Hall Effect, Electrical Resistivity and AC Susceptibility of 
(Bi$_{1.6}$Pb$_{0.4}$)Sr$_2$Ca$_2$(Cu$_{1.4}$Co$_{0.6}$)O$_y$ Superconductors

G. Ilonca$^1$, A.V. Pop$^1$, T. Jurcut$^2$, C. Lung$^1$, I. D. Tului$^1$, I. Matei$^1$, R. Stiufiuc$^1$, G. Stiufiuc$^1$ and 
N. Dulanita$^1$

$^1$ Babes–Bolyai University, 3400 Cluj-Napoca, Romania, 
$^3$ University of Oradea, Science Faculty, Oradea, Romania

Abstract

We have investigated the effect of the partial substitution of Cu by Co in the stabilized 108 K phase Bi:2223, prepared by conventional solid state reaction method, by using electrical resistivity, Hall coefficient and ac susceptibility measurements. The critical temperatures and Hall concentration depend strongly on the Co content of the samples. Up to Co concentration of $x = 0.025$ the bending of the $\rho(T)$ curves, above $T_c$, can be described in the terms of the Lawrence-Doniach theory. The intergrain and intragrain critical transition temperatures decrease by $\Delta T_{CG} = 8.5$ K and $\Delta T_c = 11.2$ K respectively, as a result of the substitution of Co for Cu in Cu-O pyramids.

1. Introduction

The partial substitution of Cu by 3d elements in Bi:2223 material is important for investigating the nature of superconductivity along with the understanding the normal state properties. The different role of Cu-O sheets and Cu-O pyramids in the superconductivity in the 2223 phase is still unknown. The bulk (Bi,Pb):2223 material consist of grains weakly coupled at the grain boundaries by Josephson junctions or weak links [1,2]. The high $T_c$ cuprates are characterized by a large number of anomalies in “mixed and normal state”, properties observed by resistivity, Hall effect, thermoelectric power, magnetic susceptibility etc [3,4]. The intra- and intergrain properties of the (Bi,Pb):2223 system are influenced by the partial substitution of cooper (Cu) by 3d elements [4,5].

In this paper we report the effect of the partial substitution of Cu by Co in the mixed and normal state on the intergrain and intragrain properties of (Bi,Pb):2223 superconductor using ac susceptibility electrical resistivity and Hall effect measurements as a function of temperature and magnetic field.

2. Experimental Details

The (Bi$_{1.6}$Pb$_{0.4}$)(Sr$_{1.6}$Ba$_{0.2}$)(Cu$_{1.4}$Co$_{0.6}$)O$_y$ samples with $0 \leq x \leq 0.05$ Co were prepared by using the conventional solid state reaction method [6]. The examination by X – ray diffraction, energy depressive X-ray analysis (EDAS) and optical microscopy revealed almost
a single phase with impurity level being less than 5%. The real $\chi'$ and imaginary $\chi''$ part of the ac susceptibility was simultaneously collected with a Lake Shore Model 7000 ac susceptometer. The electrical resistivity and Hall voltage were measured by the standard dc method, using a Keithly 220 programable current source and the Keithly 182 sensitive digital voltmeter.

3. Results and Discussion

Figures 1 show $\chi'(T)$ and $\chi''(T)$ behavior for different ac field $x=0.025$ Co. For our samples the temperature and field dependence of $\chi'(T)$ and $\chi''(T)$ shows a two-stage behavior which is found to be typical for sintered HTSC. $\chi'(T)$ exhibits two peaks at $T_P$ and $T_0$ which indicates the maximum hysteresis losses due to the motion of inter- and intragranular vortices. Both loss peaks shift to lower temperature by increasing $H_{dc}$. The absence of intragrain peak in $\chi''(T)$ suggest the presence of smaller decoupled grain in $x=0.025$ Co sample [6].

Fig. 1. Temperature dependence of the real part of $\chi'$ of the ac susceptibility (a) and imaginary part $\chi''(b)$ for $x=0.025$ Co sample at different ac field amplitudes

In order to investigate the effect for partial substitution of Cu with Co on the intergranular pinning force, we studied the $T_P$ dependence as a function of $H_{dc}$. In the ac amplitude range 50A/m – 500A/m we obtain a linear dependence of $T_P$ as a function of $H_{dc}$, in agreement with Muller critical state model. Figure 2 shows the broadening of the resistitivitive transition in an external magnetic field up to 1 Tesla for the $x=0.025$ Co sample and a linear temperature dependence of electrical resistivity in the normal state $\rho = \rho(0) + aT$. The increase in residual resistivity, $\rho(0)$ from 90$\mu\Omega$cm to 400$\mu\Omega$cm with increasing $x$ from zero to 0.025 Co is accompanied by the depression of the critical transition temperature $T_C$ from 108K to 98K with a slope $dT_C/dx \approx -5K/at\%$. These results suggest that Co atoms substitute Cu in the Cu – O pyramids in our samples in agreement with crystals doped with Ni [7]. The decreasing $T_C$ with increasing magnetic field may be responsible.

