PARACONDUCTIVITY ANALYSIS FOR Ni-DOPED BSCCO

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Abstract

The paraconductivity effect of Ni-doped 2223 BSCCO ceramic samples was studied using data obtained from resistive measurements. The temperature ranges of 2D and 3D regimes of fluctuation conductivity as well as the crossover between different temperature regimes were determined in terms of the Lawrence and Doniach theory of fluctuations.

Introduction

Although a superconductor exhibits superconductivity only below T_c, there are superconducting electron pairs present also above T_c. These pairs are referred to as superconducting fluctuations. They are caused by thermodynamic fluctuations, which continuously create and destroy electron pairs. There is always a certain number of pairs present: the closer to T_c, the more pairs. It is, however, only below T_c that a superconducting condensate penetrates the material and the resistivity is zero. Superconducting fluctuations have a number of measurable effects. They influence, for example, electrical, thermal, and magnetic properties. Fluctuations have particularly large effects in high T_c superconductors (HTS), partly because of their high anisotropy. The fluctuation effects in HTS are large and easily observable, thanks to the short coherence lengths, the high temperatures involved, and the layered structure.

One easily observable effect of fluctuations is a fluctuation resistivity (conductivity) or more commonly the paraconductivity. The resistivity curve is linear, but bends down just above T_c. This decrease in resistivity can be attributed to the superconducting fluctuations.

In this paper we study the influence of Ni doping ions on paraconductivity of two types of superconductors: $Bi_{1.8}Pb_{0.46}Sr_{1.88}(Ca_{1-x}Ni_x)_{2.06}Cu_3O_y$ (I) and $Bi_{1.6}Pb_{0.4}Sr_{1.8}Ba_{0.2}(Ca_{1-x}Ni_x)_2Cu_3O_y$ (II) using the Lawrence-Doniach (LD) model of fluctuations. Here x denote the concentration of doping metal x=0, 0.02, 0.05.

The Aslamazov-Larkin (AL) model [1] is the most intuitive one, simply reflecting the fact that the superconducting electron pairs contribute to the conduction. Hence, this term gives a positive contribution to the conductivity (i.e. a decrease of the resistance against temperature decrease). The AL model was the first model to be derived and was treated for layered structures already in 1970 by Lawrence and Doniach [2]. In this model, each Cu-O plane is considered to be a two-dimensional (2D) superconductor, separated from the neighboring planes by insulating regions. The layers are coupled by Josephson tunneling. Close to T_c, where the coherence length perpendicular to the plane is much larger than the inter-plane distance, the material shows the 3D anisotropic superconductor behavior. Far away from T_c, where the coherence lengths are shorter than the inter-plane distance, it follows a 2D behavior.

In the LD model, the AL conductivity above T_c can be written as

$$\sigma_{LD}^{AL} = \frac{e^2}{16\hbar s}\frac{1}{\left[\varepsilon(\varepsilon+\delta)\right]^{1/2}} \tag{1}$$

where $\varepsilon = (T - T_c)/T_c$ is reduced temperature, $\delta = \frac{4\xi_c^2(0)}{s^2}$ is an anisotropy parameter, $\xi_c(0)$ is the coherence length perpendicular to the planes at zero temperature, and s is the inter-plane distance.

At T_c ($\varepsilon << \delta$) expression (1) approaches

$$\sigma_{3D}^{AL} = \frac{e^2}{32\hbar\xi(0)}\varepsilon^{-1/2} \qquad (\lambda = -1/2) \tag{2}$$

and at higher temperature ($\varepsilon >> \delta$) it approaches

$$\sigma_{2D}^{AL} = \frac{e^2}{16\hbar s}\varepsilon^{-1} \qquad (\lambda = -1) \tag{3}$$

The crossover from 2D to 3D regime of fluctuations occurs when $\varepsilon \approx \delta$. This corresponds to $\xi_c^2(T) \approx s/2$ with crossover temperature T_{cross} determined by

$$T_{cross} = T_c(1+\delta) \tag{4}$$

Result and analysis

In Fig.1 and Fig.2 the temperature dependences of resistivity superconductors of types I and II with different level of doping respectively are presented.

