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Irreversibility processes from AC magnetic susceptibilities in (Bi,Pb):2223 HTS system doped by 3d elements

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The effects of Cu partial substitution by Fe in (Bi,Pb):2223 bulk HTS were investigated by a.c. magnetic susceptibilities measurements function of temperature and magnetic field amplitude. The effective volume fractions of the grains were estimated function of Fe concentration. The irreversibility of intergranular processes is discussed in relation with the influence of magnetic field amplitude,aand the concentration of Fe on the critical current density.

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1. Introduction

One of the reasons for the low critical current densities J_{cJ} in high temperature superconducting (HTS) materials is the granular nature of the sintered HTS compounds. In bulk materials, grain boundaries present nano-barriers to the passage of current and acts as a weak links (structural misalignment, dirt or other impurity phases, oxygen vacancies etc). The current can pass through many different path through grain boundaries, and the bulk SC is a multiple Josephson junction array. Misalignement between grains and their boundaries causes degradation of J_c , particularly in magnetic fields.

In the (Bi,Pb):2223 superconducting ceramic samples the competition of intra- and intergrain conductivity is strongly temperature dependent and is differently affected by the nanodefects induced by the 3d ions which substitute in the Cu positions [1-4].

A.c. susceptibility measurements have been used to investigate the intergranular critical current density J_{cJ} , which is equivalent to the transport current density J_c. The parameters obtained from a.c. data depend on the sample composition as well as the ceramic processing variables for the (Bi,Pb):2223 system[5-7].

In this paper we report the effect of Fe doping in the Cu positions of (Bi,Pb):2223 superconducting on the superconductivity and irreversibility processes by using AC magnetic susceptibility measurements function of temperature and AC field amplitude.

2. Experimental

The $(Bi_{1.92}Pb_{0.44})Sr_2Ca_2(Cu_{1-x}Fe_x)_{3.2}O_y$ (x=0.00;0.02;0.05) samples were prepared by using the conventional solid state reaction method [8]. The characterization of phase purity was carried out by recording X-ray diffraction (XRD) patterns.Our x=0.00 sample is nearly a single "2223" phase,described by a tetragonal unit cell with lattice constants a=b=5.38Å and c=37.1 Å. In the Fe doped samples most of the identified peaks belong to the 2223 phase with a few low-intensity peaks belonging to the 2212 phase.

Cylindrical specimens were cut from the sintered samples and used for AC susceptibility measurements. The real (χ') and immaginary (χ'') parts of the AC susceptibility were simultaneously collected with a Lake Shore Model 7000 AC susceptometer. The measurements were performed at a frecquency of 666.7Hz as a function of temperature at fixed AC magnetic field amplitude (H_{ac}) in a range from 0.4 to 800 A/m. The AC field was applied parallel to the cylindrical axis.

3. Results and discussions

It is well known that there are two different contributions to magnetic response of granular superconductors, namely intergranular or matrix and intragranular contribution.

In order to discriminate between the intra- and intergrain irreversibility, a.c. susceptibility measurements were performed. In Fig. 1, we display the temperature and field amplitude of the experimental AC susceptibility curves χ' (T,H_{ac}) and χ'' (T,H_{ac}) measured on our (Bi,Pb):2223 samples with x=0.0; 0.02 and 0.05 Fe .

