

The Effects of Nanoparticle Addition in Bi-2212 Superconductors

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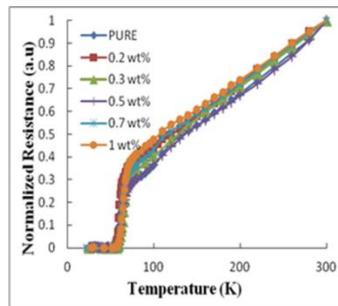
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Graphical abstract



Abstract

The effect of Y_2O_3 nanoparticle addition on the superconducting properties of $Bi_{1.6}Pb_{0.4}Sr_2CaCu_2O_y$ have been investigated. The samples were prepared using high purity oxide powders via solid state reaction method. Y_2O_3 nanoparticle with 0.0-1.0 wt. % was systematically added to the well balanced $Bi_{1.6}Pb_{0.4}Sr_2CaCu_2O_y$ before sinter in order to trace the existense of nanoparticle addition in the system. The samples were characterized by X-ray diffraction (XRD), scanning electron microscopy (SEM) and critical current density, J_c . The current density measurement was done via four-point probe method under zero magnetic fields. The critical current density, J_c and superconductivity transition temperature, T_c for sample with addition of Y_2O_3 nanoparticle were found to be higher than the pure sample. The optimal addition of Y_2O_3 nanoparticle to the sample Bi-2212 system was found at 0.7 wt. %. The crystallographic structure of all samples was evidenced to be orthorhombic where $a \neq b \neq c$. Changes in superconducting properties of Y_2O_3 nanoparticle added Bi-2212 system were discussed.

Keywords: Nanoparticles; BSCCO superconductor; solid state reaction; critical temperature; Y_2O_3

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1.0 INTRODUCTION AND BACKGROUND

Since the discovery of high superconducting temperature in Bi-Sr-Ca-Cu-O, this compound has been extensively studied [1]. With the general formula of $Bi_2Sr_2Ca_{n-1}Cu_nO_{2n+4+\delta}$, this system has three different phases, which are Bi-2201 ($n=1$), Bi-2212 ($n=2$) and Bi-2223 ($n=3$). BSCCO superconductors can be viewed as potential characteristic of a practical application in the current transport. In fact there are many reports indicating that the chemical addition actually enhanced the pinning force for BSCCO [2-7]. The critical current density, J_c is a crucial parameter of high temperature superconductor for a variety of possible applications [8]. Transport critical current density, J_c is the maximum current density that can flow before the material turns normal. The temperature dependencies of the critical current density may provide important information for identifying the flux pinning mechanism.

The behavior of the superconductor critical current density in applied magnetic field was found to be increased when nanoparticles were added in the sample [9], which can be attributed to the presence of the flux pinning centers. By pinning the flux line effectively, vortex movement can be prevented. Hence, the critical current density is increased. A strong

interaction between flux line network and magnetic texture can be expected if the magnetic impurities have the same order magnitude with the flux line network. By adding nanoparticles as pinning centers, critical current density of superconductors can be enhanced [10]. Magnetic impurities like $Y-Fe_2O_3$, Fe_3O_4 and $NiFe_2O_4$ have been employed to superconductors Bi-Sr-Ca-Cu-O and MgB_2 to enhance its transport critical current density [11-13].

In this paper, Y_2O_3 nanoparticle is introduced as flux pinning centers to enhance the transport critical current density of BSCCO. The superconducting properties and transport properties of superconductors Bi (Pb)-2212 with addition of Y_2O_3 nanoparticle were studied.

2.0 RESEARCH METHODOLOGY

Precursor powders with nominal 2212 composition such as $Bi_{1.6}Pb_{0.4}Sr_2CaCu_2O_y$ were prepared via solid state reaction method using high purity powders of Bi_2O_3 , PbO , $SrCO_3$, $CaCO_3$, and CuO (each at least 99.9% purity). The powders were weighed using digital balance and mixed it all together. Then, the powders were milled together with an absolute ethanol in alumina pot for 24 hours and dried out in the oven at $120^\circ C$ for 6 hours. The

mixed oxide powders were calcined and ground using mortar and pestle twice at 800°C and 820°C for 15 hours respectively. Then, the calcined powders were ground and added with 0.2-1.0 wt. % of Y_2O_3 nanoparticle before being pressed into pellets using 30MPa pressure. The pellets were sintered at 850°C for 50 hours. Pure BSCCO pellet was prepared for comparison. The resistivity and electrical properties of samples were measured by using the four-point probe method.

