EFFECT OF PLANAR WEIGHT DISPARITY ON THE CONDUCTIVITY FLUCTUATIONS AND CRITICAL PARAMETERS IN THE RE$_{0.5}$Y$_{0.5}$Ba$_2$Cu$_3$O$_{7-\delta}$ (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$_2$Cu$_3$O$_{7-\delta}$ (RE=Sm, Gd, Dy, Ho, Eu, Yb)

D. A. LANDÍNEZ-TÉLLEZ
Grupo de Física de Nuevos Materiales, Departamento de Física, Universidad Nacional de Colombia, dalandinez@unal.edu.co

G. PEÑA-RODRÍGUEZ
Grupo de Investigación en Tecnología Cerámica, Universidad Francisco de Paula Santander, ggabriel.p@yahoo.com

J. ROA-ROJAS
Grupo de Física de Nuevos Materiales, Departamento de Física, Universidad Nacional de Colombia, jroar@unal.edu.co

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

ABSTRACT: Synthesis and conductivity characterization of the RE$_{0.5}$Y$_{0.5}$Ba$_2$Cu$_3$O$_{7-\delta}$ (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$_2$Cu$_3$O$_{7-\delta}$ (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 exponentes críticos con la dimensionalidad de los sistemas de fluctuaciones para cada régimen Gaussiaño 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.

Dyna, year 77, Nro. 163, pp. 234-238. Medellin, September, 2010. ISSN 0012-7353
1. INTRODUCTION

Since the discovery of YBCO in 1987 [1], several substitutions in different sites on the YBa$_2$Cu$_3$O$_{7-\delta}$ compound have been made. Specially the substitution of Yttrium by trivalent rare-earth elements yields a $T_c$ similar to the YBa$_2$Cu$_3$O$_{7-\delta}$ [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$_2$Cu$_3$O$_{7-\delta}$ 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$_2$Cu$_3$O$_{7-\delta}$ (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$_2$Cu$_3$O$_{7-\delta}$ (RE=Sm, Gd, Dy, Ho, Eu, Yb) were synthesized by means the standard solid state reaction technique. The precursor powders were RE$_2$O$_3$, 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 in the superconductor state.

X-Ray diffraction analyses were made by means Phillips PW1710 diffractometer with copper radiation wavelengths $\lambda=1.54064$ 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$_2$Cu$_3$O$_{7-\delta}$ 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]:

$$\Delta\sigma = \sigma(T) - \sigma(R),$$

where $\sigma(T) = \rho^{-1}(T)$ is the measured conductivity and $\sigma(R) = \rho^{-1}(T)$ 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

$$\Delta\sigma = A\varepsilon^{-\lambda},$$

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

$$\chi_\sigma = -\frac{\partial_T\ln(\Delta\sigma)}{\partial T} = \frac{1}{\Delta\sigma}\frac{\partial(\Delta\sigma)}{\partial T}.$$
By substituting equation (2) in (3) it is obtained that
\[
\frac{1}{\lambda_d} = \frac{1}{2} [T - T_c].
\]

(4)

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

4. RESULTS AND DISCUSSION

In figure 1, we show the characteristic electrical resistivity \(\rho(T)\) for the \(\text{RE}_{0.5}Y_{0.5}\text{Ba}_2\text{Cu}_3\text{O}_{7-\delta}\) (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}\text{Ba}_2\text{Cu}_3\text{O}_{7-\delta}. This feature indicates that the synthesis process could be generates granularity differences, which enhance some substitutions more than others.

![Figure 1](image)

Figure 1. Electrical resistivity \(\rho(T)\) for the series of \(\text{RE}_{0.5}Y_{0.5}\text{Ba}_2\text{Cu}_3\text{O}_{7-\delta}\) (RE=Sm, Gd, Dy, Ho, Eu, Yb) samples as a function of temperature

From the temperature derivative of \(\rho(T)\) in the transition region we calculated the bulk \(T_c\) values. The critical temperatures are distributed around a mean value of \(T_c=94.28\pm0.46\) K.

Figure 2, shows the fluctuation regimes above \(T_c\). The \(\chi^{-1}\) curves overlapping around \(T_c\), except for \(\text{Sm}_{0.5}Y_{0.5}\text{Ba}_2\text{Cu}_3\text{O}_{7-\delta}\) and \(\text{Gd}_{0.5}Y_{0.5}\text{Ba}_2\text{Cu}_3\text{O}_{7-\delta}\) above \(T_c\).

