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THE ROLE OF ANTIMONY (Sb) ADDITION ON BSCCO SUPERCONDUCTOR

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ABSTRACT

The effect of Sb doping on 2223 phase of BSCCO system has been studied via XRD and resistance measurement to determine its crystalline structure and critical temperature, T_C respectively. Generally, all samples exhibit metallic behaviour above $T_{C\ onset}$. The value of zero resistance temperature, $T_{C(R=0)}$ decreased as the content of Sb increased except for sample x = 0.2 that shows the improvement of $T_{C(R=0)}$ by 4 K. This value was compared to that of the pure sample (Sb-free). The Sb_2O_3 was incorporated into the crystalline structure of BSCCO system since no peaks belong to this oxide was detected in XRD pattern. Samples with Sb content of $x \leq 0.3$ were dominated with 2223 phase while other samples ($x > 0.3$) were dominated with 2212 phase. All samples remain in tetragonal form which is $a = b \neq c$. The length of c-lattice that plays an important role of superconducting properties was found to decrease and hence contract the volume of unit cell as the content of Sb increased.

INTRODUCTION

Doping of BSCCO superconducting system with various elements was reported by many researchers to be useful and effective in improving the superconducting properties. Partial substitution of Pb in BSCCO system for example has produced materials of extremely high phase purity (2223 phase) and raised the T_C up to 110 K [1, 2]. Amazingly, the partial replacement of Sb (less than 10%) in Bi site has increased the T_C onset up to 135 K due to the structural disorder, such as some additional electronic reasons associated with the addition of Sb [3]. Hongbao et al reported that full replacement of Pb with Sb Bi-2223 system has raised the onset temperature, T_{Con} from 110 K to 120 K. Later, they determined the T_C onset of 132 K for $Bi_{1.9}Pb_xSb_{0.1}Ca_2Cu_3O_y$ [4]. The new phase of monoclinic system known as 4441 phase existed in $Bi_3Pb_{0.8}Pb_{0.2}Sr_{4.1}Ca_{3.9}CuO_{15+\delta}$ with the highest T_C in BSCCO system was found at 140 K [5].

Substitution of Sb at Sr-site was found to be effective in the formation of the high-T_C 2223 phase and conversion of the low-T_C 2212 phase to the high-T_C 2223 phase [4]. The presence of Sb in BSCCO system has made the system more reactive and enhanced the kinetic reaction (especially decarbonation) as well as the promotion of high-T_C phase [6]. Sb has been stated to be effective in preventing Pb from evaporating during calcinations in BSCCO system [7].

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The main purpose of this study is to identify the role of Antimony (Sb) in the $Bi_{1.6}Pb_{0.4}Sr_2Ca_2Cu_3O_y$ ceramics on structural and electrical properties via XRD and four-point probe techniques respectively

EXPERIMENTAL PROCEDURE

The Sb-doped samples were prepared from Bi_2O_3, PbO, $SrCO_3$, CaO, Sb_2O_3 and CuO powders (each at least 99.9 % purity) in the correct stoichiometric amount to produce samples with compositions of $Bi_{1.6}Pb_{0.4}Sr_2Ca_2Cu_30_dSb_x$. The concentration of Sb were in the range of x=0.1, 0.2, 0.3, 0.4 and 0.5. These powders were milled together in alumina pot for 24 hours and dried out in oven at 120 ^{O}C for 6 hours. Then the samples were calcined at 800 ^{O}C for 24 hours. Further calcination was done at 830 ^{O}C for 24 hours after grinding the powders using mortar and pestle. Finally, the powders of this nominal composition were pressed into disk shape with the diameter = 1.2 cm and the thickness = 2 mm before firing for 150 hours at 850 ^{O}C in a box furnace.

The x-ray diffraction patterns were checked using Cu-Kα radiation in the range 2^O up to 70^O of 2θ-angle with an angular step of 0.02^O. The critical temperature, T_C was determined from electrical resistance measurements using the standard four-point probe technique fitted with a closed cycle helium cooling system, which is fully computerised.

RESULTS AND DISCUSSION

Figure 1 shows the curves of normalized resistance versus temperature for all sintered samples. Generally, all samples exhibits normal metallic behaviour above the onset temperature and therefore obey the Ohm’s law (V=IR). The two-step features were clearly observed in sample with Sb concentration of 0.5 and 0.4. Both critical temperatures occurred at 110 K and 66 K for x = 0.4 and for x = 0.5 sample it’s appeared at 103 K and 70 K. When virtual straight lines were plotted for these curves, the intercepts at y-axis made an inference to the level of doping i.e. the Sb-free sample has the highest purity and the lowest purity belongs to x = 0.5 sample. The highest T_{Conset} at 112 K can be observed in samples x = 0.1 and x = 0.5 which is higher by 4 K as compared to the Sb-free sample. The optimum doping of Sb is 0.2 where the highest $T_{C(R=0)}$ was determined at 100 K. However, beyond that concentrations seem to be over-doped where $T_{C(R=0)}$ and T_{Conset} were decreased dramatically. Table 1 shows the summarized values of critical temperatures for all samples.

