

# Conductance fluctuations in high temperature critical superconducting system based on $\text{Bi}_2\text{Sr}_{1.4}(\text{Pb})_{0.6}\text{Ca}_{2-x}\text{Y}_x\text{Cu}_3\text{O}_{10+y}$ thick films

W Saldarriaga<sup>1</sup>, W Castro<sup>2</sup> and E Baca<sup>3</sup>

<sup>1</sup> Laboratorio de Materiales Cerámicos y Vítreos, Universidad Nacional de Colombia, Sede Medellín, A.A. 568, Medellín, Colombia.

<sup>2</sup> Proyecto Curricular de Ingeniería Topográfica. Universidad Distrital Francisco José de Caldas. A. A. 8668. Bogotá D. C.

<sup>3</sup> Grupo de Ingeniería de Nuevos Materiales, Universidad del Valle, A.A. 25360 Cali, Colombia.

E-mail adress: [wjsaldarriagaa@unal.edu.co](mailto:wjsaldarriagaa@unal.edu.co).

Received 4 October 2013, in final form XX November 2013

**Abstract.**  $\text{Bi}_2(\text{Sr}_{1.4})\text{Pb}_{0.6}\text{Ca}_{2-x}\text{Y}_x\text{Cu}_3\text{O}_{10+y}$  superconducting thick films were prepared and deposited on MgO (100) substrates using a Melt-Quench-Annealing method (MQA). The superconducting transition was found around 89 K. Electrical conductance fluctuations and the thermodynamic fluctuations, close to  $T_c$ , were analyzed from results of R vs T measurements on the samples. Yttrium concentration range was in the range  $0 \leq x \leq 0.8$ . Additionally, considering the Aslamazov-Larkin law, with  $T_c$  value fixed according to  $d^2R/dT^2$  criterion, the conductance trend in the samples was revealed. So, when  $x \leq 0.075$  a 3D behavior was found, on the other hand when the concentration increases to  $x = 0.8$  a 2D behavior is stabilized. From these characteristics a correlation to the structural properties of the sample can be inferred.

## 1. Introduction

One characteristic and relevant effect of the high- $T_c$  superconductors (HTSCs) concerns the thermal fluctuations near the normal-superconducting transition. In the HTSCs, the combination of short coherence length, quasi-two-dimensional (2D) structures and high operating temperatures associated with large thermal energy  $\sim K_B T$  causes a large increase in the effect of thermal fluctuations. Different models were proposed to explain the high magnitude of fluctuation effects in these high- $T_c$  superconductors. Most of the features of fluctuation phenomena in the conductivity of HTSCs are explained on the basis of Aslamazov-Larkin (AL)[1] and Maki-Thompson (MT) theories [2]. The widely undertaken analysis of excess electrical conductivity,  $\Delta\sigma$ , HTSCs from different [1-3] fluctuation theories has concentrated mostly on investigating a crossover [4-6] from a 3D fluctuation (exponent  $\lambda$ , approaching 0.5) at low temperatures to a 2D one ( $\lambda$  approaching 1.0) on warming across a crossover temperature,  $T_0$ , and on the inter-layer coupling constant J [6-9]. The electrical measurement may provide relevant information on the dynamic behavior of vortices. The study of the temperature dependence on the fluctuation-enhanced conductivity above  $T_c$  is a way to probe the dimensionality of the order-parameter fluctuations.



The layered structure of these systems with complex crystal chemistry and the inherent granularity lead to strong structural disorder at the microscopic and the mesoscopic levels, respectively. A large number of studies have been devoted to investigate the interplay between the superconducting order parameter fluctuation (SCOPF) and the inhomogeneities in HTSCs. The inhomogeneities occur at widely varying length scales as in single crystals, grain aligned films and melt-textured and sintered samples. mesoscopic inhomogeneities like grain boundaries, cracks, voids etc, have a much larger scale of length than that of coherence length  $\xi$  and, being temperature independent, do not influence the SCOPF region [10]. These inhomogeneities strongly influence the transition region below  $T_c$ . The microscopic inhomogeneities such as structural defects (twin boundaries, stacking faults) and chemical imperfections (i.e oxygen deficiencies) occur inside the grains. The scale of length of these inhomogeneities is smaller than that of the mesoscopic inhomogeneities, but still larger than  $\xi$ . These inhomogeneities therefore are expected to have negligible effect on the SCOPF region [10]. However, many studies have shown that both the mesoscopic and the microscopic inhomogeneities crucially influence the critical and the mean field region of SCOPF [11–14].

