EFFECT OF PLANAR WEIGHT DISPARITY ON THE CONDUCTIVITY FLUCTUATIONS AND CRITICAL PARAMETERS IN THE $RE_{0.5}Y_{0.5}Ba_2Cu_3O_{7-\delta}$ (RE=Sm, Gd, Dy, Ho, Eu, Yb)

EFECTO DE LA DISPARIDAD DE PESO PLANAR SOBRE LAS FLUCTUACIONES DE LA CONDUCTIVIDAD Y LOS PARÁMETROS CRÍTICOS EN EL SUPERCONDUCTOR $RE_{0.5}Y_{0.5}Ba_2Cu_3O_{7-\delta}$ (RE=Sm, Gd, Dy, Ho, Eu, Yb)

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Received for review August 28 th, 2009, accepted December 18 th, 2009, final version January, 27 th, 2010

ABSTRACT: Synthesis and conductivity characterization of the $RE_{0.5}Y_{0.5}Ba_2Cu_3O_{7-\delta}$ (RE=Sm, Gd, Dy, Ho, Eu, Yb) superconducting materials are reported. Samples were produced by the standard solid state reaction method. Rietveld-like refinement of x-ray diffraction data permit to establish the crystalline appropriated distribution of rare earth and yttrium to create substantial planar weight disparity (PWD) in alternating layers. DC resistivity measurements reveal the improvement of the critical temperature (T_c) when substitution of exact 50-50 mix of rare earth (Sm, Gd, Dy, Ho, Eu, Yb) and Yttrium is performed. A bulk $T_c \approx 94.3$ K was determined by the criterion of the maximum in the temperature derivative of electrical resistivity for the analyzed samples. The correlations of the critical exponents with the dimensionality of the fluctuation system for each Gaussian regime were performed by using the Aslamazov-Larkin theory. The genuinely critical exponent is interpreted by the 3D-XY model as corresponding with the dynamical universality class of the E-model.

KEYWORDS: Superconductivity; planar weight disparity; rare earth substitution; conductivity fluctuations

RESUMEN: En el presente artículo se reporta la síntesis y caracterización de la conductividad del material superconductor $RE_{0.5}Y_{0.5}Ba_2Cu_3O_{7-\delta}$ (RE=Sm, Gd, Dy, Ho, Eu, Yb). Las muestras fueron producidas mediante la técnica estándar de reacción de estado sólido. El refinamiento Rietveld de los datos de difracción de rayos x permitió establecer la apropiada distribución cristalina de las tierras raras y del Ytrio para crear el efecto de disparidad de peso planar (PWD) en forma de capas alternadas. Mediciones de resistividad DC mostraron que la temperatura crítica (T_c) aumenta sustancialmente cuando se sustituye en proporciones exactas 50-50 de tierra rara (Sm, Gd, Dy, Ho, Eu, Yb) e Ytrio. Se determine una temperatura crítica volumétrica $T_c \approx 94.3$ K mediante el criterio del máximo en la derivada numérica de la resistividad eléctrica con respecto a la temperatura para las muestras en estudio. La correlación de los exponents críticos con la dimensionalidad de los sistemas de fluctuaciones para cada régimen Gaussiano se establecieron por medio de la teoría de Aslamazov-Larkin. Los exponentes genuinamente críticos se interpretaron mediante el modelo 3D-XY de modo que corresponden a la clase de universalidad dinámica predicha por el modelo E.

PALABRAS CLAVE: Superconductividad; disparidad de peso planar; sustitución de tierras raras; fluctuaciones en la conductividad

1. INTRODUCTION

Since the discovery of YBCO in 1987 [1], several substitutions in different sites on the $YBa_2Cu_3O_{7-\delta}$ compound have been made. Specially the substitution of Yttrium by trivalent rare-earth elements yields a T_c similar to the $YBa_2Cu_3O_{7-\delta}$ [2,3] An exact 50-50 mix of Yttrium and a heavy rare earth has been found to significantly improve T_c in the $Lu_{0.5}Y_{0.5}Ba_2Cu_3O_{7-\delta}$ by creating substantial planar weight disparity in alternating layers, which has previously been found to increase T_c. in copper-oxide superconductors [3].

