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PARACONDUCTIVITY MEASUREMENTS AND COMPARATIVE STUDIES OF FLUCTUATIONS IN BiSrCaCuO, YBaCuO AND YBaCuO WITH Gd SUBSTITUTION.

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ABSTRACT. Information concerning the dimensionality of the superconductive fluctuations in the new high temperature superconductors can be derived from the excess conductivity (or paraconductivity) near the transition temperature. Here the "lowering" of the sample resistance in the same temperature region is used for extraction of dimensionality and generally for comparative studies of the critical behaviour of three different samples such as $YBa_2Cu_3O_7$, $Y_{0.8}Gd_{0.2}Ba_2Cu_3O_7$ and $Bi_{0.85}Pb_{0.15}SrCa_{1.2}Cu_2O_6$. The experimental data of the three samples show a similar behaviour with some distinct differences depending rather on the "metallurgical" state of the material than the composition itself. A logarithmic behaviour is present for YBaCuO and Y(Gd)BaCuO samples not close to the critical temperature and, the most important, closer to Tc YBaCuO shows a fractal behaviour, observed for the first time, similar to the one of Bi-compound observed many times before.

1.Introduction.

Since the discovery of the new ceramic high temperature superconductors, a lot of work has been done and a lot has still to be done in order to appreciate the special features of their superconductivity mechanism. Specially the microscopic view of this mechanism is not yet well understood. Crystallographic anisotropy of these compositions is a main characteristic which influences many properties such as transport and magnetic ones. Some other characteristics are influenced by the dimensionality of the system [1].

The problem of dimensionality as it appears in these new compounds was the object of research from the very beginning of the discovery of these materials[2,3,4,5]. But even before this the subject of superconductivity and dimensionality had been studied in compounds of the type MCH_2, where M represents a metal which shows a superconducting transition and CH is a chalogenide (Se, S or Te)[6], and in some quasi-onedimensional superconductive compositions[7].

The research on transport properties in the region of the transition temperature Tc, such as electrical conductivity thermoelectric power and thermal conductivity, is a tool of studying the characteristics of the superconductive phase. Among these of particular interest is the electrical conductivity or paraconductivity above the transition, from which we can study the thermodynamical fluctuations and get information about the dimensionality of the superconductive phase.

These fluctuation effects are more visible in the new high temperature superconductors than in the "classical" ones, so let's say that one can easily get results concerning their speciall features. For many reasons a series of experiments which have been done in recent years after the discovery of the new ceramic materials lead to contradictory results concerning the fluctuation dimensionality [8].

In this paper we present detailed measurements of resistivity of some samples belonging to the YBaCuO and BiSrCaCuO systems and we compare the experimental results.

2.Basic Theoretical Backround.

The fluctuation contribution of the superconducting order parameter to the conductivity of the normal phase can be distinguished from the rounding behaviour of the normal state conductivity as the critical temperature Tc is approached from higher temperatures. The excess conductivity of this temperature regime, called also paraconductivity, as a secondary event resulting from the fluctuation of the order parameter can be quantitatively estimated from the experimental data through the relation of the excess conductivity $\Delta\sigma = \sigma - \sigma_0$ where σ is the measured conductivity resulting from the influence of the fluctuation in the temperature region and σ_0 is the normally expected one. The latter can be defined in this region from the extrapolation of the normal state conductivity behaviour from a higher temperature T such as T=2Tc.

The Aslamasov-Larkin theory [9] concerning superconductive transitions predicts the following equations for the excess conductivity acording to the dimensionality of the system:

$$\Delta\sigma_3 = (e^2/32h)\,(1/\xi(0))\,\varepsilon^{-\lambda} \quad \text{with } \lambda = 1/2 \qquad \text{for three dimensions (3D)} \qquad (1)$$

$$\Delta\sigma_2 = (e^2/16h)\,(1/d)\,\varepsilon^{-\lambda}, \quad \text{with } \lambda = 1 \qquad \text{for two dimensions (2D)} \qquad (2)$$

where $\Delta\sigma$ is the above defined paraconductivity, $\varepsilon = (T-Tc)/Tc$ is the reduced temperature, expressing the deviation from the critical temperature, $\xi(0)$ is the zero temperature coherence length and d is some layer thickness which characterizes the two dimensional system.

