The Influence of Structural Inhomogeneities on Intragranular Properties of Y- and Bi-based Superconductors

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Abstract

The measurements of temperature dependence of AC magnetic susceptibility were used to study the influence of inhomogeneities on intragranular superconducting properties of $YBa_2Cu_{3−x}M_xO_Y$ (M=Fe, X=0.005;Al, X=0.01;Cr, X=0.01), $Bi_{1.7} Pb_{0.2}Sr_{0.1}Ca_2Cu_3O_Y$ and $Bi_{1.5} Pb_{0.3}Sr_{0.2}Ca_2Cu_3O_Y$ ceramics. It is found that step-like regions are revealed on AC magnetic field dependence curves $T^2_m(h_0)$ of hysterisis losses peak temperature for superconducting granuls. The steps at temperature scale depend on sample’s composition as well as on the type of atoms substituted for the copper. They range from 1 to 2 K for Y-based and about 5 K for Bi-based samples.

Possible interpretation of the obtained results is presented.
1 Introduction

The dependence of critical parameters of high-temperature superconductors (HTSCs) as a function of external influence is of great interest. Particularly, the nature of this dependence is due to the existence of structural inhomogeneities in HTSCs and the knowledge of their origins promotes to elucidate the mechanism of high-temperature superconductivity.

By now, there are several works, where the influence of inhomogeneities on critical parameters of Y-based and Bi-based HTSCs was studied by using different measurements [1-4]. In refs. [1, 3, 4] the influence of inhomogeneities on the ordering parameters was studied in superconducting ceramics, films and single crystals by measuring of the electroresistivity, above the critical temperature $T_c$.

It is worth to note, that the irradiation of HTSCs by high energy particles affects the structural inhomogeneities inside the granules. It was shown in ref. [5] that for ceramic $YBa_2Cu_{2.99}Na_{0.01}O_Y$ samples, irradiated by 8 MeV electrons with doses from $10^{14}$ to $2 \times 10^{18} \text{ e/cm}^2$, step-like regions appeared on the initial AC magnetic field dependence curve of intragranular hysteresis losses peak temperature $T_{m}^{g}$, while in [6] these regions disappeared after electron irradiation of Y-based ceramics.

In this work we have shown the existence of structural inhomogeneities in $YBa_2Cu_{3-\chi}M_\chi O_Y$ (M=Fe, X=0,005; Al, X=0,01; Cr, X=0,01), $Bi_{1.7}Pb_{0.2}Sr_{0.1}$ $Sr_2Ca_2Cu_3O_Y$ and $Bi_{1.5}Pb_{0.3}Sr_{0.2}Sr_2Ca_2Cu_3O_Y$ compounds and that their effect on the magnetic properties is due to sample’s composition.

2 Results and discussion

AC magnetic susceptibility measurements were performed by means of a equipment, the details of which were presented in refs. [7, 8]. The temperature $T$ of the samples ranges from 78 to 100 K for Y-based and from 78 to 120 K for Bi-based samples.

$YBa_2Cu_{3-\chi}M_\chi O_Y$ (M=Fe, X=0,005; Al, X=0,01; Cr, X=0,01), $Bi_{1.7}Pb_{0.2}Sr_{0.1}$ $Sr_2Ca_2Cu_3O_Y$ and $Bi_{1.5}Pb_{0.3}Sr_{0.2}Sr_2Ca_2Cu_3O_Y$ superconducting samples were prepared by the conventional solid state reaction technique. Subsequently, they will be referred to as Y-Fe, Y-Al, Y-Cr, B1 and B2, respectively (see the table). The samples had cylindrical form. The values of the bulk
density, onset of superconducting transition temperature $T_{c}^{on}$ and decreasing rate $|dT_{m}^{g}/dh_{0}|$ (detected for initial low magnetic field in the linear dependence region) for the samples are presented in the table. The temperature of samples was detected within ± 0.1 K by measuring a copper wire resistance. We have determined by examining $T_{c}^{on}$ the higher temperature inflection point of the $\chi'(T)$ curve for AC magnetic field amplitude $h_{0} = 10$ mOe (fig.1, curve c), while $T_{m}^{g}$ was obtained from the position of the higher temperature peak of the imaginary part of magnetic susceptibility $\chi''(T)$ (fig.1, curves a and b; fig.2). We have chosen the frequency of applied AC magnetic field to be 1 kHz, with the amplitude $h_{0}$ varying in the range from 10 mOe to 30 Oe.