For a highly anisotropic layered material like  $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+y}$  (BSCCO) where the anisotropy ratio  $\gamma = 0.02$ , the conductivity fluctuation is well-described [15,16] by the 2D AL theory in the wide temperature range  $-4 \leq \ln(\varepsilon) \leq -2$ , where  $\varepsilon = (T - T_c)/T_c$  is the reduced temperature. However, fluctuation phenomena have been explained [17-19] in  $\text{YBa}_2\text{Cu}_3\text{O}_{7-x}$  (YBCO) and in similar systems taking the MT theory into account as well. For very anisotropic materials, the MT contributions, which increase the apparent width of the transition, have been ignored because they are probably absent in HTSC as a consequence of the pair-breaking effect of strong inelastic electron scattering [20] and these are treated as a very clean system because  $\xi_0/l$  (where  $\xi_0$  and  $l$  is the zero-temperature in plane coherence length and electronic mean free path, respectively) is very small.

The aim of this work is to analyze the contribution of the thermal fluctuations on the electric conductivity at zero magnetic field in the mixed state near  $T_c$  of the  $\text{Bi}_2(\text{Sr}_{1.4})\text{Pb}_{0.6}\text{Ca}_{2-x}\text{Y}_x\text{Cu}_3\text{O}_{10+y}$  (Bi-2223) thick film.

## 2. Experimental procedure

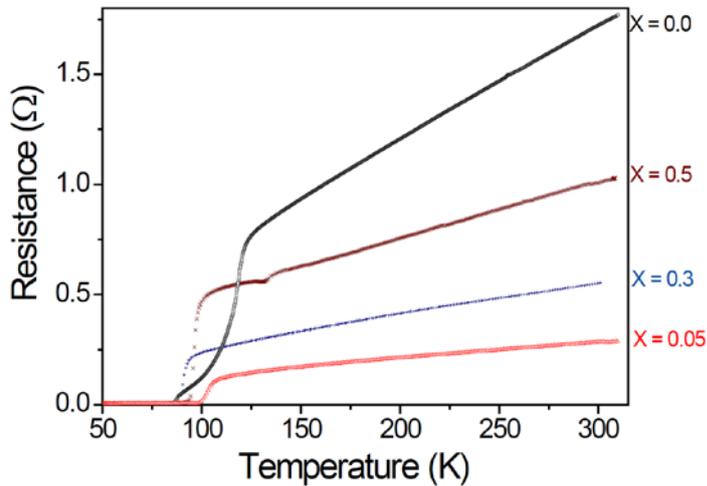
Superconductor precursor material was prepared by solid state reaction. Stoichiometric ratios of the precursor powders  $\text{Bi}_2\text{O}_3$ ,  $\text{SrCO}_3$ ,  $\text{PbO}_2$ ,  $\text{CaCO}_3$ ,  $\text{Y}_2\text{O}_3$  and  $\text{CuO}$  (purity 99.99%) were finely ground and thoroughly mixed to finally obtain  $\text{Bi}_2\text{Sr}_{1.4}(\text{Pb})_{0.6}\text{Ca}_{2-x}\text{Y}_x\text{Cu}_3\text{O}_{10+y}$ .

A melt-quench and annealing process was applied for growing  $c$ -axis textured Bi-2223/MgO substrate with a dimension of  $10 \times 10 \times 1 \text{ mm}^3$ . In the melt-quench step, the Bi-2223/MgO precursor was pushed into a furnace which was preheated to a melting temperature of  $1050 \text{ }^\circ\text{C}$ . After keeping the sample at the melting temperature for about 10 minutes, the sample was rapidly quenched to room temperature. The samples consisted mainly of the Bi-2223 phase. In the annealing step, the melt-quenched sample was annealed at temperatures of  $865 \text{ }^\circ\text{C}$  in air to be converted to  $c$ -axis textured Bi-2223/MgO thick film.

The electrical resistance of the samples was obtained using the standard four-terminal configuration (Van Der Pauw technique) in a He closed cycle cryostat within the range of 14 K-300 K, a 2400 SourceMeter (Keithley) and a temperature controller 9700 (Leybold) (0.1 K resolution) were used.

