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Paraconductivity along c-axis direction in a plane of a thin film of YBaCuO

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Thin films of YBaCuO have been grown using a $PrBa_2Cu_3O_{7-x}$ template with the c-axis aligned in the plane of the films. Conductivity and hence paraconductivity have been measured along the c-axis direction on this plane. Thermal fluctuation studies have been attempted along this direction, and the dimensionality effect was studied for this configuration. As a main characteristic a dimensionality equal to zero is emerged from the data. This dimensionality is consistent with the phenomena of fluctuation along the c-axis.

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1. INTRODUCTION

A lot of work has yet to be done in order to appreciate the special features of the new superconducting materials. The metallurgical state, grain boundaries, twins, voids, oxigen vacancies and other defects and imperfections are closely relevant to their physical properties. Some other characteristics are also influenced by the dimensionality of the system. Crystallografic anisotropy of these materials is a main characteristic which influences many properties. A main characteristic is the presence of CuO_2 layers in the ab-plane and CuO chains along b-axis.

The study of the transport properties espesially in the region of the transition temperature T_c is a tool of studying the characteristics of the superconducting phase. Among those of interest is the electrical conductivity and excess conductivity or paraconductivity above the transition temperature. This conductivity is related to the thermodynamical fluctuations in these materials.

One of the important features of high-T_c superconductors are the large fluctuation effects observable well above the mean-field transition temperature T_c which may be restrictive for some applications. In the new cuprate materials the combina-

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tion of short coherence length, quasi-two-dimentional structures and high operating temperatures associated with large thermal energy kT enhance the effect of thermal fluctuations. Special features of these effects are also connected to the quasi-two-dimentional character of electron conduction.

Experimental data obtained from paraconductivity measurements are of particular interest. The high resolution achieved with these studies gives a good insight into the temperature range in which fluctuations are of great importance. Fluctuation conductivity, as many other transport properties, has been mainly studied in the ab-plane[1-10] from where the two dimentional character was revealed. Conductivity and paraconductivity along crystallografic directions have been studied mainly in single cryatals[11-13] and rarely in thin films[14]. In this communication measurements are presented in thin films of YBaCuO. Especially, films grown with the c-axis in plane are used for the study of fluctuation conductivity

2. THEORETICAL BACKGROUND

Excess conductivity or paraconductivity related to fluctuation phenomena in high temperature cuprate semiconductors has been intensively studied since their discovery[1-10]. Although the theory of fluctuation conductivity in superconductors near the transition temperature was developed rather long time ago, the detailed investigation of new superconducting cuprates revived the theoretical interest of this problem. Different modeles were proposed to explain the high magnitude of fluctuation effects in these materials. Special features of these effects are also connected to the quasi-two-dimentional character of electron conduction.

Paraconductivity is the excess conductuvity ($\Delta\sigma = \sigma - \sigma_0$) i.e. the difference between the measured conductivity σ and the normal state conductivity σ_0. The finite difference is considered to arise from the local superconductivity fluctuation above T_c. Among the different models proposed to explain the fluctuation effects, the most appreciated ones are that of Aslamasow and Larkin (A-L) and Maki and Thompson (M-T), but the model of Lawrence and Doniach (L-D) is also used. Most of the features of fluctuation phenomena can be explained on the basis of the first two models if peculiarities relevant to the short coherence length and the two dimensional character of electron conduction are taken into account.

Although electron pairing above T_c is not favoured because of the high associated energy, there are always pairing fluctuations. These fluctuations increase the conductivity to much higher values as T_c is approached and their presence becomes more prominent. This excess conductivity $\Delta\sigma$ can be expressed through different relations according to the dimensionality of the superconducting system. Generally one has

$$\Delta\sigma_{A-L} = A_D \varepsilon^{-\lambda} \tag{1}$$

where A_D is a temperature independent parameter, $\varepsilon = (T - T_c)/T_c$ and $\lambda = 2 - D/2$. D is the dimensionality of the fluctuating system.

As mentioned above, crystallografic anisotropy plays a crucial role in the oxide superconductors. Thus anisotropy influences the features of many properties such as conductivity. If anisotropy is taken into account, we may distinguish two different fluctuation conductivities, one in the ab-plane and one in the c-direction.