$T_{m}^{g}(h_{0})$ curves for Bi-based and Y-based samples are plotted in figs. 3 and 4, respectively. As it is seen from fig.3, there is a linearly decreasing region on the $T_{m}^{g}(h_{0})$ curves for relatively low fields in Bi-based samples. However, the length of this region is different depending on the sample doping. It is known, that the value of $|T_{m}^{g}/dh_{0}|$ characterizes the pinning force for the Abrikosov magnetic vortices penetrating into the grains [9]. The pinning force is lower for higher values of decreasing rate $|T_{m}^{g}/dh_{0}|$.

In all samples, with increasing the magnetic field from some critical value $h_{0}$, a transformation process of $T_{m}^{g}(h_{0})$ curve occurs, which is accompanied by appearance of steps with different heights and widths. For Bi-based samples this phenomenon is relatively greater than that of in Y-based ones. Numerous investigations showed that Bi-based samples are more sensitive to external influences than Y-based ones. The reason of such a behaviour is that Bi-based compounds have more complicated structure and hence contain relatively greater concentration of structural defects. It is known that in HTSCs the CuO planes are responsible for superconductivity [10]. The number of these

| #  | Sample | Content | $T_{c}^{on}$, K ($h_{0}=10$ mOe) | $\rho$, $\rho/\text{cm}^{3}$ | $|dT_{m}^{g}/dh_{0}|$, K/Oe |
|----|--------|---------|------------------|----------------|------------------|
| 1  | Y-Fe   | YBa$_{2}$Cu$_{2.95}$Fe$_{0.05}$O$_{Y}$ | 91.3          | 4.71            | 0.3              |
| 2  | Y-Al   | YBa$_{2}$Cu$_{2.99}$Al$_{0.01}$O$_{Y}$ | 91.25         | 3.78            | 0.1              |
| 3  | Y-Cr   | YBa$_{2}$Cu$_{2.99}$Al$_{0.01}$O$_{Y}$ | 91.85         | 3.85            | 0.25             |
| 4  | B1     | Bi$_{1.7}$Pb$_{0.2}$Sr$_{0.1}$Ca$_{2}$Cu$_{2}$O$_{Y}$ | 108.0         | 3.03            | 0.35             |
| 5  | B2     | Bi$_{1.5}$Pb$_{0.3}$Sr$_{0.2}$Ca$_{2}$Cu$_{2}$O$_{Y}$ | 106.5         | 2.68            | 0.2              |

Table 1: Some initial critical parameters for samples
planes in a unit cell of Bi-based compounds reaches up to three, and even the lowest amount of defects induced in there may result in strong variations of the critical temperature. This probably causes relatively higher steps on $T_{m}^g(h_0)$ curves for B1 and B2 samples as compared with those for Y-based ones.

It should be noted that the substitution of Bi by Pb and Sb leads to the stabilization of $Bi_2Sr_2Cu_2O_8\cdot Y$ (2223) samples [11]. As it is seen from fig. 1, c the B2 sample with higher content of Pb and Sb at relatively low temperature has greater diamagnetism, and the superconducting transition curve $\chi'(T)$ is sharpen than that of for B1. At the same time, the peaks on the $\chi''(T)$ curve for B2 sample become narrower too. Such a behaviour of AC susceptibility indicates that the addition of Pb and Sb impurities increases the homogeneity of the samples [12]. This can be seen also from fig. 3 where the initial slope of $T_{m}^g(h_0)$ curve decreases with increasing the concentration of Pb- and Sb- doping. The latter means an increase of the pinning force for the Abrikosov vortices. Such a behaviour coincides with ref. [11], where the Pb and Sb doping leads to the increase of 2223 phase fraction in the sample and results in the stabilization of it’s magnetic properties.