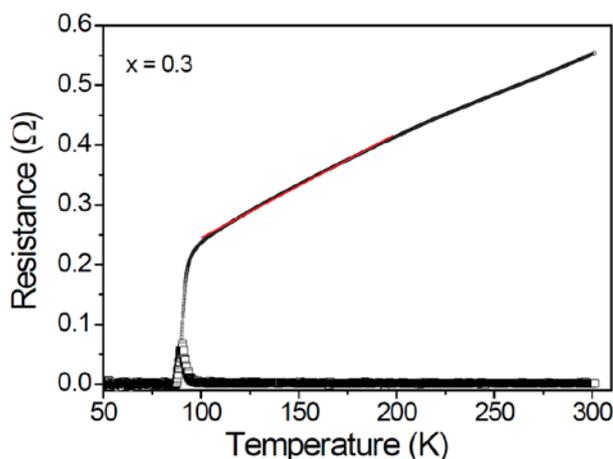
## 3. Results and discussion

We have analyzed our resistance vs. temperature experimental data by adopting the simplest fluctuation conductivity approach [21] (see Fig.1). The fluctuation induced enhancement in conductivity, termed as conductance excess or paraconductivity,  $\Delta G = G - G_R$ , where  $G$  is the measured conductance, i.e.,  $G = 1/R$ , and  $G_R = 1/R_R$  is the regular term extrapolated from the high temperature behavior. According to the Aslamazov-Larkin (AL) proposal [1], the fluctuation conductivity diverges as a power law of the type  $\Delta G = A\varepsilon^{-\lambda}$ , where  $A$  is a constant and  $\lambda$  is the critical exponent.



**Figure 1.** Temperature dependence of electrical resistance of  $\text{Bi}_2\text{Sr}_{1.4}(\text{Pb})_{0.6}\text{Ca}_{2-x}\text{Y}_x\text{Cu}_3\text{O}_{10+y}$  thick films for different Y contents.

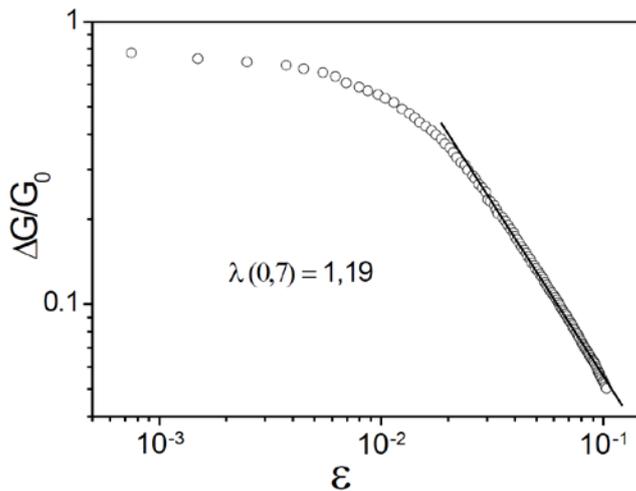
The main problem in the SCOPF analysis is related to the difficulty of assessing the mean-field critical temperature  $T_c$ . The  $T_c$  in each theoretical model is never directly accessible due to the presence of fluctuation effects, which round the critical behavior of any observable near  $T_c$ . In the attempt to directly determine  $T_c$  from the experimental data, Han *et al* [22] extrapolated the excess conductivity raised to the inverse of critical exponent  $\lambda$ , where  $T_c$  is determined from the intercept on the temperature axis from the mean field region. Direct determination of  $T_c$  has also been attempted by analyzing the temperature dependence of the inverse of the logarithmic temperature derivative of fluctuation conductivity [21]. Both methods, however, do not rule out error in  $T_c$  determination since the exponent in the SCOPF region varies over a large range. We have used the derivative of the resistance data as a function of temperature ( $dP/dT$ ), with  $T_c$  defined as the peak position of this derivative (Fig. 2) as has been done by many [21,23,24]. The effect of uncertainty in the determination of the  $T_c$  results in a temperature range corresponding to the critical region, where the excess conductivity depends sensitively on the reduced temperature [25,26]. Therefore, we have selected a temperature window around the mean field region and restricted our data analysis mainly to this region.



**Figure 2.** Representative plot of the resistance and temperature derivative of resistance near  $T_c$  as a function of temperature in  $\text{Bi}_2\text{Sr}_{1.4}(\text{Pb})_{0.6}\text{Ca}_{2-x}\text{Y}_x\text{Cu}_3\text{O}_{10+y}$  thick films.

