

Improvement of Granular Critical Current Density in Bi: 2212 Superconductors

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Authors' contributions

This work was carried out in collaboration between the authors. Author AS suggested the problem, synthesis and measuring the R-T of the samples. After that, the authors are participating together in managed the literature, data analysis and plotting, data interpretations, writing the first draft and also preparing the final manuscript for submission. Finally, the authors read and approved the final manuscript.

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ABSTRACT

We report here structural and superconducting properties of $\text{Bi}_{1.7}\text{Pb}_{0.3}\text{Sr}_2\text{Ca Y}_x\text{Cu}_2\text{O}_y$ superconductors with various x values ($x = 0.00, x = 0.15$). It is found that addition of Y^{3+} does not influence the phase purity of Bi: 2212, while lattice parameters are affected. Furthermore, the critical temperature T_c of Bi: 2212 is improved Y addition. On the other hand, the behavior of flux pinning and its impact on critical current density for pure and Y substituted samples is investigated. The magnetic hysteresis loops (MHLs) are measured over the temperature range ($4 \text{ K} \leq T \leq 75 \text{ K}$) using vibrating sample magnetometer (VSM) and at different fields up to 100000 Oe. The critical current density as a function of both temperatures and applied fields is estimated by using Beans model in terms of full width of magnetization loop ΔM . It is found that the partial substitution of Y chemical doping enhances the flux pinning in Bi: 2212 system and the critical current density is improved as well as critical temperature.

Keywords: Critical temperature; Bi: 2212; flux pinning; critical current; hysteresis loops.

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1. INTRODUCTION

For large applications of high T_c superconductors in some great fields such as energy storage system, current limiters, magnetic bearings, a large critical current density J_c is required. However, one of the most effective methods to improve J_c has directed to introduce efficient pinning centers [1-3]. The flux pinning mechanism in high T_c superconductors is a complex phenomenon, which is not yet fully understood. Beside oxygen defects, dislocations and heavy ion beam irradiation, the chemical doping can be considering an effective method to increase J_c [3-4].

BSCCO high T_c system is the most promising material for high- current applications. However, the major limitations of the Bi- system application are the inter-grain weak links and weak flux pinning capability [5]. Many efforts have been made in order to improve phase purity, grain alignment, and in turn reduce weak links in Bi: 2223/Ag tapes [6-8]. Some of chemical substitutions such as ZrO_2 nanopowders, B_2O_3 and MgO were incorporated into BSCCO compounds and resulted in a greatly enhanced J_c as compared to reference sample [9-13].

The rare-earth elements have an incomplete inner shell, different magnetic moments and different ionic radii. Therefore, they have great importance as a substitution for studying the physical properties of high T_c superconductors. The replacement of Ca^{2+} in Bi: 2223 superconducting system by rare earth elements R^{3+} has a significant effect on their normal, mechanical and superconducting properties. Interestingly, the values of T_c are gradually decreased with the increased of R^{3+} content [14-17]. It is also found that Y addition improves the connection between superconducting grains of Bi: 2212 system and superconducting properties are improved [18]. While, the opposite behavior is reported for Cd substituted at Ca sites in Bi: 2223 system [19-20]. However, recently we have shown that addition Y to Bi: 2212 improved the T_c and also increase the low field critical current density J_c deduced from the low field ac susceptibility measurements [21]. With this goal in mind, we are continuity to investigate the effect of Y addition to Bi: 2212 high T_c superconductors on the granular critical current density J_c through magnetic hysteresis loops measurements.

2. EXPERIMENTAL DETAILS

$Bi_{1.7}Pb_{0.3}Sr_2Ca Y_xCu_2O_y$ samples with various Y addition ($x = 0.00$ and $x = 0.15$), i.e. Y added to Bi: 2212. are prepared by solid-state reaction method. The ingredients Bi_2O_3 , SrO, Y_2O_3 , $CaCO_3$ and CuO of 4N purity are thoroughly mixed in required proportions and calcined at $820^\circ C$ in air for 16 h. This exercise is repeated three times with intermediate grinding at each stage. The resulting powder is reground, mixed, pressed into pellets at applied load of 6 tons. These pellets are sintered in air at $840^\circ C$ for 50 h and left in the furnace for slow cooling to room temperature. The maximum rate of heating/cooling is nearly about ($5^\circ/min$ s). The phase purity of the samples is examined by using x-ray diffractometer with Cu-K α radiation. The electrical resistivity of the samples is measured by the standard four-probe technique in closed cycle refrigerator [cryomech compressor package with cryostat Model 810-1812212, USA] within the range of 10-300 K. High quality silver paint is used for electrical contacts of the leads with the samples. Nanovoltmeter Keithley 2182, current source Keithley 6220 and temperature controller 9700 (0.001 K resolution) are used in this experiment. The magnetic hysteresis loops (MHLs) over the temperature range ($75 K \geq T \geq 4 K$) are recorded by using a computer controlled PAR- 4500/150A vibrating sample magnetometer (VSM) at different fields up to 100000 Oe. In this case, the magnetic field is applied along the plane of the sample. The temperature is measured in the range using a calibrated carbon glass resistor located near the specimen. After cooling the sample, the field is applied parallel to the c- axis and the magnetization curves are obtained.