The following expression is valid for the exponent :

$$\lambda = 2\text{-}D/2 \quad \text{or} \quad D=4\text{-}2\lambda \tag{3}$$

where D is the dimension of the fluctuating system. So the extraction of the exponent λ from paraconductivity measurements can easily give information on the dimensionality of the superconducting order parameter. Although data analysis does not prove that this is the case.

Several parameter concerning either the material (stoichiometry, homogeneity etc) or the experimental condition (high accurancy, density of points per temperature interval etc.) and ways of analysing data may influence the results [8].

The above theoretical model is not the only one. There are other contributions to paraconductivity based on different models such as the ones by Maki and Thomson [10-11] or Laurence and Doniach [12] depending on the temperature regimes. For more details on these models look at [8] in this volume.

In our case in order to minimize any infuence from the procedure of the elaboration of the experimental data we follow the Ausloos et al [8] procedure. We analyse R istead of σ since R is the directly measured quantity and an error R on the resistance becomes a large error on the conductivity when approaching Tc ($\delta\sigma = \delta R/R^2$).

So finally we do not look at the excess conductivity but at the lowering of the normal state resistance $\Delta\varrho = \varrho - \varrho_0$ as we approach Tc from above (here we have $\varrho = 1/\sigma$ and $\varrho_0 = 1/\sigma_0$).

Conclusions concerning the dimensionality of fluctuations are derived from comparison of the measured σ (or equally ϱ) to the above equations (1) and (2). The value of ϱ_0, the normal state backround and proper choice of Tc are crucial factors for the extraction of the final results. In order to eliminate the influence of the choice of the normal state resistivity ϱ_0, the temperature derivative of $\Delta\varrho$ is analysed instead of $\Delta\varrho$ itself. The following relation holds for this derivative :

$$d\Delta\varrho/dT = \varepsilon^{-(\lambda+1)}. \tag{4}$$

In this report the critical temperature Tc is defined in a different way from that used in our previous works [4,5,8,14,15]. Here Tc is strictly determined as the temperature for which $d^2R/dT^2 = 0$.

Finally from the presentation of the data on a ln(dR/dT) versus lnε plot and hence from the slope of a straight line fit, the critical exponent λ and through relation (3) the dimensionality D is deduced.

3. Experimental

The High Temperature ceramic materials where made in general by the conventional technique of the solid state reaction as it is mentioned before by many researchers in their papers. For this study we have prepared three polycrystaline samples. One of the composition $Y_{0.8}Gd_{0.2}Ba_2Cu_3O_7$ labelled Y(Gd)BaCuO, one of $Bi_{0.85}Pb_{0.15}SrCa_{1.2}Cu_2O_6$ labelled as Bi(Pb)SrCaCuO and one of $YBa_2Cu_3O_7$ labelled as YBaCuO. The Y(Gd)BaCuO compound was considered in our measurements as to validate the assumption that rare earth substitution for Y does not substansially modify the physical properties.

The YBaCuO and Y(Gd)BaCuO compounds were made by the usual solid state technique and a similar procedure was followed for the Bi(Pb)SrCaCuO sample as it is mentioned in [15].For reliable results concerning the study of the critical regime of the transition the experimental method must be characterized by a high accuracy of the measurements and a high density of the experimental points per temperature interval. The quality of the sample is an other main factor, but since what is a good sample quality is not yet well defined, a good description of the parameters which may characterize a sample is necessary.

The experimental method of measuring resistivity is based on the four probe d.c. technique. The usual current used was that of 10 mA which corresponds to a current density of about 0.2 A/cm2 since the mean values of the dimensions of the samples which are parallelepiped in shape are about 10mm x 3mm x 1mm. No serious changes were observed for other similar values of the current. The d.c. voltage was measured by a Keithley 181 Nanovoltmeter and the resulting accuracy was 10^{-6}. The temperature was measured by a Pt resistance sensor with a 10mK resolution. Data have been taken under equilibrium conditions with a sweeping rate of a few degrees Kelvin per hour and with such a density that derivatives with respect to temperature can be numerically computed and analyzed.

For more details concerning the method of experimental data analysis and the experimental procedures as well one may look at [14,15].