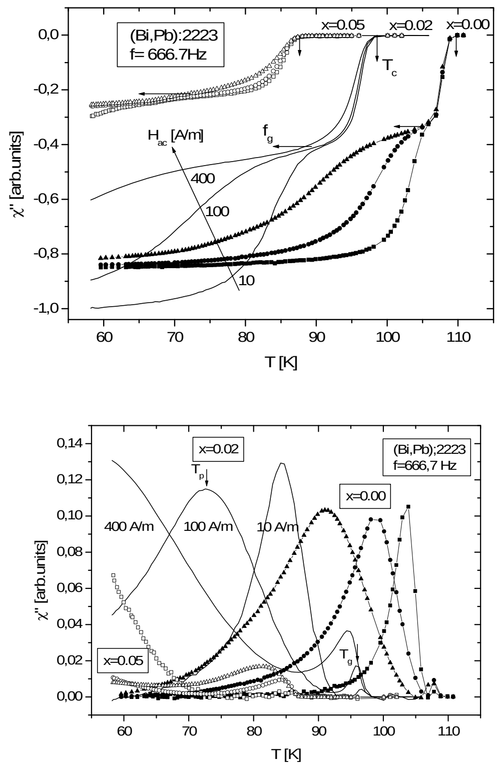

Fig.1.Real part $\chi'(T)$ and immaginary part $\chi''(T)$ at H_{ac}=10, 100 and 400 A/m amplitudes, for undoped (x=0.00),and Fe doped samples (x=0.02;0.05.

The curves of χ' vs.T shows two step process which reflects the shielding of flux from and between the grains, as T decreases. The vertical arrow shows critical transition temperature .When the samples are just below T_c, the superconducting grains first shield the applied magnetic field. The superconducting transition temperature T_c decrease by increasing x (Table 1) and the intragranular transition width increase. The end of the intragranular transition (shown by horizontal arrow in figure 1) is a measure for the volume fraction of the grains f_g.By decreasing temperature, intergranular component of χ' appears. For x=0.00, and for amplitudes of AC applied field up to H_{ac} = 600 A/m, below 70 K, the curve $\chi'(T)$ saturates and the volume of sample is expected to be shielded by the supercurrent circulating around the sample along the grains and through the matrix.For sample with x=0.02 Fe the saturation appear only for lower values of H_{ac} , and in x=0.05 sample the saturation is absent for all H_{ac} values up to 600 A/m.

Two peaks in the temperature dependence of the immaginary part $\chi''(T)$ of the complex AC susceptibility reflecting the inter- and intragranular losses in ceramic superconductor can be distinguished in figure 1. The first peak appears at a temperature T_g slightly below T_c and indicate a maximum hysteresis loss for the motion of intragranular Abrikosov vortices inside the superconducting grains. The second large loss peak appears at a temperature T_p lower than T_g , and is caused by the motion of intergranular (Josephson) vortices. The intragranular loss peak centred at T_g is shifted to lower temperature and broadens by increasing x and H_{ac}.This result shows that the partial substitution of Cu by Fe increases the intragranular dissipation processes. To separate the intra- and intergrain contribution, one has to know the effective volume fraction of the grains f_g. Method of calculations for f_g is reported by several workers, see for example Refs.[9-12]. In reference [12] the experimental AC susceptibility data $\chi''(T)$ and $\chi'(T)$ were normalized to the $/\chi'_{min}/$ at the lowest temperature and the lowest field amplitude for each sample. Applying the same procedure in fig.2, we obtained that the values of f_g for x=0.00 and x=0.02 samples (see Table 1) are in good agreement by the f_g values estimated at the end of intragranular transition in $\chi'(T)$ curves (horizontal arrow in Fig.1). This procedure lead for x = 0.05 sample to a value f_g = - 0.65, which is larger comparatively to f_g = - 0.2 value estimated from Fig.1. The procedure from Fig.2 no work for this sample because of the very large intragranular transition, and the absence of intergranular peak (which suggest very weak links between grains). It should be noted that the f_g value slightly increase by increasing x to 0.02 Fe.

Table 1. List of some superconducting parameters for (Bi,Pb):2223 sample, for H_{ac} = 100 A/m.

