The influence of partial substitution of Ca by Sm on
dissipation processes in (Bi_{1.6}Pb_{0.4})(Sr_{1.8}Ba_{0.2})(Ca_{1-x}Sm_{x})_{2}Cu_{3}O_{y}
superconductor

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Abstract. Superconducting polycrystalline samples (Bi\textsubscript{1.6}Pb\textsubscript{0.4})(Sr\textsubscript{1.8}Ba\textsubscript{0.2})(Ca\textsubscript{1-x}Sm\textsubscript{x})\textsubscript{2}Cu\textsubscript{3}O\textsubscript{y}
with 0\leq x \leq0.05 were prepared by the conventional solid-state reaction. X-ray diffraction
measurements showed the influence of Sm concentration on the phase purity of samples. The
influence of partial substitution of Ca by Sm on the normal state properties and the flux
dynamics were investigated by electrical resistance versus temperature and systematic a.c.
susceptibility measurements function of temperature and $H_{ac}$ field amplitude. The evolution of
some parameters sensitive to Sm concentration were evaluated from resistivity data and a.c.
susceptibility data. The influence of Sm on the intergranular pinning force density was
discussed by using Muller critical state model for experimental linear dependence of $T_{p}$ for
maximum of imaginary $\chi''(T)$ peak as a function of $H_{ac}$.

1. Introduction
Substitution of various elements into Bi: 2223 high temperature superconductor was experimented to
obtain superconductors with higher critical temperatures and higher critical current densities.

Superconductivity of Bi: 2223 system may be directly influenced for substitution in the CuO\textsubscript{2} plane
itself, or indirectly for substitution in the Ca or Sr positions (affecting a charge transfer to or from
CuO\textsubscript{2} planes [1]). Studies of partial substitution of divalent cation Ca by trivalent cations Y or rare
earth (Re) ions in Bi: 2223 system was found to induce nanodefects which decreases the hole
concentration and affect the normal and superconducting properties [2-4]. The Sm and Yb addition on
the bulk Bi: 2212 is that the critical current density is seven times higher than that of pure sample [5].
Sm was also substituted for Ca in Bi-2223 system [6-8]. The substitution of Sm\textsuperscript{3+} (mean ionic size is
0.96 Å) for Ca\textsuperscript{2+} (mean ionic size is 0.99Å) is found to change the superconducting properties of the
Bi(Pb)SrCaCuO system. The results show that the Ca\textsuperscript{2+} substitution by Sm\textsuperscript{3+} influence the carrier
concentration, which in turn lowers the offset critical transition temperature $T_{c,off}(p=0)$ and decreases
the volume fraction of the Bi-2223 superconducting phase [2]. The reason for Tc reduction might be
due to modification of the crystallographic structure of the Bi- 2223 phase with Sm doping [8]. The
bulk (Bi,Pb):2223 material consists of grains weakly coupled at the grain boundaries by junctions or
weak links. The macroscopic critical current density $J_{c}$ is limited by the intergranular vortex pinning
force at the grain boundaries. The main purposes of the ac susceptibility studies are to investigate
intragrain and intergrain shielding, vortex pinning and vortex creep [9,10]. Two peaks in the temperature dependence of the imaginary part $\chi''(T)$ of the complex a.c. susceptibility reflecting the inter- and intragranular losses can be distinguished in bulk system (Bi,Pb)(Sr,Ba):2223 [11-12]. In this paper we report the influence of the partial substitution for Ca by Sm on the purity of samples in 2223 phase, normal state properties by using electrical resistance versus temperature, and the intergranular flux dynamics by using systematic a.c. susceptibility measurements as a function of temperature and alternative $H_{ac}$ amplitude, respectively.

2. Experimental
Polycrystalline samples with nominal composition $(Bi_{1.6}Pb_{0.4})(Sr_{1.8}Ba_{0.2})(Ca_{1-x}Sm_x)_{2}Cu_{3}O_y$ with $0 \leq x \leq 0.02$ were prepared by the conventional solid - state reaction. The partial substitution of Sr by Ba was used to induce the reduction of the modulation period [13]. Appropriate amounts of Bi$_2$O$_3$, PbO, SrCO$_3$, BaO, CaCO$_3$, Sm$_2$O$_3$ and CuO were mixed in agate mortar and calcined at 800°C for 36 hours. The calcinated powder was pressed into pellets and sintered at 8450°C for 200 hours. The pellets were grinding, pressed and resintered for 60 hours at 850°C. Cylindrical samples with diameter around $d=3$mm were cut from the sintered pellets and used for a.c. susceptibility measurements. The phase purity was determined by Brucker X-ray diffractometer with Cu-K$_{\alpha}$ radiation. The XRD analysis confirmed the presence of a majority "2223" phase with some traces of "2212" phase in the x=0.00 and x=0.01 samples. In the samples with $0.02 \leq x \leq 0.05$ the amount of "2212" phase increase from 10%vol. for x=0.02 to 80%vol. for x=0.05.

The standard four point method was used for electrical resistivity measurements in the 77K-300K temperature range. High quality electrical contacts were made by applying silver loaded paint and using golden leads.

The real ($\chi'$) and imaginary ($\chi''$) parts of the a.c. susceptibility were simultaneously collected with a Lake Shore Model 7000 a.c. susceptometer in the temperature range from 77K to 110K, by using a frequency of 1000 Hz and a.c. field amplitudes $H_{ac}$ situated in the ranges from 20 A/m to 800 A/m respectively.

3. Results and discussion
Fig.1 shows the temperature dependences of the electrical resistivity, $\rho(T)$, for the samples with 0.00$\leq x \leq 0.05$ Sm.