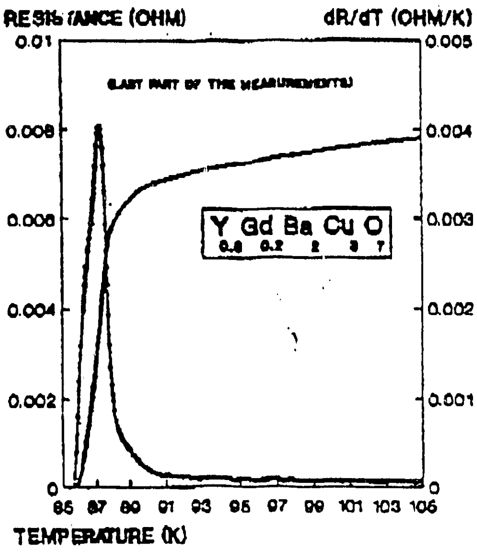
4. Critical behaviour and discussion

The critical behaviour of the three different samples as it is deduced from the measurements of the resistance of the three samples above the critical temperature Tc is in someway similar but not the same as is exposed bellow. Here the experimental data are presented for each sample followed by a comentary discussion of the results and finally a comparative conclusion for all three samples is given.

4.1. Y(Gd)BaCuO

In this sample part of Y has been replaced by Gd resulting to the nominal composition $Y_{0.8}Gd_{0.2}Ba_2Cu_3O_7$. As it has been shown [16], rare earth element substitution for Y does not drastically modify the characteristic physical parameters of the compound, so we expect similar critical behaviour to that of the pure YBaCuO. The resistance of the sample is rather low (less than 5mΩ at 100K) comparable to that found by other researchers and the fact argues for a sample of good quality. In Fig 1a the plot of the resistance change with temperature and its first derivative are shown. The critical temperature Tc which is used in the further analysis, is infered from the second derivative of the resistance (which is drawn in Fig.1b) and is equal to Tc=87.25. Hence the redused temperature is deduced and the plot of ln(dΔR/dT) versus lnε is shown in Fig.1c .

One observes two regimes expressed by two different lines (with different slopes) fitting the experimental data. Scanning these data from higher temperature above Tc, one distinguishes a linear part from $\ln\varepsilon = -1.5$ to $\ln\varepsilon = -3.25$ with a slope which coresponds to a critical exponent $\lambda_1 = 0.18$. For ε equal to 0.0387 (or $\ln\varepsilon = -3.25$) this slope changes and a linear part fits up to $\ln\varepsilon = -5$ with a slope which corresponds to a critical exponent $\lambda_2 = 0.53$. Then at about $\ln\varepsilon = -5.5$ (e.g. very close to Tc) a rounding behaviour follows which



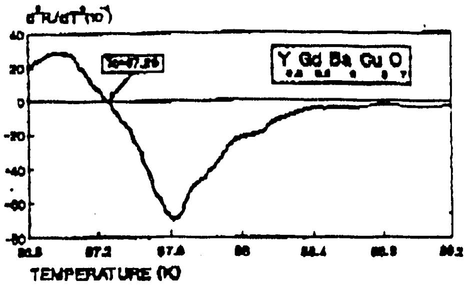


Fig 1a (on the left) shows the electrical resistance R and dR/dT versus T
Fig 1b (on the rigth) shows d^2R/dT^2 from which the Tc is defined