We assumed that T_c is the temperature where $d\rho/dT$ is a maximum, although there are other several methods to find T_c listed in the literature [3]. The linear (metallic) behavior of $\rho(T)$ dependence is considered to be above $2T_c$ temperature and could be fitted to $\rho_N(T) = \rho(0) + BT$.

Using the normal and total resistivity data shown in Fig.1, 2 and expression (1) we can extract the paraconductivity of these samples. The results are shown in Fig.3, 4 in a *log-log* scale. In brackets the R-squared coefficient of determination of fitted lines is indicated.

From these diagrams the crossover from 2D (λ = -1) to 3D (λ = -0.5) regime of superconducting fluctuations of studied samples except $Bi_{1.6}Pb_{0.4}Sr_{1.8}Ba_{0.2}(Ca_{1-x}Ni_x)_2Cu_3O_y$ with x=0.02 was identified (table 1). For above mentioned sample the 2D regime was not identified: the dimensional crossover occurs from 1D (λ = -1.5) regime directly to 3D regime (λ = -0.5). This sample contains 90% of 2223 phase with some 2212 and 2201 phase. Probably these small phases distributed randomly in the 2223 phase form wire type conductivity. In case of $Bi_{1.6}Pb_{0.4}Sr_{1.8}Ba_{0.2}(Ca_{1-x}Ni_x)_2Cu_3O_y$ sample with x=0.05 the phase content of 2223 is 65% and 2212 phase is 25%. Here the 2D regime of conductivity occurs. The superconductor type I with x=0.02 contain 90% of 2223 phase without any other phases while for x=0.05 this superconductor contains 25% of 2223 phase and 65% of 2212 phase.

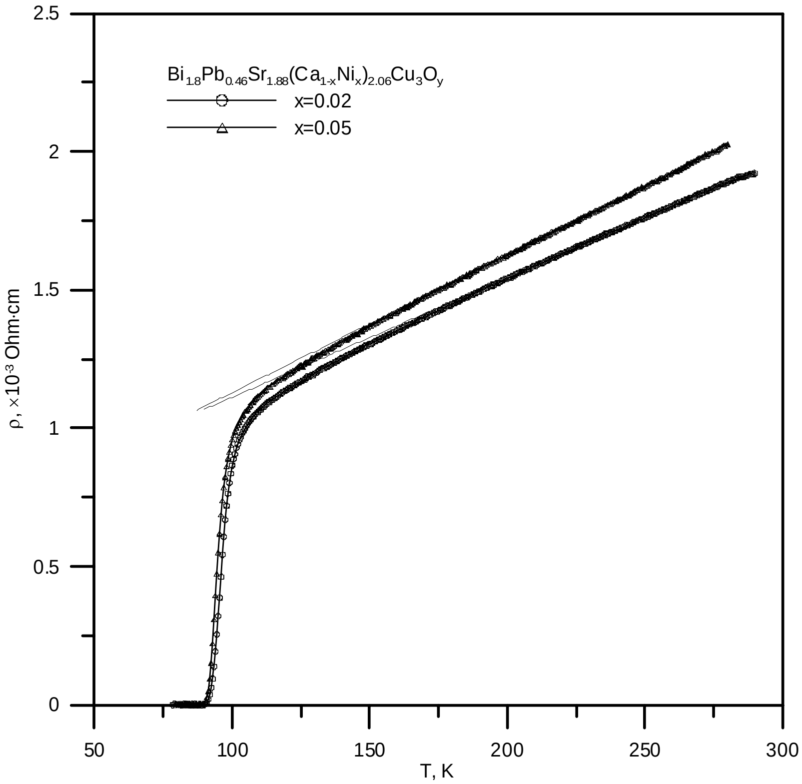

Fig.1. The temperature dependence of resistivity for type I superconductor.