Above the excess conductivity region, in the 150K-290K temperature range, we assume that our samples are characterised by a linear temperature dependence of the electrical resistive:

$$\rho = \rho_0 + \alpha^*T,$$

where $\rho_0$ is the residual resistivity and $\alpha$ is the slope of resistivity in the normal state.

As shown in Fig.1, residual resistivity $\rho_0$ increases with increasing x. The increase of $\rho_0$ suggests that the number of scattering centers in the intra- and intergrain regions increase. The granular microstructure and the nature of contacts between the grains strongly influenced the residual resistivity. Structural defects and inhomogeneities force the current to meander through the cuprate enhancing the normal resistivity. The measured normal resistivity in bulk samples is related to the intrinsic resistivity in CuO$_2$ (a-b) plane of a single crystal, by the relation [14]:

$$\rho = p(\rho_{ab} + \rho_{ct}),$$

The coefficient $p$ account for a mean percolative lengthening of the conduction paths and for the mean shrinking of the current cross-section [15],

$$\rho_{ab} = \rho_{in} + \alpha_{*}T$$

is the in plane resistivity for a single crystal and $\rho_{ct}$ is associated with the contact resistance between the grains.

In our samples, the increase of $p$ suggests a gradual reduction of the transport current cross sections and the lengthening of conduction paths with increasing Er concentration. Another parameter sensitive to Ca substitution for Sm is the critical temperature for zero resistivity $T_{c}(\rho=0)$. The insert of figure 1
show the local maximum of $T_c(\rho=0)$ for $x=0.01$, and a linear decrease of $T_c(\rho=0)$ by increasing $x$. $T_c(\rho=0)$ dependence versus $x$ may be in relation by phase content and intergrain dissipation processes. In order to elucidate the above supposition, a. c. susceptibility as a function of temperature and amplitude of magnetic field were performed.

Figure 2 shows the dependences of real $\chi'(T)$ and imaginary $\chi''(T)$ susceptibilities for $x=0.00;0.01;0.02$ and $0.05$ Sm samples, by using for a. c. field an amplitude $H_{ac}=10$ A/m and a frequency $f=1000$ Hz.

With increasing temperature, the real part $\chi'(T)$ shows a two step behavior, characterizing the flux penetration in the intergranular matrix and in the grains respectively the end of the upper step (the end of the superconductor diamagnetism) corresponds to the intragrain critical temperature $T_c$. With increasing the Sm concentration the intergranular drops shift to lower temperatures. For all Sm doped samples, $\chi'(T)$ exhibit a single peak at $T_p$, which indicate the maximum hysteresis losses due to the motion of intergranal (Josephson) vortices.

In our samples $T_c$ from $\chi'(T)$ data are very close to the inflection point temperatures $T_c$ in the resistivity data and the $T_p$ temperatures are nearly the same as the $T_c(\rho=0)$. The behavior of $T_p(x)$ is similar to $T_c(\rho=0)$, and confirmed that the intergranular dissipation processes are sensitive to Sm content. The increase of $T_p$ with increasing $x$ up to $x=0.01$ Sm, suggest the increase of intergranular coupling. In order to investigate the effect for partial substitution of Ca with Sm on the intergranular pinning force, we studied the $T_p$ dependence as a function of $H_{ac}$. As can be seen from Fig. 3, we obtain for all samples a linear dependence of $T_p$ as a function of $H_{ac}$, in the a.c. amplitude range $200A/m<H_{ac}<800A/m$.

The linear fits are:

$$T_p = T_{p0} - A*H_{ac} [K]$$

where $T_{p0} = (98.5;104;98.8;82.5)$ K and the slope $A= (9.8; 6.5; 7.4; 3.7) 10^{-3}$ (Km/A), for $x = 0.00; 0.01; 0.02; 0.05$ Sm.

This linear dependence $T_p (H_{ac})$ is described in the Müller critical state model by the relation:

$$T_p = T_{p0} - T_{p0} [\mu_0\mu_{eff}(0)/(2d\alpha(0))]^{1/2}H_{ac}$$

where $d$ is the height of cylindrical sample, $\mu_{eff}(0)$ is the effective permeability of the ceramic and $\alpha(0)$ is the intergranular pinning force density. The decrease of slope $A= T_{p0} [\mu_0\mu_{eff}(0)/(2d\alpha(0))]^{1/2}$ suggest that $\alpha(0)$ increase. By using experimental values for $A$, $T_{p0}$, $d$ and $\mu_{eff}(0)$ (from $\chi'(T)$ data) we
obtain that $\alpha_J(0)$ increase by increasing $x$, but in different manner function of 2223/2212 ratio of volume phases (is larger for $x=0.05$ sample with majority Bi:2212 phase that in $x=0.02$ with majority Bi:2223 phase). For $x=0.01$ Sm we obtain in the temperature range (99-104K) an intergranular pinning force density $\alpha_J(0)$ which is 1.5 larger that in $x=0.05$ Sm sample (in the range 80K-84K).

4. Conclusions
The parameters obtained from electrical resistivity and AC magnetic susceptibility measurements function of temperature are sensitive to partial substitution of Ca by Sm in (Bi,Pb):2223 bulk superconductor.

X-ray diffraction measurements show that the volume fraction of (Bi,Pb):2212 increase with increasing Sm concentration which substitute Ca.

In normal region, above 200 K, all samples show a linear temperature dependence of electrical resistivity function of temperature. Above the concentration $x=0.01$ Sm, the increase of residual resistivity agree with the decrease of temperatures $T_c(\rho=0)$ and $T_p$.

The intergrain critical temperature $T_p$ are linear as a function of the AC field amplitude higher than 200A/m. This result agrees with Müller critical state model.

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