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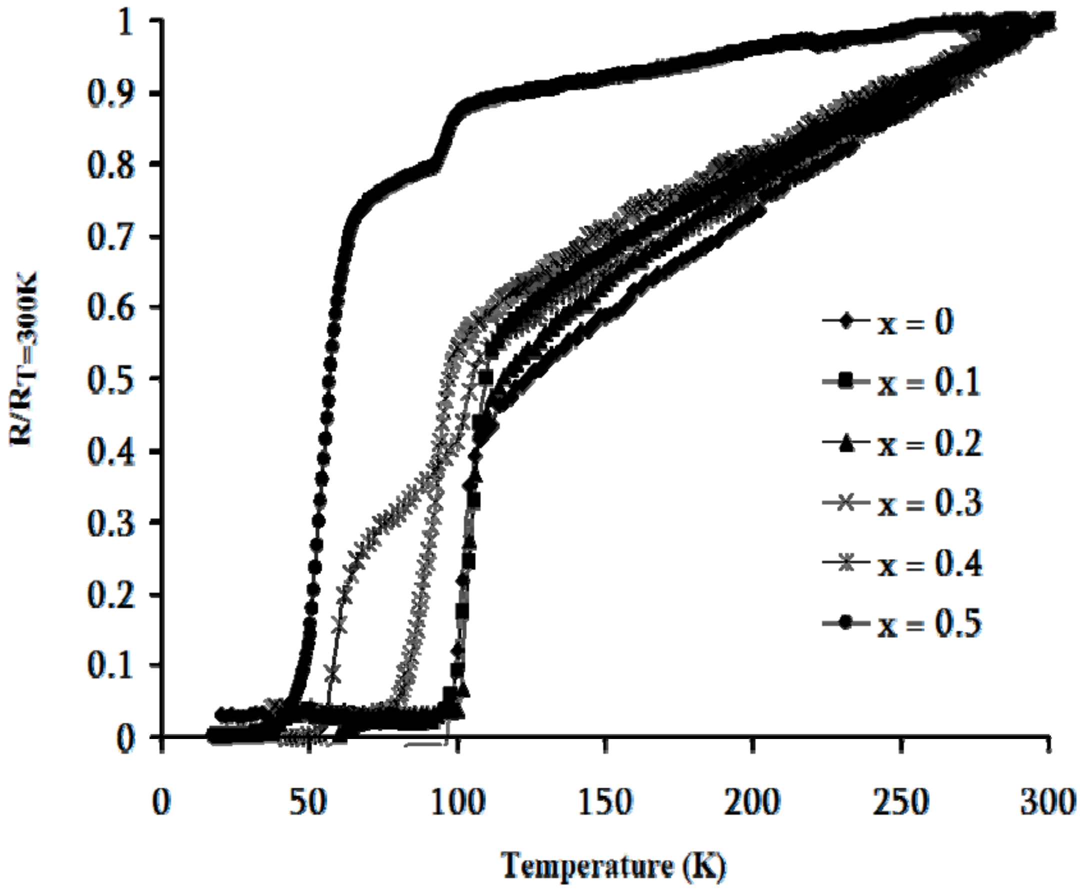

Figure 1: R-T curve normalized at room temperature (300K)

Table 1: Summarized values of transition temperature for all samples

Sb Concentration	$T_{C(R=0)}$ (K)	1st T_{Conset} (K)	2nd T_{Conset} (K)
0	96	108	-
0.1	98	112	-
0.2	100	112	-
0.3	80	104	-
0.4	54	110	66
0.5	38	103	70

The suppression of T_C towards Sb concentration in BSCCO system exhibits the strength of grains coupling were decreased and therefore increased the weak-links [9]. Another factor that should be considered is wave pairing function $\psi = \psi_O^{-i\phi}$ where the superconducting material can be destroyed by the reduction of amplitude (ψ_O) or by destroying the phase coherent (ϕ) [10, 11]. The pair breaking effect may contribute to the sustaining of T_C at approximately 110 K [12, 13]. The carriers coupling in Cu-O_2

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plane also plays an important role in superconducting phenomenon of Bismuth-based superconductor. Substitution of impurities such as Sb in Copper atoms can change the superconducting properties and therefore altered the electronic structure of BSCCO system. It is possible that the spinning of impurity's electron such as Sb prevents the appearance of the superconducting correlation and thus decreased the zero temperature, $T_{C(R=0)}$ [14].