Three Gaussian fluctuations regions were identified in Ho, Yb, Eu substitutions, which were labeled \(\lambda_{3D}\) \(\lambda_{2D}\) and \(\lambda_{1D, 2D}\). 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:

\[
\lambda = 2 - \frac{d}{2}.
\]

The \(\lambda_{2D}\) and \(\lambda_{3D}\) exponents correspond to homogeneous 2D and 3D regimes. As showed in table I, the exponent \(\lambda_{1D, 2D}\) 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 \(\lambda_{1D}\) exponent was observed for RE=Eu, Sm, Yb and Ho. This regime is related with fluctuations develop in the 1D space.

<table>
<thead>
<tr>
<th>RE</th>
<th>Regime</th>
<th>(\lambda)</th>
<th>(d)</th>
<th>(\varepsilon)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dy</td>
<td>(\lambda_{2D})</td>
<td>0.97±0.05</td>
<td>2.0</td>
<td>0.022 ≤ (\varepsilon) ≤ 0.034</td>
</tr>
<tr>
<td></td>
<td>(\lambda_{3D})</td>
<td>0.57±0.02</td>
<td>3.0</td>
<td>0.009 ≤ (\varepsilon) ≤ 0.015</td>
</tr>
<tr>
<td>Eu</td>
<td>(\lambda_{1D})</td>
<td>1.54±0.15</td>
<td>1.0</td>
<td>0.034 ≤ (\varepsilon) ≤ 0.057</td>
</tr>
<tr>
<td></td>
<td>(\lambda_{2D})</td>
<td>0.95±0.03</td>
<td>2.0</td>
<td>0.015 ≤ (\varepsilon) ≤ 0.029</td>
</tr>
<tr>
<td></td>
<td>(\lambda_{3D})</td>
<td>0.52±0.03</td>
<td>3.0</td>
<td>0.012 ≤ (\varepsilon) ≤ 0.015</td>
</tr>
<tr>
<td>Gd</td>
<td>(\lambda_{2D})</td>
<td>1.08±0.02</td>
<td>2.0</td>
<td>0.028 ≤ (\varepsilon) ≤ 0.035</td>
</tr>
<tr>
<td></td>
<td>(\lambda_{3D, 2D})</td>
<td>0.90±0.03</td>
<td>3.0</td>
<td>0.013 ≤ (\varepsilon) ≤ 0.019</td>
</tr>
<tr>
<td>Sm</td>
<td>(\lambda_{3D})</td>
<td>0.58±0.05</td>
<td>3.0</td>
<td>0.059 ≤ (\varepsilon) ≤ 0.083</td>
</tr>
<tr>
<td>Yb</td>
<td>(\lambda_{1D})</td>
<td>1.43±0.17</td>
<td>1.0</td>
<td>0.033 ≤ (\varepsilon) ≤ 0.052</td>
</tr>
<tr>
<td></td>
<td>(\lambda_{2D})</td>
<td>0.93±0.04</td>
<td>2.0</td>
<td>0.024 ≤ (\varepsilon) ≤ 0.032</td>
</tr>
<tr>
<td></td>
<td>(\lambda_{3D, 2D})</td>
<td>0.76±0.01</td>
<td>2.5</td>
<td>0.021 ≤ (\varepsilon) ≤ 0.027</td>
</tr>
<tr>
<td></td>
<td>(\lambda_{3D})</td>
<td>0.47±0.08</td>
<td>3.0</td>
<td>0.015 ≤ (\varepsilon) ≤ 0.024</td>
</tr>
<tr>
<td>Ho</td>
<td>(\lambda_{1D})</td>
<td>1.43±0.02</td>
<td>1.0</td>
<td>0.021 ≤ (\varepsilon) ≤ 0.028</td>
</tr>
<tr>
<td></td>
<td>(\lambda_{2D})</td>
<td>0.92±0.04</td>
<td>2.0</td>
<td>0.017 ≤ (\varepsilon) ≤ 0.021</td>
</tr>
<tr>
<td></td>
<td>(\lambda_{3D})</td>
<td>0.50±0.04</td>
<td>3.0</td>
<td>0.013 ≤ (\varepsilon) ≤ 0.018</td>
</tr>
</tbody>
</table>
Closer to $T_c$ a fourth power law region is observed in figure 2, identifies by the exponent $\lambda_{CR}$. This regime corresponds to genuine critical fluctuations, which were predicted to occur by Lobb [9]. The values of $\lambda_{CR}$ 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 $\lambda_{cr} = 0.33$. According to the experimental precision of the critical exponents values listed in the table II, the exponents 0.42 $\pm$ 0.02 (Dy sample) and 0.41 $\pm$ 0.01 (Ho sample) cannot be considered as critical exponent values.

5. CONCLUSION

We performed conductivity fluctuation analysis in the RE$_{0.5}$Y$_{0.5}$Ba$_2$Cu$_3$O$_{7-\delta}$ (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 $T_c = 94.28 \pm 0.46$ K. For some doping rare earths like Sm and Gd, the $\chi^{-1}$ 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).

REFERENCIAS