3. RESULTS AND DISCUSSION

The obtained peaks of XRD shown in Fig. 1 could be identified with those of Bi: 2212 and Bi: 2201 phases. The moderate amount of Bi: 2212 phase already exists as a major phase, while the Bi: 2201 phase being minor. The presence of Bi: 2201 peaks like (113), (115) and (109) may be due the syntactic growth of various phases. It is interesting to note that the friction of 2201 phase is reduced by Y, indicating that Y entering into the crystal structure of Bi: 2212, and probably favors the formation of Bi: 2212 phase. It is observed that there is a contraction along the c-parameter and a simultaneous expansion along a/b axes by Y addition. This is also supported by

decreasing the orthorhombic distortion (OD), see Table 1.

The elongation of a/b - parameters is generally associated by increasing the bond length between Cu and O in the CuO_2 planes, which controls the dimension in the basal planes of the Bi: 2212 system. Contraction of c - parameter by Y addition indicates that some of Y^{3+} (1.03 Å) are replaced for Ca^{2+} (1.12 Å) at the same fold coordination. The other reason may be related to increasing of excess oxygen inserted into BiO layers of Bi:2212 system, see Table 1. Then the net positive charge in the Bi-O planes reduces, and consequently the repulsion between them is decreased. This results in the reduction of c -axis length and thereby improves the stability of Bi: 2212 phase, in agreement with the previous data [22-26].

Fig. 2 depicts the electrical resistivity as a function of temperature for $\text{Bi}_{1.7}\text{Pb}_{0.3}\text{Sr}_2\text{CaY}_x\text{Cu}_2\text{O}_y$ samples. It can be observed that the resistivity decreases almost linearly from room temperature and beyond which it turns to superconducting state at critical temperature T_c . The T_c is increased from 92 K for pure sample to 106 K by 15% of Y doping. It is interesting to note that the resistivity of the sample with $Y = 0.15$ reaching to true zero value only at low dc currents up to 2 mA, but it is gradually appears with increasing the current above 2mA. It is also noted that the substituted sample exhibit a clear metallicity, and the linear part of the ρ (T) curves has a positive slope $d\rho/dT$ as well as the undoped sample. The resistivity drop occurred in a single step implying that the samples are dominantly of single phase. The $(d\rho/dT)$ values shown in Table 1 indicate that $(d\rho/dT)$ is 0.007 for Y sample, which is

higher than that of pure sample (0.004), which indicating an improvement of metallic behavior by Y addition. Furthermore, ρ_{300} is increased by Y content, but ρ_0 is depressed by Y addition and shifted to negative value (-0.21 $\text{m}\Omega\cdot\text{cm}$). This behavior indicates that the electron scattering by impurities is also affected by Y addition

The possible reasons for improving T_c by Y additions in Bi: 2212 system as follows; the first reason implies that Y occupies the crystal structure of Bi: 2212, and decreased c -parameter. This is attributed to the fact that addition of Y leads to an increase in the oxygen which could be incorporated into the Bi-O layers, and consequently an increase in the covalence of Bi-O bonds may be obtained [27]. Furthermore, the reduction of c -parameter decreases anisotropy and improves the coupling between the CuO_2 planes, and consequently T_c is improved.

The magnetization curves of the samples at different fields (0-80000 Oe) and different temperatures (4- 65 K) are shown in see above. Fig. 3 (a, b). The critical current density J_c is extracted from the measured MHLs and shown in Fig. 4. (a, b) by using the following extended Benn's' critical state model expression [28];

$$J_c = \frac{20\Delta M}{a(1 - \frac{a}{3b})} \cong 10^6 \Delta M \quad (1)$$

where a , b ($a \leq b$) are the cross-sectional dimensions of the sample perpendicular to the applied field in cm . ΔM is the full width of the magnetization loop in between ascending and descending branches.