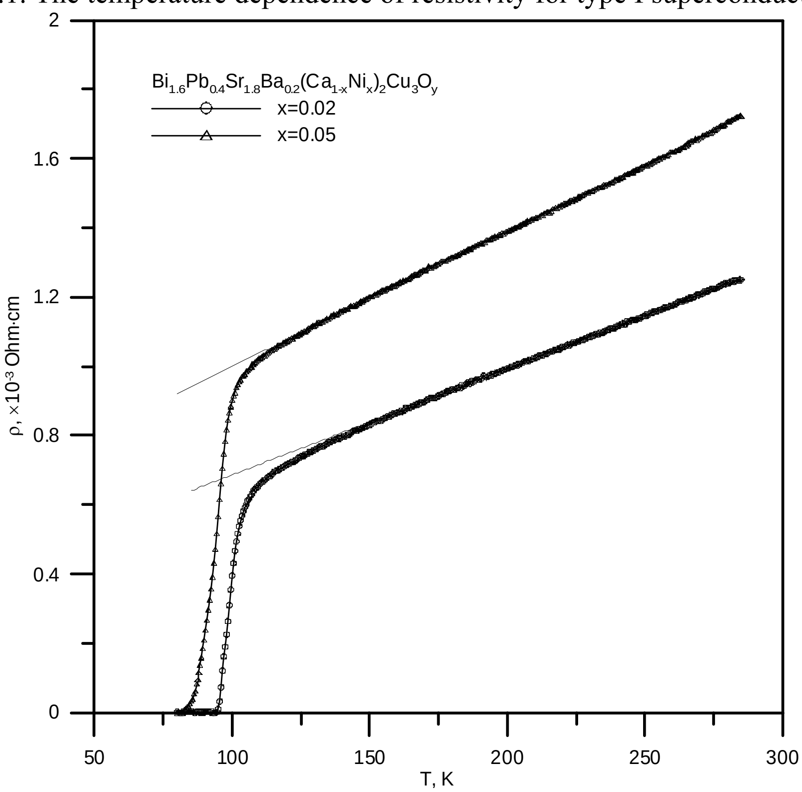

Fig.2. The temperature dependence of resistivity for type II superconductor.

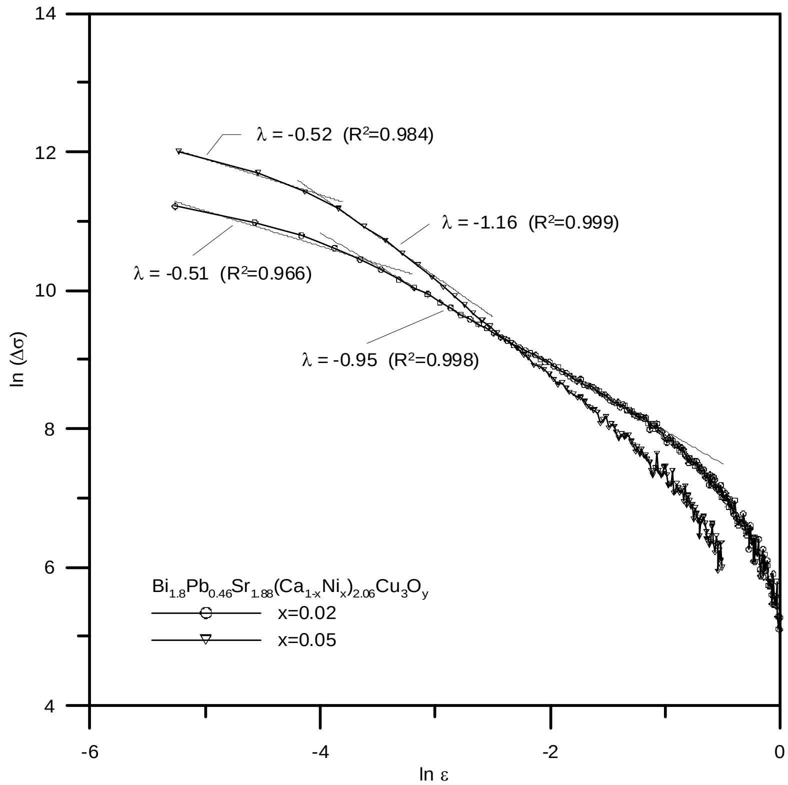

Fig.3. The ln(Δσ) vs lnε plot for type I superconductor.