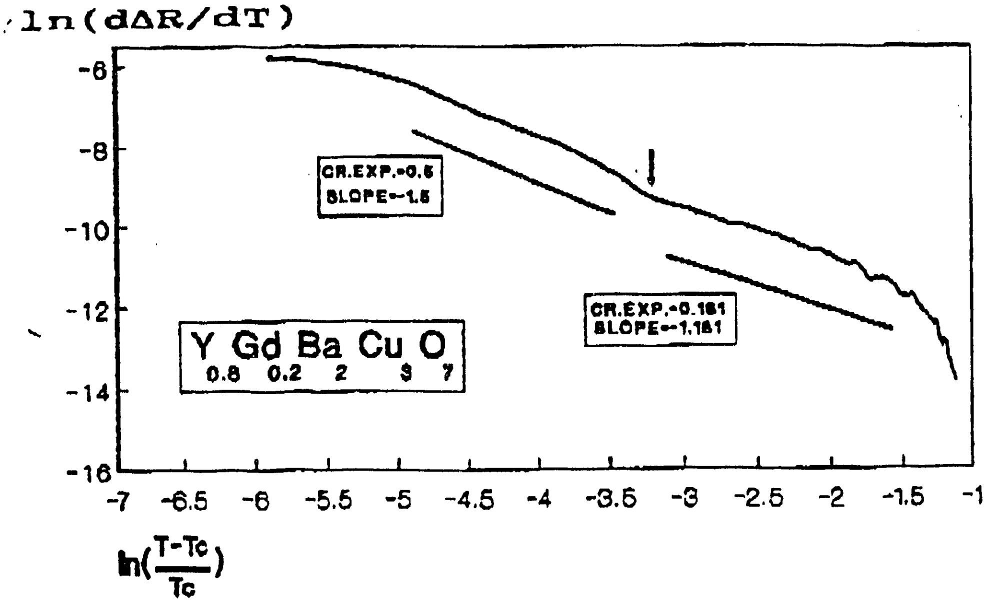
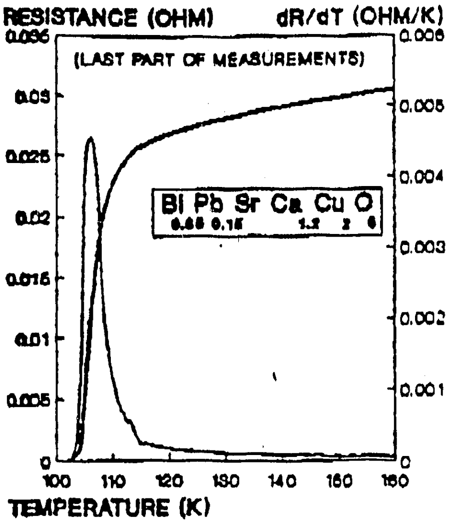


Fig 1c Plot of $\ln(d\Delta R/dT)$ versus ln(T-Tc/Tc) for the same sample
Straight lines indicate power law behaviour with the quoted slopes and critical exponents



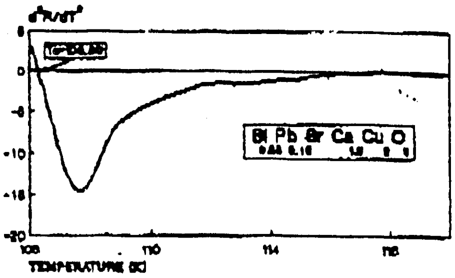


Fig 2a (on the left) shows the electrical resistance R and dR/dT versus T
Fig 2b (on the rigth) shows d^2R/dT^2 from which the Tc is defined

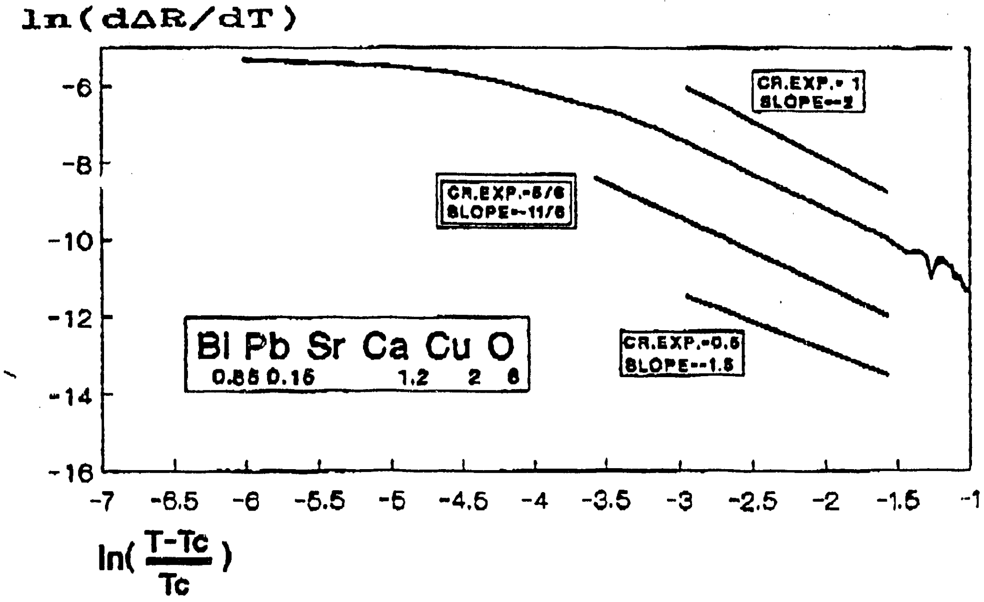


Fig 2c Plot of ln(dΔR/dT) versus ln(T-Tc/Tc) for the same sample
Straight lines indicate power law behaviour with the quoted slopes
and critical exponents

is common to all polycrystallic samples oxide superconductors and in monocrystals as well.