Sample	T_c [K]	T_p [K]	$-f_g$	$\chi''_{m\,max}$ [a.u]	$-\chi'_m(T_p)$ [a.u.]
x=0.00	109.5	98.8	0.38	0.215	0.35
x=0.02 Fe	98.7	72.4	0.42	0,198	0.39
x=0.05 Fe	89	-	0.20	-	-

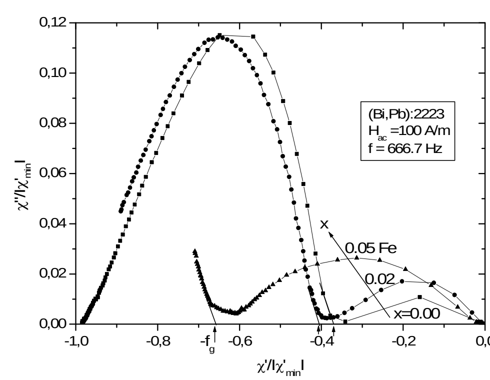

Fig.2. Plot of immaginary $\chi''(T)$ vs. real $\chi'(T)$ components (normalized to the $/\chi'_{min}/$). The arrows shows the values of f_g for all samples.

The experimental matrix susceptibilities χ'_m and χ''_m can be extracted from the measured susceptibilities employing the following equations [13]:

$$\chi'' = (1 - f_g)\chi''_m$$

$$\chi' = -f_g + (1 - f_g)\chi'_m$$

We have calculated $\chi''_{m,\ max}$ and $\chi'_m(T_p)$ in H_{ac} =100A/m and tabulated in Table 1 for x=0.00 and x=0.02 samples). For the samples of cylinder shape, according to the Bean model [14], the theoretical value of χ''_{max} is equal to 0.212 and the corresponding value of χ' is -0.333.Our values χ''_{max} and $\chi'_m(T_p)$ tabulated in Table 1 differ slightly from theoretical values, and we concluded that all the samples can be treated in the framework of the Bean model.

Fig.4.shows the imaginary part of the experimental AC susceptibility at 60K, χ'_{60}, as a function of field amplitude for x=0.00 and x=0.02 samples.

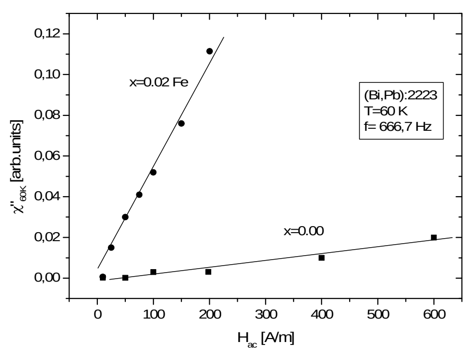

Fig.4.Immaginary part of experimental AC susceptibility at 60K at a function of field amplitude.

The linear dependence of χ''_{60} vs. H_{ac} is in agreement by the result obtained for infinite slab when H_{ac} is less than the full penetration field H*:

$$\chi'' = \frac{2}{3\pi}\frac{H_m}{H^*}$$

The slope of the straight lines in Fig.4 is inversely proportional to the full penetration depth, hence the critical current density ($H^* = j_{cm} R$).

According to this result, the critical current density decreases with increases x and the irreversibility intergranular processes is strongly influenced by partial substitution of Cu by Fe.

4. Conclusions

The partial substitution of Cu by Fe (x=0.00;0.02;0.05) in $(Bi_{1.92}Pb_{0.44})Sr_2Ca_2(Cu_{1-x}Fe_x)_{3.2}O_y$ bulk superconductor was performed.

The effective volume fractions of the grains f_g is influenced by x.

The experimental matrix susceptibilities values $\chi''_{m,\ max}$ and $\chi'_m(T_p$) extracted from the measured χ''(T)and χ'(T) differ slightly from theoretical values, and we concluded that x=0.00 and x=0.02 samples can be treated in the framework of the Bean model.

The slope for the linear dependence of χ''_{60} vs. H_{ac} shows that critical current density decreases by incrasing x, and irreversibility for intergranular processes is strongly influenced by partial substitution of Cu by Fe..

Acknowledgments

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