The AL relation is based on the Ginzburg–Landau (GL) mean field theory and is valid only in a mean field temperature range between  $\sim 1.01T_c$  and  $1.1T_c$  (see Fig. 3). We can summarize the results in Table 1, for values of  $\varepsilon < 0.00001$  the paraconductivity does not vary significantly, indicating that the coherence length begins to be significant to these temperatures.  $\lambda$  values as obtained from the adjustment can be seen in the Table 1 are of the order of unity for  $x > 0.075$ , which corresponds to a

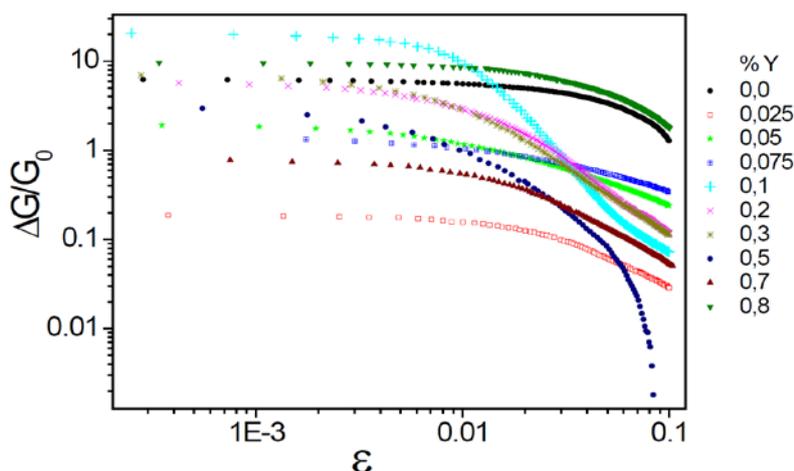
2D conduction process as predicted by the equation  $\lambda = 2 - D/2$  (AL model), where  $D$  represents the dimensionality for the fluctuation spectrum. Log-Log plots of excess conductivity as a function of reduced temperature for  $\text{Bi}_2\text{Sr}_{1.4}(\text{Pb})_{0.6}\text{Ca}_{2-x}\text{Y}_x\text{Cu}_3\text{O}_{10+y}$  on MgO substrates for different Yttrium contents can be seen in fig 4.



**Figure 3.** Effect of different  $T_c$  values on excess conductance. The sensitivity on the transition temperature is more pronounced in the critical region close to  $T_c$ .

**Table 1.**  $\lambda$  values obtained from the AL relation.

Yttrium Concentration	$\lambda$	$T_c$ (dR/dT)	Yttrium Concentration	$\lambda$	$T_c$ (dR/dT)
X = 0.000	0.255	106.78	X = 0.200	0.876	93.01
X = 0.025	0.472	121.24	X = 0.300	0.904	89.70
X = 0.050	0.431	103.42	X = 0.500	1.190	95.82
X = 0.075	0.329	92.26	X = 0.700	1.190	94.58
X = 0.100	1.060	89.00	X = 0.800	1.190	94.83



**Figure 4.** Log-Log plots of excess conductivity as a function of reduced temperature for  $\text{Bi}_2\text{Sr}_{1.4}(\text{Pb})_{0.6}\text{Ca}_{2-x}\text{Y}_x\text{Cu}_3\text{O}_{10+y}$  thick films for different Y contents.

When the dopant is  $x < 0.1$ , the dimensionality of the order parameter tends to 3D, while the concentration  $x > 0.1$  tends to 2D. (see Table 1). According to results reported to YBCO, the fluctuations of dimensionality are 2D or 3D, depending on the nature of the samples while for BSCCO are quasi 2D for polycrystalline samples. Two-dimensional behavior in the Bi system exhibits a decoupling of the CuO planes and is similar to the YBCO system, showing 3D behavior. This analysis shows systematic changes on the paraconductivity in the critical exponent for the yttrium-doped

BSCCO system; in our case,  $\lambda$  tends to increase with the concentration of yttrium, having a value of close to half (3D behavior) in  $0 < x < 0.1$  tends to saturate between 1 and 3/2 (possibly 2D)  $0.1 < x < 0.8$  for higher levels of dopant. Other changes of the exponent have already been reported [23]. Where it has been found that the increase of the concentration of Ni in the system (Bi, Pb)SrCaCuO  $\lambda$  increases, it is consistent with our results.