According to Aslamasov-Larkin theory analysis of the data, closer to Tc, a regime which corresponds to critical exponent λ_2, the extracted value of D through relation (3) is close to 3 and three dimensional fluctuations of the superconducting phase are obviously favored from these experimental results. The second linear part has a linear exponent with a small value equal to 0.18. This value is similar to the ones found by Pureur et al [17] for the same temperature regime and close to the value 0 found by Ausloos et al [3]. This value leads to a curious dimensionality (value of D) but indeed it is an experimental fact since this same value is infered from thermoelectric power measurements [18]. This value leads to D=4. As it is known from singular function analysis, $\lambda=0$ indicates a "logarithmic singularity" [19]. On the other hand Maki and Thompson [10,11,20] have predicted such a logarithmic behaviour for σ and consequently for $\Delta\sigma$ and $\Delta\varrho$. This behaviour comes from a pair breaking mechanism of the fluctuating Cooper pairs, being at this temperature under a weak pair breaking process.

4.2. Bi(Pb)CaSrCuO

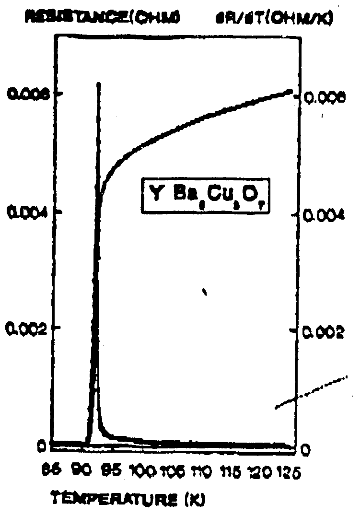
For this sample its resistance change with temperature and its first derivative (dR/dT) are shown in Fig.2a. From the plot of the resistance second derivative (d^2R/dT^2) with temperature (Fig. 2b) the critical temperature Tc is defined equal to 106.3K. The value of the resistivity, its change with temperature and the critical temperature of the sample are similar to those of the other samples of the same batch with similar composition [5].

From the plot of ln(dΔR/dT) versus lnε which is shown in Fig.2c, it is clear that a straight line can fit the main part of the curve before rounding (very close to Tc, for $\ln\varepsilon<-4.5$) e.g. for $-3<\ln\varepsilon<-1.6$. The slope of this line equals to -11/6 from which the critical exponent λ is deduced equal to 5/6. Consequently D equals to 7/3.

This curious value of D is not predictable from Aslamazov-Larkin theory. It is an experimental fact though, as it can be assured from the resistivity measurements on similar samples of the same batch [5,21] and thermoelectric power measurements [22,23]. The dimensionality value (7/3) of such an "anomalous" superconductivity fluctuation can be acceptable if the relation (3) is generalized to contain non integer values of D. The latter implies a fractal description of inhomogeneous granular material. If we think of the superconductive system consisting of a percolation network, then in a fractal description of percolation networks [24,25] we really expect this system to behave as one of lower dimensionality from a dynamical point of view [21]. For example in an inhomogeneous superconductivity state inside the grains [17] according to Char and Kapitulnik [26] equation (3) may be written as $\lambda=2\text{-}d/2$ where d is the fracton or spectral dimension [24]. As one can easily observe the value D=7/3 may be analyzed in 1+4/3, but 4/3 is the fractal dimension for linear percolating systems [24,25,27].