It is known that a superconducting granule has a complex structure, as well as critical parameters close to those for single crystals [12]. The detailed investigation of intragranular structure of Y-based samples was performed in [13] by means of scanning electron microscopy. These results suggested that the granules have polyedric forms with an average size of a several microns. The porosity is the main feature of granules. Besides the structural defects, as well as the nonsuperconducting $Y_2BaCuO_5$ phase and the majority of amorphous phase are mainly concentrated in subsurface layer of granule. It was suggested in [14] that during the sintering of Bi-based samples firstly a low temperature $Bi_2Sr_2CaCu_2O_8\cdot Y$ (2212) phase is formed, which is further wrapped by a layer of 2223 with higher critical temperature. In B1 sample the slope of $T_{m}^g(h_0)$ for $h_0$ up to 15 Oe is due to the pinning force of the Abrikosov vortices penetrating into the 2223 layer, while for higher values of $h_0$ this slope may be attributed to the motion of vortices through the layer consisting of 2212 phase inside the granule. The latter phase is more sensitive to the application of a magnetic fields and an inflection point on $T_{m}^g(h_0)$ curve is observed near the $h_0 = 15$ Oe. As the Pb- and Sb- doping increases the 2223 phase fraction, the B2 sample becomes more stable in respect to a magnetic field which is partially manifested in a shift of the
corresponding inflection point on the \( T^g_m(h_0) \) curve from 15 to the 25 Oe. Besides, for B2 sample higher \( T^g_m \) values are observed in magnetic field \( 17 \leq h_0 \leq 28 \) Oe region in compared with the B1 sample. The structure of the subsurface layer of granule, indeed, varies depending on sample’s content. This leads to the formation of layers around the granule with different values of critical parameters, which cause the observed step-like regions on \( T^g_m(h_0) \) curves.

Fig. 4 shows that for Y-Fe sample the number and forms of steps on \( T^g_m(h_0) \) curve differ from those for other samples. This difference may be due to the relatively higher bulk density of Y-Fe sample (see the table), which results in the oxygen deficiency of the compound. The latter make the influence of microinhomogeneities caused by the Fe doping on the sample’s superconducting properties more expressed [15]. This confirmation is supported by fig. 2, which shows, that for Y-Fe sample (curve a) the inhomogeneity is the highest, because it’s \( \chi''(T) \) peak is the most broaden [12]. It is not ruled out that the above mentioned difference might be also due to the induced several oxygen environments of Fe, substituted for Cu atoms (see ref. [8] and references therein).

It was shown [6], that the observed minima on the initial \( T^g_m(h_0) \) curves for \( YBa_2Cu_3O_{Y} \), \( YBa_2Cu_{2.99}Fe_{0.01}O_Y \) and \( YBa_2Cu_{2.99}Ni_{0.01}O_Y \) samples disappeared after irradiation by 8 MeV electrons with dose \( 2 \times 10^{16} \) e/cm\(^2\). One of the reasons of the observed phenomenon is that the electron irradiation can redistribute the initial structural defects in sample and create new ones, leading to the variation of crystalline lattice ordering. This is consistent with the result that the electron irradiation induces the uniform distribution of structural defects in a sample [10].

### 3 Conclusions

From the above mentioned we can conclude that the appearance of the steps on the \( T^g_m(h_0) \) curves may be attributed to the existence of different structural defects in granules, which can act as a flux pinning centers with definite pinning force values. These centers are responsible for the penetration of the Abrikosov vortices into the granules. The existence of ”weak” and ”strong” pinning centers is due to inhomogeneous distribution of the structural defects, and their coexistence leads to the inhomogeneous penetration of magnetic
fields into the granule. This causes the formation of the step-like regions on $T_m^g(h_0)$ curves. The effect is better expressed in Bi-based samples than in Y-based ones. This difference may be explained by relatively complex structure of Bi-based samples. The step-like behaviour of $T_m^g(h_0)$ curve for the Y-Fe sample is distinctly expressed among the Y-based samples. Such a behaviour may be due to the relatively higher content of defects, created by the oxygen deficiency because of the higher bulk density of the Y-Fe sample.