In summary, the conduction behavior, even with low dimensionality of the order parameter observed in our samples, is due to yttrium doping which induces the percolative transport. This interpretation suggests that the yttrium ions substitute Cu not only in the pyramid but also in the arrangement of square planar Cu-O centers

## References

- [1] G L Aslamazov, A I Larkin, *Phys. Lett.* **26** (1968) 238.
- [2] K Maki, R S Thompson, *Phys. Rev. B* **39** (1988) 2767.
- [3] W E Lawrence, S Doniach, in: E. Kanada (Ed.), *Proceedings of the 12th International conference on Low temperature Physics*, Kyoto, Japan, Keigaku, Tokyo, (1980) 361.
- [4] J Y Juang, M C Hsieh, C W Luo, T M Uen, K H Wu, Y S Gou, *Physica C* **329** (2000) 45.
- [5] [5] S K Bandyopadhyay, P Barat, S K Kar, Udayan De, P Mandal, B Ghosh, C K Majumdar, *Solid State Commun.* **82** (1992) 397.
- [6] S K Bandyopadhyay, P Sen, P Barat, Udayan De, K Mandal, S K Kar, C K Majumdar, *Physica C* **267** (1996) 303.
- [7] D Sanyal, K Mandal, Udayan De, *CPTA-98*, Saha Institute of Nuclear Physics, Calcutta, Feb, 1998.
- [8] Udayan De, K Mandal, D Sanyal, D Banerjee, C K Majumdar, *Regional Meeting on Radiation Physics*, Bose Institute, Calcutta, November 1995.
- [9] Udayan De, A Sarkar, D Sanyal, D Banerjee, R Kumar, *Proceedings of the International Workshop on High-Tc Superconductors*, Rajshahi University, Bangladesh, 2-6 November (1998) 483.
- [10] Maza J and Vidal F *Phys. Rev. B* **43** (1991) 10560.
- [11] Cukauskas E J and Allen L H. *J. Appl. Phys.* **84** (1998) 6187.
- [12] Aswal D K, Singh A, Sen S, Kaur M, Viswandham C S, Goswami G L and Gupta S K. *J. Phys. Chem. Solids* **63** (2002) 1797.
- [13] Sato T, Hakane H, Yamazaki S and Mori N *Physica C* **372** (2002) 1208.
- [14] Sidorenko A S, Zdravkov V I, Ryazanov V V, Klemm M, Horn S, Tideeks R, Muller C and Wixforth A *J. Supercond.* **17** (2004) 211
- [15] D H Kim, A M Goldman, J H Kang, K E Gray and R T Kampwirth. *Phys. Rev. B* **39** (1989) 12275.
- [16] V Calzona, M R Cimberle, C Ferdeghini, D V Livanov, D Marre, M Putti, A S Siri, G Balestrino and E Milani, *Solid State Commun.* **87** (1993) 397.
- [17] Y Matsuda, T Hirai, S Komiyana, T Terashima, Y Bando, K Iijima, K Yamamoto, and K Hirata, *Phys Rev. B* **40** (1989) 5176.
- [18] U Welp, S Flesher, W K Kwok, R A Kñemm, V M Vinokur, J Downy, and G W Crabtree, *Phys. Rev. Lett.* **67** (1991) 3180.
- [19] K H Kim, K E Gray, and M D Trochet, *Phys. Rev. B* **45** (1992) 10801.
- [20] Thomas Lemberger and Liam Coffexy, *Phys. Rev. B* **38** (1988) 7058 .
- [21] P Pureur, R Menegotto Costa, P Rodríguez, Jr., J Schaf and J V Kunzler, *Phys. Rev. B* **47** (1993) 11420.
- [22] S H Han and M Anderson, *Physica B* **194** 196 (1994) 1513.
- [23] Vidal F, Torron C, Vina J and Mosqueira J *Physica C* **332** (2000)166.
- [24] Demirel A I *Supercond. Sci. Technol.* **14** (2001) 978.
- [25] N Mori, J A Wilson, H Ozaki, *Phys Rev B*, **45** (1992) 10633.
- [26] Q Y Ying and H S Kwok, *Phys. Rev. B.* **42** (1990) 2242.