3.0 RESULTS AND DISCUSSION

The electrical resistivity was performed to investigate the effect of Y_2O_3 nanoparticle addition on the superconducting properties of $Bi_{1.6}Pb_{0.4}Sr_2CaCu_2O_y$ samples. The normalized resistances at room temperature as a function of temperature between 25 K and 300 K with various wt. % addition of Y_2O_3 nanoparticle to Bi-2212 powders are shown in Figure 1. The curve indicated a normal metallic behavior for all the samples at normal state with a single step of superconducting transition. Table 1 shows the critical temperature, T_c and the critical current density, J_c for all samples. From the result obtained, the critical temperature, T_c increase but the critical current density, J_c decrease with increasing the amount of Y_2O_3 nanoparticle. The sample with addition 0.7 wt. % of Y_2O_3 nanoparticle shows the highest $T_{c\ zero}$ at 60 K. This could be due to the optimum numbers of Y_2O_3 nanoparticle at the grain boundaries to improve grain connectivity [14].

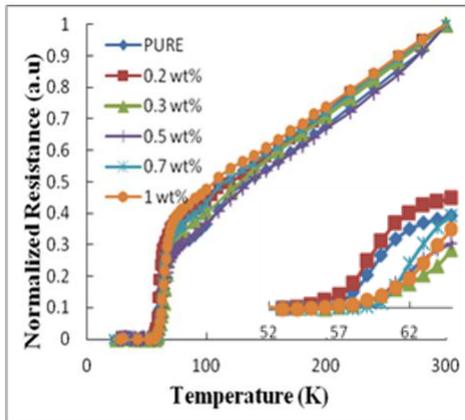


Figure 1 Normalized resistance at room temperature as the function of temperature

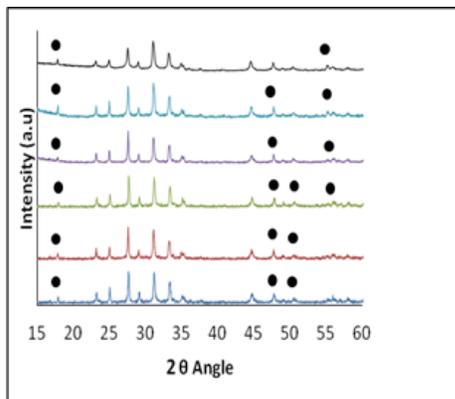


Figure 2 XRD pattern of the samples (the peaks indexed● represent Bi-2223)

Figure 2 shows the X-ray diffraction patterns of $Bi_{1.6}Pb_{0.4}Sr_2CaCu_2O_y$ added with different amount of Y_2O_3 nanoparticle. The major phases detected are Bi-2212 and Bi-2223. Y_2O_3 nanoparticle addition does not lead to the variation in crystal structure due to small amount of Y_2O_3 nanoparticle does not enter the BSCCO crystal structure. No peaks belong to Y_2O_3 nanoparticle were found in the XRD pattern as the amount of addition is very low and it was incorporated into the crystal structure. The volume fractions of the Bi-2212 and Bi-2223 phases were determined from the peak intensities using the following expression [15]:

$$Bi - 2212(\%) = \frac{\sum I_{2212}}{\sum I_{2223} + \sum I_{2212}} \times 100\% \quad (1)$$

$$Bi - 2223(\%) = \frac{\sum I_{2223}}{\sum I_{2223} + \sum I_{2212}} \times 100\% \quad (2)$$

The proportion of Bi-2212/Bi-2223 (%) are shown in the Table 2. The relative volume fractions of the Bi-2212/Bi-2223 phases and lattice parameters were determined from the peak intensities of the same reflections.