The paraconductivity of the Aslamazov-Larkin (AL) type in the normal state, close to T_c. [4], follows a quasi-universal behavior, which is strongly related with Gaussian and genuinely critical fluctuations. Below T_c, close to zero resistance state, the fluctuation effects are enhanced by the granular-like disorder. The aim of this work is to study the fluctuation effects above T_c in the perovskite-like $RE_{0.5}Y_{0.5}Ba_2Cu_3O_{7-\delta}$ (RE=Sm, Gd, Dy, Ho, Eu, Yb) superconducting system with planar weight disparity. In order to analyze the paraconductivity, we use the concept of logarithmic derivative of the conductivity excess. From analysis of experimental data, we identify the critical regimes near T_c in the normal state.

2. EXPERIMENTAL

Polycrystalline samples of $RE_{0.5}Y_{0.5}Ba_2Cu_3O_{7-\delta}$ (RE=Sm, Gd, Dy, Ho, Eu, Yb) were synthesized by means the standard solid state reaction technique. The precursor powders were RE_2O_3, barium carbonate, yttrium and copper oxides. The mixed powders pressed in disk-shaped pellets were annealed at 910 °C for 24 hours. The samples were then grinded and pelletized for sintering at 910 °C during 12 hours. Finally, these pellets were heated at 450 °C in flowing oxygen for 24 hours.

Resistivity measurements were carried out by the four-probe method, using the Keithley 2182A nanovoltmeter and 6221 current source in delta mode, and electric contacts by spring-loaded contact gold pins, allowing reaching a lecture about 10 nΩ I n the superconductor state.

X-Ray diffraction analyses were made by means Phillips PW1710 diffractometer with copper radiation wavelengths λ=1.54064 Å. X-Ray diffraction results indicated the formation of the orthorhombic structure when Yttrium is partially substituted with trivalent rare-earths. For the $Yb_{0.5}Y_{0.5}Ba_2Cu_3O_{7-\delta}$ a little fraction of $BaCuO_2$ was formed. This content phase cannot be reduced by solid-state reaction [5].

3. ANALYSIS METHOD

The analysis of results for the fluctuation contribution on electrical conductivity is performed by assuming that the conductivity excess is given by [6]:

$$\Delta\sigma = \sigma(T) - \sigma_R(T), \qquad (1)$$

where σ (T) = $1/\rho$ (T) is the measured conductivity and $\sigma_R(T) = 1/\rho_R(T)$ is the regular term extrapolated from the resistivity curve in the normal region. According to the Aslamazov-Larkin proposal [4], the fluctuation conductivity diverges as a power law of the type

$$\Delta\sigma = A\varepsilon^{-\lambda}, \qquad (2)$$

where A is a constant, $\varepsilon = (T-T_c)/T_c$ represent the reduced temperature and λ is the critical exponent. Analogously to the Kouvel-Fisher method of analysis of critical phenomena [7], the logarithmic temperature derivative of Δσ is given by $\partial_T Ln(\Delta\sigma)$. Then, the inverse of logarithmic temperature derivative is defined as

$$\chi_\sigma = -\frac{\partial Ln(\Delta\sigma)}{\partial T} = \frac{1}{\Delta\sigma}\frac{\partial(\Delta\sigma)}{\partial T}. \qquad (3)$$

By substituting equation (2) in (3) it is obtained that

$$\frac{1}{\chi_\sigma} = \frac{1}{\lambda}\left[T - T_C\right]. \quad (4)$$

Thus, simple identification of linear temperature behavior in plots of χ_σ^{-1} as a function of temperature allow simultaneous determination of critical temperature T_c of fluctuation regime and the corresponding critical exponent λ. We notice that the bulk T_c values obtained from derivative method approximately correspond to the extrapolation of the linear $\chi_\sigma(T)^{-1}$ for the genuine critical regime.