Along the c-direction the "transverse" component of the fluctuation conductivity was found[14] to modify the above relation (1) to

$$\Delta\sigma^c_{A-L} = \frac{e^2}{16a}\left(\frac{w\mathrm{a}}{v_F}\right)^2 \frac{\left(\sqrt{\delta_0^2 + (T-T_c)/T_c} - \sqrt{(T-T_c)/T_c}\right)^2}{\delta_0^2\sqrt{(T-T_c)/T_c}\sqrt{\delta_0^2 + (T-T_c)/T_c}} \tag{2}$$

where $\delta_0^2 = 7\varsigma(3)w^2/(8\pi^2T_c^2)$ is the parameter which characterises the effective transverse size of the Copper pairs in the c-direction.

Relation (2) for ξ_c <<a reduces to[14,15]

$$_{0D}\Delta\sigma^c_{A-L} = \frac{7\varsigma(3)e^2}{2^9\pi^2\mathrm{a}}\left(\frac{w\mathrm{a}}{v_F}\right)^2\left(\frac{w}{T_c}\right)^2\left(\frac{T_c}{T-T_c}\right)^2 \tag{3}$$

for dimentsionality equal to 0, while for ξ_c >>a relation (2) takes the form

$$_{3d}\Delta\sigma^c_{A-L} = \frac{e^2}{8\mathrm{a}}\left(\frac{2\pi^2}{7\varsigma(3)}\right)^{1/2}\left(\frac{w\mathrm{a}}{v_F}\right)\left(\frac{T_c\mathrm{a}}{v_F}\right)\left(\frac{T_c}{T-T_c}\right)^{1/2} \tag{4}$$

which refer to dimensionality equal to 3.

The above relations are calculated at the clean limit, so Maki-Thompson contributions are not taken into account.

Another contribution to the fluctuation conductivity results from the fluctuation decrease of the density of one-electron state at the edge of Fermi level near T_c which has as a result the decrease of the transverse conductivity as temperature decreases[14,16]. This contribution, proportional to the first power of the interlayer hopping probability, is substracted from equation (2). Therefore, due to the small value of the hopping integral w, the density of states contribution can overcome the paraconductivity contribution giving a peak in the resistivity along the c-direction. This peak is common in Bi-cuprates[17] while it seems to be attributed to the oxygen depletion in YBaCuO.

3. SAMPLE PREPARETION AND EXPERIMENTAL PROCEDURE

The YBaCuO thin films was grown using a $PrBa_2Cu_3O_{7-x}$ template. The film was homoepitaxially grown on top of the template (grown on $SrTiO_3$), the details of the thin film deposition procedure are given elsewhere[18]. The thickness of the film is about 200 nm. The c-axis of the film is in the plane of the substrate, as confirmed by X-ray measurements, and parallel to one of the edges as also indicated by the higher resistivity compared to the other edge. Four gold dots were symetrically sputtered on the film in a tetragonal arrangement parallel to the edges of the substrate. For the conductivity measurements the standart four point DC technique was used. The analysis of the results follows a specific procedure presented previously[10]. Instead of $\Delta\sigma$, ΔR is used and the dependence of $d(\Delta R)/dT$ on ε is examined on log-log plot. From this plot λ and hence the dimensionality D is extracted.

4. RESULTS AND DISCUSSION

The geometry of the current flow is parallel to the short edge of the substrate (where the resistivity is higher) and hence along the c-direction. Fig.1 displays the resistance dependence on temperature and the superconducting transition of material at lower temperature. The transition temperature T_c which is further used in the data analysis is inferred from the maximum of $d(\Delta R)/dT$. Its value is 88.77 K and the transition width defined at the half maximum of the temperature derivative is $\sim$ 3 K. The dR/dT behaviour is shown in Fig.2. Fig.3 shows a representative data analys in a $\log(\Delta R)/dT$ vs. $\log \varepsilon$ representation. From this plot we get the slope of the fitted line which according to the relation $d(\Delta R)/dT = A_d \varepsilon^{-(\lambda+1)}$ must be equal to $-(\lambda+1)$. From that the value of λ is deduced from which we ger the dimensionality of system.