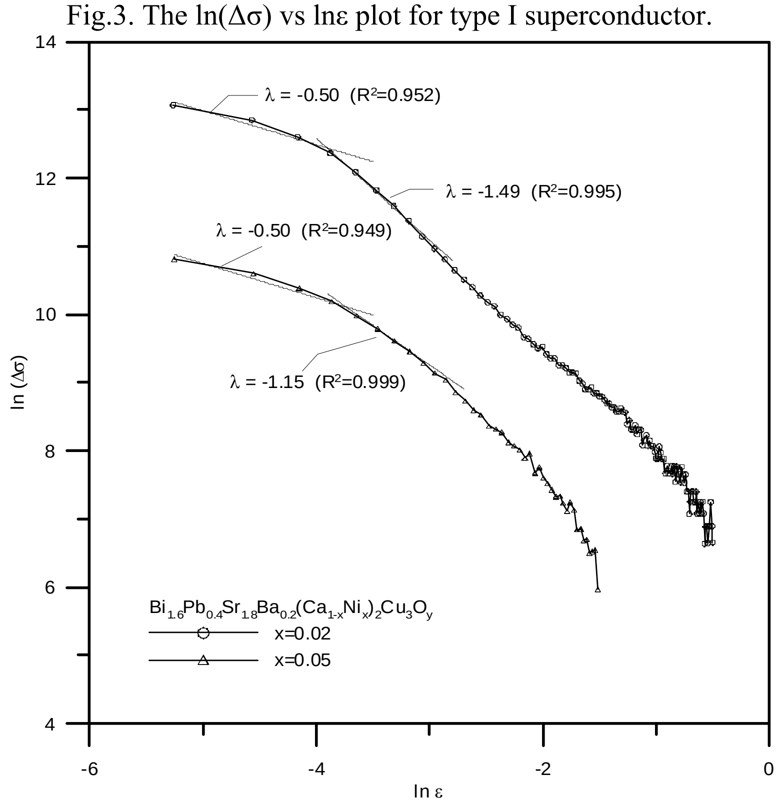

Fig.4. The ln(Δσ) vs lnε plot for type II superconductor.

Table 1. The parameters obtained from Fig.3, 4

	$Bi_{1.8}Pb_{0.46}Sr_{1.88}(Ca_{1-x}Ni_x)_{2.06}Cu_3O_y$		**$Bi_{1.6}Pb_{0.4}Sr_{1.8}Ba_{0.2}(Ca_{1-x}Ni_x)_2Cu_3O_y$**	
x	0.02	0.05	0.02	0.05
T_c, K	96.5	93.5	96.5	95.5
T_{cross}, K	99.3	95.1	98.5	97.7
$\xi(0)$, Å	13.9	6.9	2.1	20.4
δ	0.029	0.017	0.021	0.023
3D regime	$-5.3 < \ln \varepsilon < -3.5$	$-5.3 < \ln \varepsilon < -3.9$	$-5.3 < \ln \varepsilon < -3.8$	$-5.3 < \ln \varepsilon < -3.8$
2D regime	$-3.4 < \ln \varepsilon < -1.5$	$-3.8 < \ln \varepsilon < -3.0$	-	$-3.7 < \ln \varepsilon < -3.0$

In [4] the dimensional crossover from 0D to 1D near T_c was identified. The authors refer this crossover to fact that small islands of the 2223 phase distributed in 2212 phase could form quiasi-1D dimensional percolation structure above T_c.

Conclusion

The investigation of 2D and 3D conduction in Ni-doped 2223 BSCCO ceramic samples has confirmed the usefulness of the paraconductivity in the identified temperature ranges over which copper planes and chains conduct. For all samples the crossover occurs at the temperature $T_{cross} \approx 1.03T_c$. However in the case of $Bi_{1.6}Pb_{0.4}Sr_{1.8}Ba_{0.2}(Ca_{1-x}Ni_x)_2Cu_3O_y$ sample (x=0.02) the crossover from 1D to 3D regime was identified. Also, the coherence length $\xi(0)$ at temperature T = 0K was determined (Table 1).

References

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