field b on the temperature dependence of the third harmonic of the response signal was studied. As seen from the experimental data, the temperature region T = 120 ÷ 102 K, the third harmonic U_3 has a zero value, i.e. The sample responds linearly to the alternating magnetic field (Fig. 6).

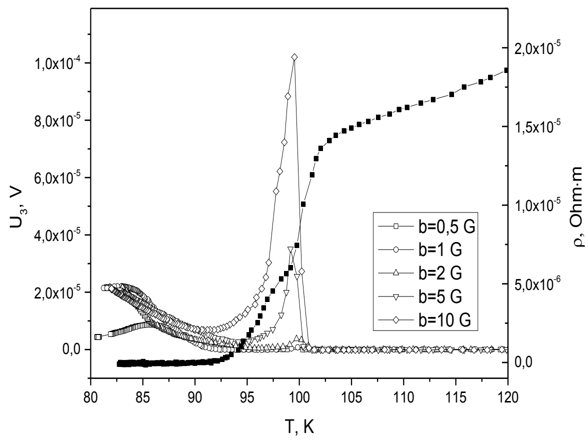


Fig. 6. Influence of the amplitude of the alternating magnetic field on the dependence $U_3(T)$ at f = 1000 Hz

The investigated superconductors of the Bi-Sr-Ca-Cu-O system have a complex structure consisting of Bi-2223 and Bi-2212 phase crystallites separated by weak bonds with weaker critical parameters (J_c, T_c). An electric current induced by an alternating magnetic field with density J transforms the weak links into a resistive state and their current-voltage characteristic becomes nonlinear. It can be described by the following power-law dependences [6]

$$U = AJ^N, \quad (1)$$

or

$$U = (J - J_c)^N, \quad (2)$$

where $U(J_c)$ is the voltage drop in the elementary volume of the superconductor; J_c is the critical current; A, N are constants determined experimentally. The quantity $U(J_c)$ depends nonlinearly on the current density, which determines the nonlinear properties of the superconductor and, accordingly, the signal of its response to the alternating magnetic field. If N is an odd number, which is observed in our experiments, then the odd harmonics are present in the response signal of the superconductor. (see Fig. 5).

Let us single out the contributions of the nonlinear response of crystallites and the system of weak bonds between the crystallites. To do this, we analyze the dependencies obtained for the powder obtained from the sample.

The results of measurements of the temperature dependence of the third harmonic of the response signal to an alternating magnetic field for a powder are shown in Fig. 7. The value of $U_3(T)$ was normalized per unit volume, taking into account the sample density.

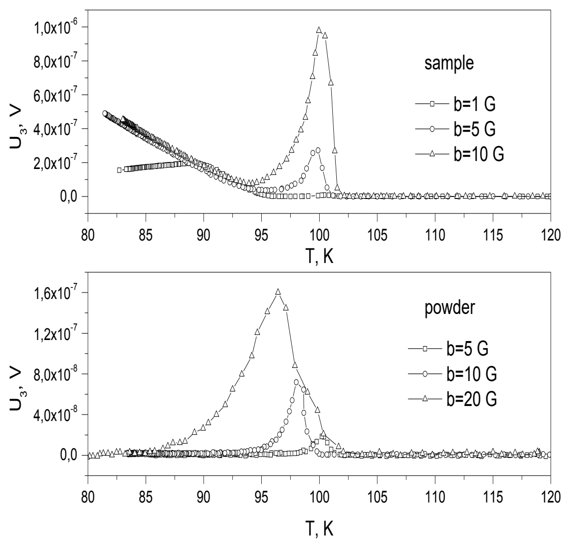


Fig. 7. Influence of the amplitude of the alternating magnetic field on the dependence $U_3(T)$ at f = 1000 Hz

As can be seen from Fig. 7, for a powder obtained from a sample, in the absence of a percolation superconducting network, only one maximum is observed on the $U_3(T)$ curve, the mechanism of which is analogous to the third harmonic generation mechanism in the integral samples described in [3]. The contribution of the nonlinear response in the volume of crystallites of the Bi-2223 phase is approximately 100 times less than in the system of weak bonds of the Bi-2223 phase.

4 Conclusions

The nonlinear properties of the investigated samples in the resistive state are determined mainly by the nonlinear current-voltage characteristics of the system of weak bonds between the crystallites. The observed effect of the generation of odd harmonics in the response signal to an alternating magnetic field can be used as a tool for investigating the dissipative processes of multiphase or inhomogeneous superconductors.

References

1. V. Ya. Pokrovskii, I. G. Gorlova, and S. G. Zybtsev, Physica C, **4**, 2077 (1997).
2. N. V. Dalakova, B. I. Belevtsev, E. Yu. Belyaev, and A.S. Panfilov, Low Temp. Phys. **40** (5), 397 (2014).
3. A. I. Golovashkin, N. D. Kuz'michev, and V. V. Slavkin, Tech. Phys. **53** (10), 1314 (2008).
4. I. M. Golev, A. V. Sergeev, V. G. Kadmenskii, and O.V.Kalyadin, Vestn. Voronezh. Gos. Tekh. Univ. **11** (5), 129 (2015).
5. I. M. Golev, A. V. Sergeev, and O.V.Kalyadin, Phys. Solid State, **59** (1), 19 (2017).
6. Babic E., Prester M., Biskup N. Phys. Rev.B, **41** (10A), 6278 (1990).