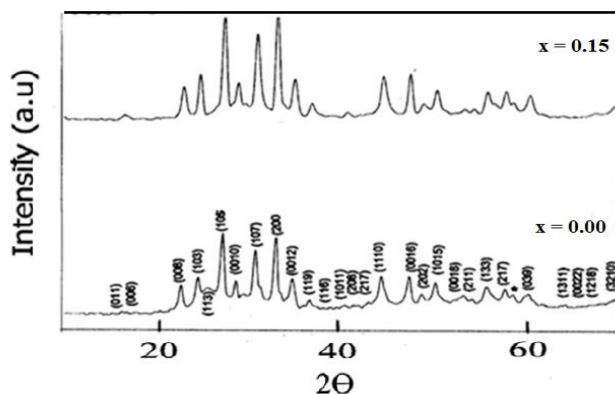


Fig. 1. X-ray diffraction of pure and Y substituted samples

Table 1. a, b and c, orthorhombic distortion, oxygen content, T_c , dp/dT , ρ_0 and ρ_{300} for pure and Y samples

Y cont.	a Å	b Å	c Å	(b-a)/b	Y	T_c (K)	dp/dT (mΩ.cm) / K	ρ_0 (mΩ.cm)	ρ_{300} (mΩ.cm)
0.00	5.384	5.395	30.815	0.0020	8.03	92	0.004	0.054	1.14
0.15	5.407	5.400	30.779	0.0013	8.12	106	0.007	-0.21	2.05

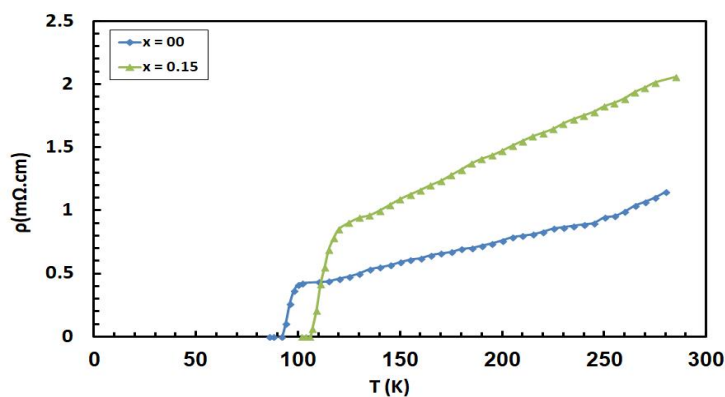


Fig. 2. Resistivity versus temperature for pure and Y substituted samples

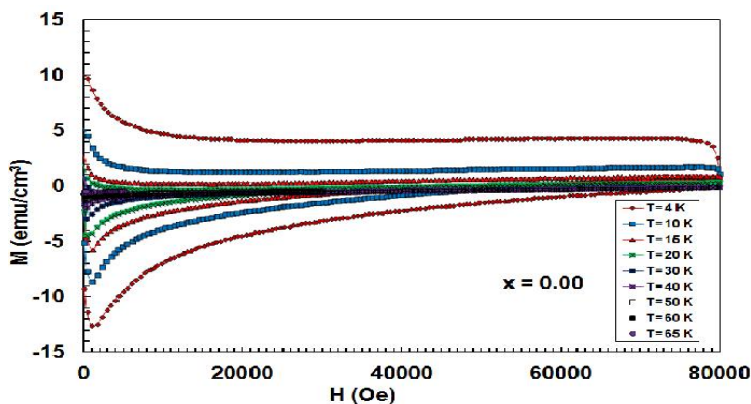


Fig. 3(a). Magnetization curves of the pure sample

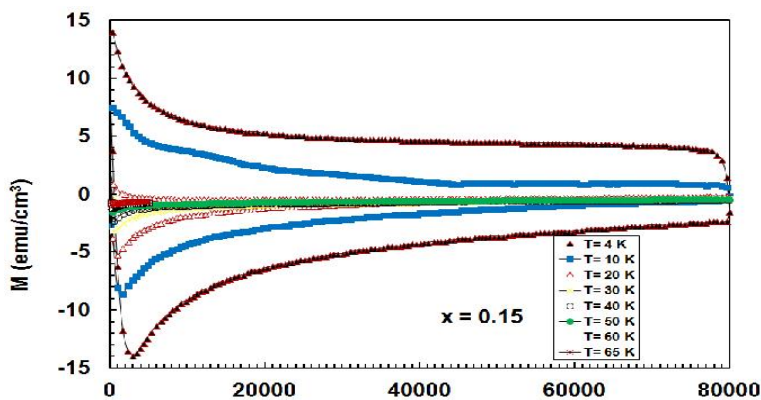


Fig. 3(b). Magnetization curves of the Y substituted sample

It is found that the critical current density increases as the field increases up to 8000 Oe for both samples. But it is slightly higher for Y doped samples as compared to pure. For simplicity, the J_c at 0K is improved by Y addition, only at low temperature up to 20 K, as shown in Fig. 5. 20 K, the J_c at 0K is almost the same for the two samples. This can be understood that Ca is replaced by Y, and may be the precipitated

Y and Ca ions react with Bi and Cu ions to form a secondary phases rich in Cu. These secondary phases may lead to the formation of different kinds of structural point like defects in the order of nanoscale which are very rich by superconducting volume fraction. These points acts as vortex pinning centers and can increase the critical current density J_c [24-26,29].