The basic characteristic of the structure does not change with Y_2O_3 nanoparticle addition, but the c -axis length decreases with an increase in Y_2O_3 wt. %, while a -axis and b -axis lengths increase. The decrease in the difference in lengths a and b axes also shows that the orthorhombic nature of the crystals changes with an increase in wt. %

Table 1 Critical temperature, T_c and critical current density, J_c for all samples

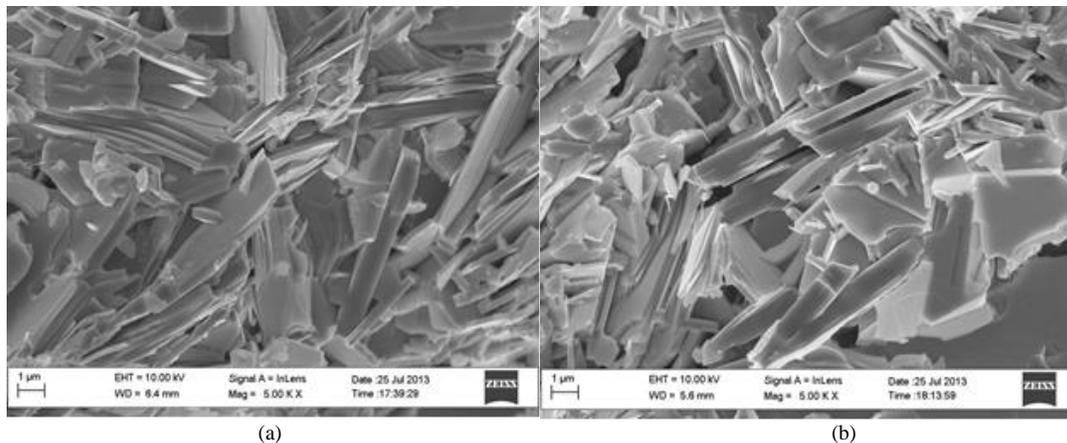
Sample (wt. %)	Critical temperature, T_c (K)			Critical current density, J_c (A/cm ²)		
	$T_{c\text{ onset}}$	$T_{c\text{ zero}}$	ΔT_c	30 K	40 K	50 K
0.0	63	57	6	4.6248	3.8087	2.237
0.2	66	56	10	2.9218	2.3162	1.5439
0.3	69	59	10	2.7024	2.0555	1.3426
0.5	71	59	12	1.2983	1.2173	0.3239
0.7	69	60	9	4.8712	3.8177	2.4479
1.0	72	58	14	2.3756	1.8588	0.8926

Table 2 Lattice parameter and relative volume fraction of the samples

Sample (wt. %)	Lattice parameter (Å)			Volume (Å ³)	Volume fraction (%)	
	a	b	c		Bi-2212	Bi-2223
0.0	5.4033	5.4889	30.8556	915.1268	87.0802	12.9198
0.2	5.3842	5.5352	30.8242	918.6401	82.8279	17.1721
0.3	5.3874	5.4155	30.8054	898.7606	85.7940	14.2061
0.5	5.3810	5.4323	30.6966	897.3017	82.3699	17.6301
0.7	5.4003	5.4046	30.8260	899.7115	85.7143	14.2857
1.0	5.3810	5.4792	30.7246	905.8722	85.3620	14.6390

The SEM surface morphology of (a) pure BSCCO and (b) addition 0.7 wt. % of Y_2O_3 nanoparticle as shown in Figure 3 was investigated. Morphology of samples from SEM revealed that the grains of pure BSCCO sample (a) were closely packed and well linked with random crystal orientation of the grain. It

is seen from figure that the sample with addition 0.7 wt. % of Y_2O_3 nanoparticle (b) gives plate like grains with some improvement to the grain alignment of samples which resulting the increase of J_c .

**Figure 3** SEM morphology (a) pure BSCCO and (b) addition 0.7 wt. % of Y_2O_3 nanoparticle.

4.0 CONCLUSION

This paper reports on the effects of Y_2O_3 nanoparticle addition on the superconducting properties of $Bi_{1.6}Pb_{0.4}Sr_2CaCu_2O_y$ superconductor that had been prepared via solid state reaction method by using high purity oxide powders. 0.0–1.0 wt. % of Y_2O_3 nanoparticle was added and the best values for T_c and J_c has been obtained from the sample with addition 0.7 wt. % of Y_2O_3 nanoparticle. By introducing nanoparticle within the structures of the samples, the value of J_c as well as T_c could be increases. The pattern of XRD shows that the addition of nanoparticle does not changes the crystallographic structure of the samples and remained in orthorhombic unit cell.

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