4.3. YBaCuO

The YBaCuO sample was prepared with the solid state reaction. The conditions of sintering were 5 hours heating to 940°Cand then cooling to 450°C and anealing in air for 24 hours. For this sample the same procedure was used in order to study its critical behaviour above Tc. In Fig.3a the resistance and its first derivative versus temperature are shown from where we notice the low resistance of the sample (lower than that of Y(Gd)BaCuO) and the short temperature interval (approx. 3K) of the transition. Fig.3b shows the resistance second derivative change with temperature, from which the critical



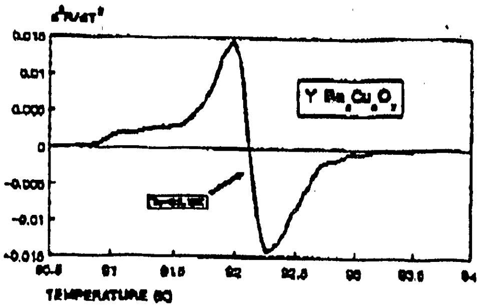


Fig 3a (on the left) shows the electrical resistance R and dR/dT versus T
Fig 3b (on the rigth) shows d^2R/dT^2 from which the Tc is defined

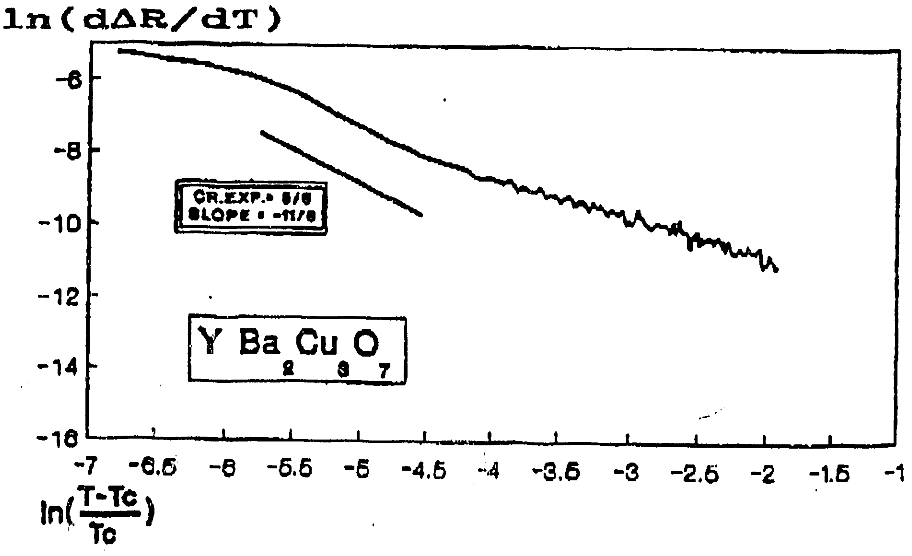


Fig 3c Plot of ln(dΔR/dT) versus ln(T-Tc/Tc) for the same sample
Straight lines indicate power law behaviour with the quoted slopes and critical exponents

temperature is defined equal to 92.12K. In Fig.2c where we have the plot of $\ln(d\Delta R/dT)$ versus $\ln\varepsilon$ we can distinguish a part of the data points for $-4.3<\ln\varepsilon<-5.5$ where a straight line fits with slope -1.820 which coresponds to a critical exponent $\lambda = 5/6$. This value of λ throught relation (3) gives $D=7/3$. It is the first time, as far as we know, that such a value of D is observed in YBaCuO, though it is already well observed in Bi-compounds as we have mentioned above [5,23].

Such a value indicates that a fractal description for inhomogeneous systems is more suitable to describe the granular state of this YBaCuO sample. The fractal nature of the material arises and the same arguments as those used above for the Bi-compound may be used here, e.g. for a fractal description of the percolative behaviour of the inhomogeneous superconductive state. Last but not least for $-4<\ln\varepsilon<-3$ a critical exponent equal to 0.064 (e.g. very close to 0) can be observed. This value may be compared to the ones observed before in YBaCuO samples leading to the same speculations as those mentioned above for this material.

4.4. CONCLUSION

In conclusion the comparative studies of the critical behaviour of these three samples, from the point of view of the resistance behaviour, shows that the results are closely related to the samples themselves (rather connected to the metallurgical state or the granularity .) and hence to the intrinsic properties of the grains such as inhomogeneity. The fractal nature of these materials - and maybe of all the new high temperature superconductors - is a common physical feature. The latter may compromize the different views concerning the observed dimensionality of YBaCuO (D=2 or 3) as it depends not on the composition itself but on the intragranular state.

Acknowledgement

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