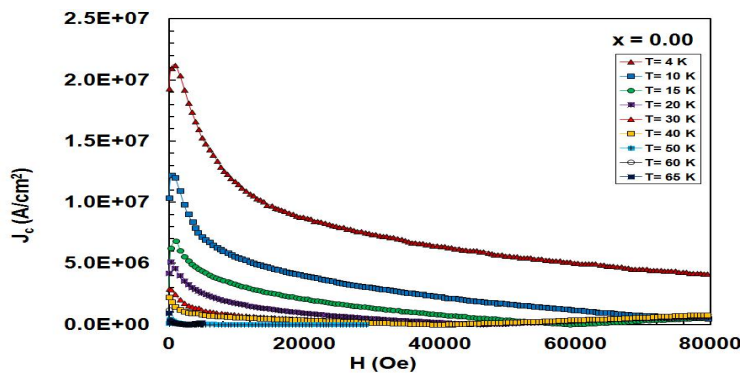


Fig. 4(a). J_c versus magnetic field for pure sample

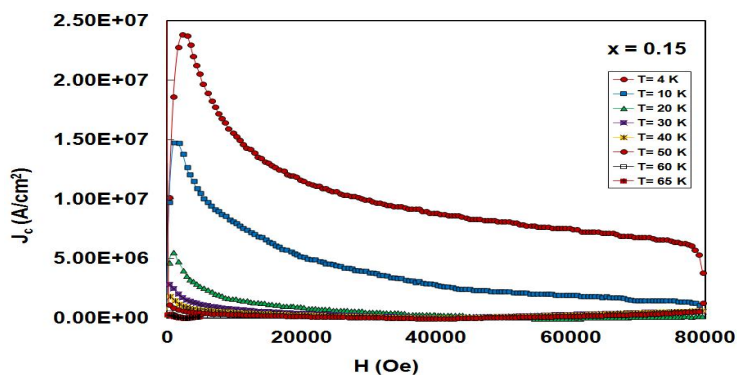


Fig. 4(b). J_c versus magnetic field for Y substituted sample

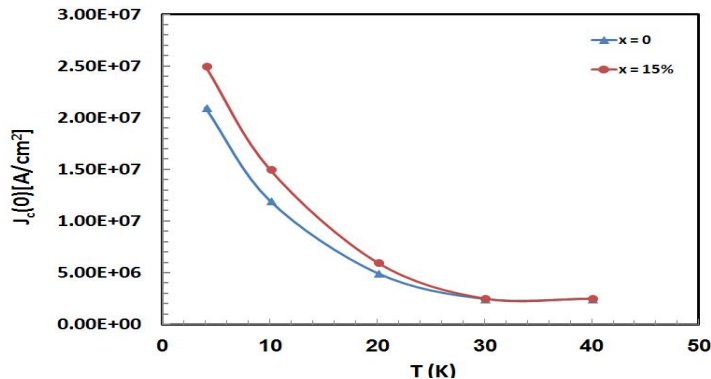


Fig. 5. J_c versus magnetic field for Y substituted sample

The alternative reason is brought by Y^{3+} addition to Bi:2212 system, and leads to electronic or chemical in-homogeneity in the charge reservoir layer (BiO/SrO), and supplies the charge carriers to the CuO_2 planes through which the actual super-current is believed to flow refers [22,25-26]. In the light of these observations, one can say that the change of excess oxygen, and carrier concentration, which are produced by Y addition in Bi: 2212 system, are responsible for reducing the path of current flow in the superconducting system, and eventually the superconductivity is improved.

4. CONCLUSION

Structural and superconducting properties of $Bi_{1.7}Pb_{0.3}Sr_2CaY_xCu_3O_y$ superconductors with various x values are investigated. We have shown that addition of Y^{3+} improved T_c of Bi: 2212. On the other hand, the partial substitution of Y enhances the flux pinning in Bi: 2212 system and the critical current density is improved as well as critical temperature. It is supposed that addition of Y, in Bi: 2212 system may be responsible for reducing the path of current flow in the superconducting system, and eventually the superconductivity is improved.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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