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Thermal Fluctuations of Bismuth Based 1G Tape

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The thermal fluctuations of bismuth based commercial 1G tape were studied near the critical temperature $T_c = 110.2$ K. The detailed analysis of the temperature dependence of resistivity measurements was made in the temperature region from the zero resistance critical temperature up to 300 K. The thermal fluctuations of conductivity were analysed using the Aslamazov-Larkin microscopic approach and the critical exponents were calculated close to the transition temperature.

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1. Introduction

The high temperature superconductors (HTS) possess special features in comparison to the classical ones. HTS are extreme second type with the large penetration depth λ of the order of $10^3 - 10^4$ Å [1] and very small coherence length ξ of the order of 10 Å [2]. That makes the Ginzburg–Landau parameter $\kappa = \lambda/\xi$ of the order of 10^2 or more. Other important superconducting parameters are also extremely anisotropic (e.g. the ratio of c- to abdirection of penetration depths $\gamma = \lambda_c / \lambda_{ab}$ is of the order of $10-10^2$ for YBCO and of the order of 10^4 for BSCCO) like the critical currents, the irreversibility fields and others, because of the anisotropic layered structure of weakly coupled CuO_2 superconducting planes. As a consequence the huge thermal fluctuations around the critical temperature of the superconducting transitions in HTS are observed. Within this critical region the competition between the critical fluctuations at lower temperatures and the Gaussian (stochastic) fluctuations at the temperatures above the critical temperatures exists and depends on the applied magnetic field as well as the applied pressure [3–5]. Because of the huge anisotropy the superconductors exhibit generally the three-dimensional (3D) to the two-dimensional (2D) transition in the critical region for polycrystalline, single crystal as well as for thin film samples [6–9]. There are also observed the crossover from 2D to 1D in Hg-Tl 1223 polycrystalline superconductor [10]. In this paper the thermal fluctuations of the 1G commercial BSCCO tape in the superconducting transition were studied. The critical exponents were obtained as well.

2. Experimental

The commercial first generation bismuth based superconducting tape was manufactured by the American Superconductor Company (AMSC). The commercially identifying of this tape is as follows: 1G High Strength Plus 135A Ic min "5715 135" BSCCO.

The temperature dependences of the resistance were measured using the standard four-point ac method to take advantage from Stanford SR 830 lock-in nanovoltometer. The temperature from 77 K to 300 K was monitored by a Lake Shore temperature controller with applied a chromel–gold–0.07% Fe thermocouple with an accuracy of ± 0.05 K. The electrical contacts were soldered with tin. The distance between the voltage contacts was 2 cm. The current applied during the measurements was 8 mA. Each data point is the average from the 25 time repetition.

3. Results and discussion

The thermal fluctuations of 1G BSCCO tape were studied on the basis of the temperature dependences of the resistance that is shown in Fig. 1. The critical parameters of this sample are as follows: the zero resistance critical temperature $T_{c0} = 109.8$ K that was obtained using the 1 μ V/cm electrical field criterion, $T_{c50\%} = 110.2$ K and $T_{c_onset} = 111.6$ K. We also obtained the transition width which is $\Delta T_{90\%-10\%} = 0.7$ K. $T_c = 110.6$ K, respectively. This indicates that the transition to the superconducting state is three-step process. The position T_A corresponds to the weak intergranular links and the zero resistance critical temperature. The position T_B corresponds to the grains and the $T_{c50\%}$ critical temperature and finally the position T_c is related to the fluctuations near onset superconducting transition.

The analysis of thermal fluctuations has been made on the basis of the following formula [11]:

$$\Delta \sigma = K \varepsilon^{-\lambda},\tag{1}$$

where σ is the temperature dependence conductivity, $\varepsilon = (T - T_c)/T_c$, λ is a critical exponent and K is a constant. The temperature dependence of excess conductivity is defined within the Ginzburg–Landau mean field approximation as

$$\Delta\sigma(T) = \frac{1}{R(T)} - \frac{1}{R_{\rm R}(T)},\tag{2}$$

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Fig. 1. Resistance versus temperature of BSCCO tape using the applied current of 8 mA. Inset: the resistance data from room temperature down to the onset temperature that was fitted by the linear function (see text).



Fig. 2. Derivative of the resistance as a function of temperature. There are characteristic temperatures related to the three peaks: A, B and C described in the text.