Further structural measurements are needed for exact interpretations of obtained results.

References

[1] J. Maza and Felix Vidal, Phys. Rev. B, 43, #13 (1991).
[2] A. Kapitulnik and G. Deutcher, J. Phys. A, 16, L255 (1983).
[3] J. A. Veira and F. Vidal, Physica C, 159, 468 (1989).
[4] J. A. Veira, G. Domarco, J. Mara, F. Migueler, C. Torron and F. Vidal, Physica C, 162-164, 375 (1989).
[5] S. K. Nikogosyan, A. A. Sahakyan, G. N. Yeritsyan, A. G. Sarkisian and V. M. Aroutiounian, J. Contemporary Physics (Armenian Academy of Sciences), 29, #6, 26 (1994).
[6] S. K. Nikogosyan, A. A. Sahakyan, Y. Keheyan, H. N. Yeritsyan, V. A. Grigoryan, to be published.
[7] A. A. Sahakyan, G. N. Yeritsian, A. S. Oganesyan, S. K. Nikogosyan, Preprint YerPhi-1201(78) - 89 (Russian).
[8] S. K. Nikogosyan, A. A. Sahakyan, H. N. Yeritsyan, V. A. Grigoryan, E. G. Zargaryan, A. G. Sarkissyan, Physica C, 299, #1-2, 65 (1998).
[9] K. -H. Müller, Physica C, 159, 717 (1989).
[10] F. Rullier-Albenque, A. Legris, H. Berger, L. Forro, Physica C, 254, 88 (1995).
[11] J. Bartolome, F. Lera, R. Navarro, C. Rillo J. M. Gonzalez-Calbet, J. Ramirez, M. Vallet, M. Carrera, J. Fontcuberta, X. Granados, X. Obradors and F. Perez, Physica C, 162 -164, 863 (1989).

[12] B. Loegel, D. Bolmont, H. Dalderop and A. Mehdoui, Sol. State Commun., 78, #2, 621 (1991).

[13] V. G. Pushin, V. V. Sagaradze, E. N. Frizen, Superconductivity: Phys., Chem., Tech., 3, #10, 2041 (1990).

[14] V. E. Gasumyants, S. A. Kazmin, V. I. Kaidanov, S. A. Likov, V. A. Poliakov, S. E. Khabarov, Superconductivity: Phys., Chem., Tech., 4, #3, 586 (1991).

[15] S. K. Nikogosyan, A. A. Sahakyan, H. N. Yeritsyan, V. A. Grigoryan, Preprint YerPhi-1518(18)-98, Report-no cond-mat/9808086.
Figure 1: The temperature dependence of real $\chi'$ (c) and imaginary $\chi''$ (a,b) parts of AC magnetic susceptibility for samples B1 (a) and B2 (b). a) sample B1; at applied values of $h_0$(Oe): 1- 5; 2 - 15; 3 - 30. b) sample B2; at applied values of $h_0$(Oe): 1- 5; 2 - 15; 3 - 30. c) 1 - B1 sample ; 2 - B2 sample ; for $h_0 = 10$ mOe.
Figure 2: The temperature dependence of imaginary $\chi''$ part of AC magnetic susceptibility.  

a) sample Y-Fe; at applied values of $h_0(Oe)$: 1 - 1.5; 2 - 10; 3 - 30. 

b) sample Y-Al; at applied values of $h_0(Oe)$: 1 - 1; 2 - 10; 3 - 30. 

c) sample Y-Cr; at applied values of $h_0(Oe)$: 1 - 1; 2 - 10; 3 - 30.
Figure 3: The intragranular hysteresis losses peak temperature $T_{gm}^2$ versus AC magnetic field amplitude $h_0$ for B1 (curve 1) and B2 (curve 2) samples.
Figure 4: The intragranular hysteresis losses peak temperature $T_m^g$ versus AC magnetic field amplitude $h_0$ for Y-Cr (curve 1), Y-Al (curve 2) and Y-Fe (curve 3) samples.