4. RESULTS AND DISCUSSION

In figure 1, we show the characteristic electrical resistivity ρ(T) for the $RE_{0.5}Y_{0.5}Ba_2Cu_3O_{7-\delta}$ (RE=Sm, Gd, Dy, Ho, Eu, Yb) material. In the normal state, all samples have a metallic-like behavior, except for the $Dy_{0.5}Y_{0.5}Ba_2Cu_3O_{7-\delta}$. This feature indicates that the synthesis process could be generates granularity differences, which enhance some substitutions more than others.

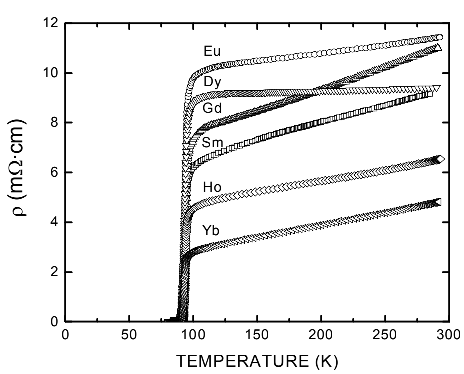

Figure 1. Electrical resistivity ρ(T) for the series of $RE_{0.5}Y_{0.5}Ba_2Cu_3O_{7-\delta}$ (RE=Sm, Gd, Dy, Ho, Eu, Yb) samples as a function of temperature

From the temperature derivative of ρ(T) in the transition region we calculated the bulk T_c values. The critical temperatures are distributed around a mean value of T_c=94.28±0.46 K.

Figure 2, shows the fluctuation regimes above T_c. The χ_σ^{-1} curves overlapping around T_c, except for $Sm_{0.5}Y_{0.5}Ba_2Cu_3O_{7-\delta}$ and $Gd_{0.5}Y_{0.5}Ba_2Cu_3O_{7-\delta}$ above T_c.

Three Gaussian fluctuations regions were identified in Ho, Yb, Eu substitutions, which were labeled λ_{3D}, λ_{2D} and $\lambda_{3D\text{-}2D}$. For Dy and Gd substitutions only two Gaussian regimes could be found and only 3D regime for the Sm substitution. We interpreted the characteristic regimes on the basis of the Aslamazov-Larkin theory [4], which proposes that the critical exponents are related with the dimensionality d of the fluctuation system, through the expression:

$$\lambda = 2 - \frac{d}{2}. \quad (5)$$

The λ_{2D} and λ_{3D} exponents correspond to homogeneous 2D and 3D regimes. As showed in table I, the exponent $\lambda_{3D\text{-}2D}$ do not correspond to an integer dimensionality. It was demonstrated by Char and Kapitulnik [8], using an expression similar to Eq. (5) in the framework of a topological fractal space. A region with λ_{1D} exponent was observed for RE=Eu, Sm, Yb and Ho. This regime is related with fluctuations develop in the 1D space.

Table 1. Gaussian λ_{1D}, λ_{2D} and λ_{3D} exponents, dimensionalities d and reduced temperature ε for fluctuation regimes

RE	Regime	λ	d	ε
Dy	λ_{2D}	0.97±0.05	2.0	$0.022 \le \varepsilon \le 0.034$
	λ_{3D}	0.57±0.02	3.0	$0.009 \le \varepsilon \le 0.015$
Eu	λ_{1D}	1.54±0.15	1.0	$0.034 \le \varepsilon \le 0.057$
	λ_{2D}	0.95±0.03	2.0	$0.015 \le \varepsilon \le 0.029$
	λ_{3D}	0.52±0.03	3.0	$0.012 \le \varepsilon \le 0.015$
Gd	λ_{2D}	1.08±0.02	2.0	$0.028 \le \varepsilon \le 0.035$
	$\lambda_{3D\text{-}2D}$	0.90±0.03	3.0	$0.013 \le \varepsilon \le 0.019$
Sm	λ_{3D}	0.58±0.05	3.0	$0.059 \le \varepsilon \le 0.083$
Yb	λ_{1D}	1.43±0.17	1.0	$0.033 \le \varepsilon \le 0.052$
	λ_{2D}	0.93±0.04	2.0	$0.024 \le \varepsilon \le 0.032$
	$\lambda_{3D\text{-}2D}$	0.76±0.01	2.5	$0.021 \le \varepsilon \le 0.027$
	λ_{3D}	0.47±0.08	3.0	$0.015 \le \varepsilon \le 0.024$
Ho	λ_{1D}	1.43±0.02	1.0	$0.021 \le \varepsilon \le 0.028$
	λ_{2D}	0.92±0.04	2.0	$0.017 \le \varepsilon \le 0.021$
	λ_{3D}	0.50±0.04	3.0	$0.013 \le \varepsilon \le 0.018$