Fig. 2. The temperature dependence of the square of the temperature dependence of the resistance $\rho(T)$ for $x=0.025$ Co sample

Fig. 3. The temperature dependence of the square of the temperature dependence of the resistance $\rho(T)$ for $x=0.025$ Co sample

The thermal activated phase shift Josephson coupling energy of the high current limit the resistivity obeys the expression $\rho(T) = \rho(0) + aT$, the energies $U$ were calculated by using ABC fields. The temperature dependence of $\rho(T)$ is shown in Fig. 3. A linear decrease of resistivity with a slope around $T=250$ K and this is in agreement
The real $\chi'$ and imaginary $\chi''$ part of $\chi$ with a Lake Shore Model 7000 ac stage were measured by the standard dc source and the Keithly 182 sensitive digital

for different ac field $x=0.025$ Co. For our $\chi(T)$ and $\chi'(T)$ shows a two-stage HTSC $\chi(T)$ exhibits two peaks at $T_p$ and $T_c$ due to the motion of inter- and inner temperature by increasing $H_{ac}$. The presence of smaller decoupled grain in

Cu – O pyramids in our samples in agreement with others results obtained on Bi:2212 single crystals doped with Ni [7]. The decrease of the intragrain Josephson coupling energy with increasing magnetic field may be responsible for the broadening in $\Delta T_c$.

![Graph showing the temperature dependence of electrical resistivity in the mixed state of $x=0.025$ Co sample in an applied magnetic field up to 0.7T.]

**Fig. 2.** The temperature dependence of electrical resistivity in the mixed state of $x=0.025$ Co sample in an applied magnetic field up to 0.7T.

![Graph showing the temperature dependence of the Hall concentration $n_H$ and the square of the temperature dependence of the inverse mobility for $x=0.025$ Co sample.]

**Fig. 3.** The temperature dependence of the Hall concentration $n_H$ and the square of the temperature dependence of the inverse mobility for $x=0.025$ Co sample.

The thermal activated phase slippage (TAPS) theory predict the reduction of the Josephson coupling energy of the high $T_c$ grain bounding junctions and that in the low current limit the resistivity obeys the relation $\rho(B,T) = \rho_0 \exp (-U/K_B T)$ The activation energy $U$ were calculated by using Arhenius plot $\ln(\rho/\rho_0) = f(1/T)$ for all applied magnetic fields. The temperature dependence of the Hall concentration for the Co doped samples is shown in Fig. 3. A linear decrease of $n_H$ can be seen with increases of $x$, with a charge of slope around $T=250$ K and this is in agreement with data reported in Ref. 8. The square of the
temperature dependence of the inverse mobility for $x=0.025$ Co is shown in the inset of Fig. 3. The straight lines represent the fit in the temperature range $160 - 250$ K according to Anderson's theory [8]. The change in the mobility of the carriers is most probably related to the chemical phase separation process [9].

4. Conclusions

In conclusion, we have separated simultaneous magnetoresistively and Hall effect measurements and ac-susceptibility on Bi-2223 doped with Co. The intergrain critical temperature $T_c$ is linear as a function of the ac field amplitude for $x=0.00$ and $0.025$ Co samples and agrees with Muller critical state model. The Co ions induce the increase for $\alpha$, intergrain pinning force density. The temperature dependence of the electrical resistivity is linear above the paraconductivity region. The residual resistivity increases with the $x$. The width of intragrain transition slowly increases with increasing magnetic field. The activation energy obtained from the magnetoresistivity measurements in $x=0.025$ Co sample, evidenced two distinct TAF regimes at high temperature (h) and lower temperature (l). The activation energies are proportional to $\ln B$ (regime h) and $B^1$ (regime l). In $x=0.00$ sample only the regime in which activation energy proportional to $\ln B$ is present. In normal state the charge carrier concentration depend strongly on the Co contents in the samples. The anomalies on $n_0(T)$ and $\mu(T)$ around the temperature 250K are discussed in the framework of phase theory.

References