Fig. 3. $\log(\Delta \sigma)$ vs. $\log(\varepsilon)$ dependence of BSCCO tape with lines fitted to linear regions. The zero resistance critical temperature $T_{c0} = 109, 8$ K was used to calculate ε .

where R(T) is the measured resistivity and $R_{\rm R}(T)$ is the resistivity obtained by the linear extrapolation of the resistivity data from room temperature down to the onset temperature (see inset in Fig. 1). To acquire the $\Delta\sigma$ it is necessary to determine $R_{\rm R}(T)$ which is made by extrapolating normal state behaviour as follows:

$$R_{\rm R}(T) = R_0 + \left(\frac{\mathrm{d}R}{\mathrm{d}T}\right)T,\tag{3}$$

where R_0 and dR/dT are constants. R_0 is the intercept of line fitted to measured data in high temperatures. The way to determine the critical exponents was described in detail in the papers [3, 5, 12].

To obtain values of critical exponents λ Eq. (1) was transformed into the following formula:

$$\log \Delta \sigma = -\lambda \log \varepsilon + C,\tag{4}$$

where the searched value of critical exponent λ is equal to negative value of the slope of the fitted line to the linear parts of the dependence of Eq. (4). The dependence expressed by Eq. (4) with lines fitted to linear regions is shown in Fig. 3. The zero resistance critical temperature $T_{\rm c0} = 109.8$ K was used to calculate argument ε .

In our analysis of thermal fluctuations two regimes have been distinguished where power law behaviour was very distinct. First regime was defined from 110 K to 110.3 K and second one from 111.2 K to 114.1 K. The obtained values of critical exponents are $\lambda_1 = 1.71$ and $\lambda_2 = 0.88$, respectively.

The critical exponent λ_1 placed in the critical region corresponds with the critical fluctuations. For the critical region the full scaling theory [13] predicts that the fluctuation conductivity diverges at T_{c0} with exponent

$$\lambda = \nu \left(2 + z - d + \eta\right),\tag{5}$$

where ν is the critical exponent for the coherence length, z is the dynamical exponent, d is the dimensionality of fluctuations spectrum and η is exponent for the order parameter of the correlation function. According to the paper [14] we can substitute the following values: $\nu \approx 2/3$, $z \approx 3/2$ and $\eta \approx 0$ to Eq. (5) in critial fluctuations region. If we put the $\lambda_1 = 1.71$ in this equation we get d = 0.94. This substitution results in a 1D fluctuating system.

The second regime is located above the zero critical temperature $T_{\rm c0}$ and in accordance with literature [5, 12] it is dominated by Gaussian fluctuations. In this case the mean field Ginzburg-Landau theory [11] predicts $\nu \approx 1/2$, $z \approx 2$ and $\eta \approx 0$. Thus Gaussian fluctuations can be described with the following formula:

$$\lambda = 2 - \frac{d}{2}.\tag{6}$$

After using Eq. (6) for the values $\lambda_2 = 0.88$ the dimension of fluctuations was calculated to be d = 2.24. It means that in this region there is also 2D fluctuating system. One can say that there is crossover from 2D to 1D fluctuating system. The similar crossover was observed in the polycrystalline (Hg,Tl) 1223 superconductors and described in paper [10]. The authors contended that the appearance of 1D fluctuating system suggests the existence of conducting channels in the superconductors. In the case of bismuth based superconductors the dimensional behaviour depends mainly on their stoichiometry. For Bi 2212 superconductors there is practically two-dimensional system [15], whereas for Bi 2223 superconductors some authors [16] find two-dimensional behaviour while others [17] propose the crossover from 2D to 3D fluctuations. Our current study of bulk Bi 2223 superconductor [18] shows that the calculated critical exponent close to the zero critical temperature was found to be $\lambda = 1.75$. This exponent is very close to that reported in this paper.

4. Conclusions

The temperature dependence of the resistance was carried out for 1G BSCCO commercial tape. From the measurement we obtained base superconducting parameters which are as follows: $T_{\rm c0} = 109.8$ K, $T_{\rm c50\%} = 110.2$ K and $T_{\rm c_onset} = 111.6$ K.

The critical exponents of measured sample have been calculated in the temperatures range from the zero resistance critical temperature to onset temperature. At the temperatures range in the vicinity of the zero critical temperature $T_{\rm c0}$ the critical exponent $\lambda_1 = 1.71$ was calculated and 1D fluctuating system was recognized. In the temperature range from 111.2 K to 114.1 K the critical exponent $\lambda_2 = 0.88$ was obtained and 2D fluctuating system appeared.

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