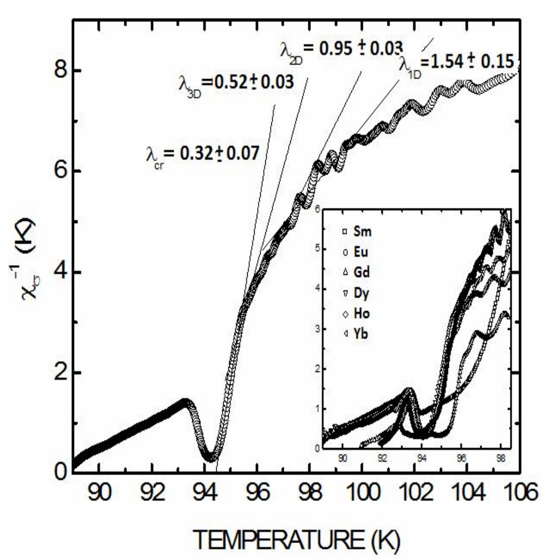

Figure 2. Fluctuation regimes identified in χ_σ^{-1} as a function of temperature for the $Eu_{0.5}Y_{0.5}Ba_2Cu_3O_{7-\delta}$ sample. The inset show χ_σ^{-1} as a function of T for others rare earths substitutions

Closer to T_c, a fourth power law region is observed in figure 2, identifies by the exponent λ_{CR}. This regime corresponds to genuine critical fluctuations, which were predicted to occur by Lobb [9]. The values of λ_{CR} are presented in Table II. The genuine critical regime is expected to be described by the 3D-XY model [10], which predicts a critical exponent λ_{cr} = 0,33. According to the experimental precision of the critical exponents values listed in the table II, the exponents 0,42 ± 0,02 (Dy sample) and 0,41 ± 0,01 (Ho sample) cannot be considered as critical exponent values.

Tabla 2. Exponentes críticos y temperatura reducida para el régimen de fluctuaciones genuinamente crítico

RE	λ_{CR}	ε
Dy	0.42±0.02	$0.005 \leq \varepsilon \leq 0.009$
Eu	0.32±0.07	$0.005 \leq \varepsilon \leq 0.014$
Gd	0.33±0.02	$0.007 \leq \varepsilon \leq 0.013$
Sm	0.34±0.03	$0.040 \leq \varepsilon \leq 0.056$
Yb	0.31±0.04	$0.012 \leq \varepsilon \leq 0.018$
Ho	0.41±0.01	$0.008 \leq \varepsilon \leq 0.015$

5. CONCLUSION

We performed conductivity fluctuation analysis in the $RE_{0.5}Y_{0.5}Ba_2Cu_3O_{7-\delta}$ (Sm, Eu, Gd, Dy, Ho, Yb) high temperature superconducting materials. Close and above T_c the analysis reveals the occurrence of critical and Gaussian fluctuation regimes. We interpret Gaussian regions as corresponding to fluctuations which occurs in 3D, 2D and 1D. Another intermediated regime was identified for the cases when rare earth is Gd and Yb. This is related with fluctuations which develop in spaces with fractal topology between three and two dimensionalities. The genuinely critical exponent is interpreted by the 3D-XY model. The critical temperatures has a mean value of T_c=94.28±0.46 K. For some doping rare earths like Sm and Gd, the χ_σ^{-1} curve diverges from the potential behavior. We attribute this characteristic to the requirement that every used rare-earth for doping the YBCO needs their own thermal synthesis process to reach the single phase and optimal granularity.

6. ACKNOWLEDGMENTS

This work was partially supported by the División de Investigaciones Sede Bogotá (DIB).

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