According to the above analysis - as may be seen from Fig.2 $-(\lambda+1)$ is equal to 3 which means that $\lambda = 2$. This value is valid in the range from $\ln\varepsilon = -2.8$ down to about $\ln\varepsilon = -3.6$, at which point a change in the slope starts to become evident. At lower values of $\ln\varepsilon$ and for a of short interval a slope 1.5 is fitted before the slope takes a value close to zero. The main slope which corresponds to $\lambda = 2$ gives a dimensionality equal to $D = 0$ while the value of $\lambda = 1.5$ corresponds to $D = 3$. These values are consistent with the physics of fluctuations.

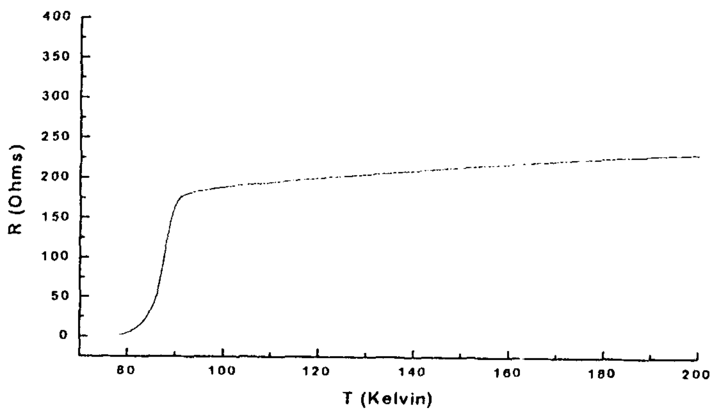

Fig. 1. Resistance along the c-direction versus temperature.

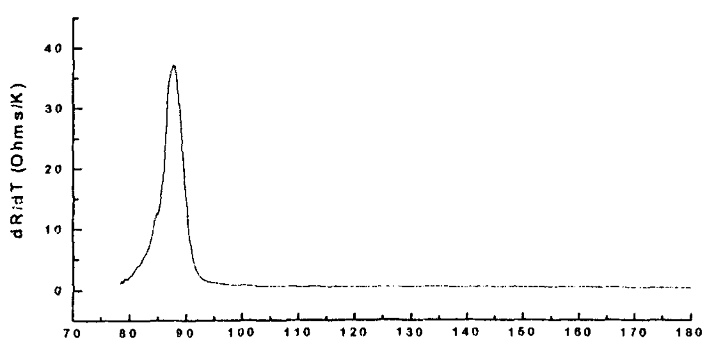

Fig. 2. dR/dT along the same direction from which T_c is deduced equal to 87.6 K.

Conductivity in the superconducting state along the c-axis means that superconducting electrons have to jump from plane to plane which is scarcely done when the coherence length along the c-axis is much smaller than the interlayer spacing ($\xi_c \ll$a). So we may speak about a fluctuation regime[13] of zero dimensionality.

When $\xi_c \gg$a a 3D fluctuation is expected. It is worthy to mention here that fluctuations perpendicular to the layers are smaller and disappear more rapidly. Therefore they are expected to manifest themselves at lower values of $\ln\varepsilon$. On the other hand the influence of 3D-fluctuations seems to be very closer[13] to T_c, a regime which is not clearly evident from our data.

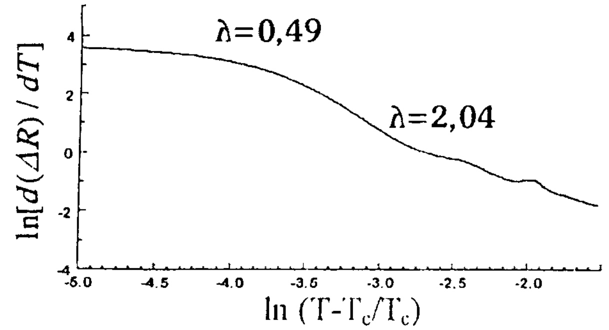

Fig. 3. $\ln[d(\Delta R)/dT]$ versus $\ln\varepsilon$ from the slope of which the values of λ are extracted.

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