The x-ray diffraction patterns for all samples are plotted in Figure 2. All the samples consist of mixed phases such as 2212 and 2223. For x = 0.4 and x = 0.5 samples, the peaks belong to 2201 exists and therefore lowered the T_C as shown in Table 1. No peaks of Sb_2O_3 were detected in the diffraction patterns meaning that this oxide was incorporated into the crystalline structure in the BSCCO system. The intensity of peaks H(013), H(111), H(00<u>12</u>), H(01<u>11</u>) and H(00<u>14</u>) were observed to decrease in sample x = 0.1 as compared to that of Sb-free sample. The low concentration of Sb samples was dominated by high-T_C 2223 phase. However, in higher doping (x > 0.2) concentration, the low T_C-phase 2212 is dominant. These results reflect the values of the critical temperature listed in table 1.

Table 2: Summarized values of lattice parameter for $Bi_{1.6}Pb_{0.4}Sr_2Ca_2Cu_3O_\delta Sb_x$ samples

Sb concentration	a (nm)	b (nm)	c (nm)	Volume (nm^3)
0.00	0.5389	0.5389	3.8311	1.1126
0.10	0.5382	0.5382	3.7916	1.0981
0.20	0.5388	0.5387	3.7705	1.0943
0.30	0.5376	0.5372	3.7441	1.0813
0.40	0.5386	0.5386	3.7257	1.0807
0.50	0.5382	0.5382	3.7280	1.0798

The calculated values of lattice parameter and volume of unit cell was tabulated in Table 2. All the samples remain in tetragonal structure which is a = b ≠ c. Obvious changes in c-parameter that is shortened towards Sb concentration and therefore contract the volume of unit cell. This characteristic could be due to several factors such as the increment of oxygen in BSCCO system [15]. Another factor could be due to the interaction between additional band crosses the Fermi level that grabs the holes from CuO band [16]. This attractive interaction caused the decreased of the distance between CuO_2 levels.

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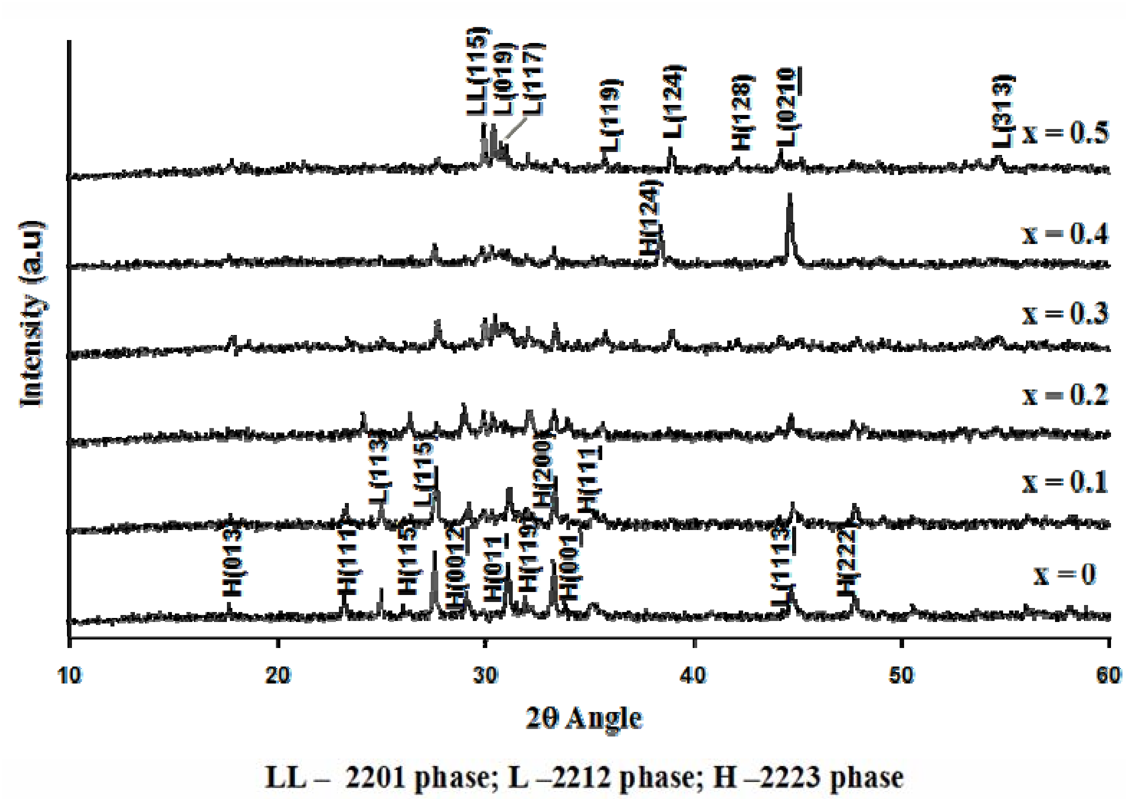

Figure 2: XRD patterns for Sb-doped samples

Figure 3 shows the volume percentage of superconducting phases versus Sb concentration. It is observed that the volume of 2223 phase decreased as the concentration of Sb increased however for other phases such as 2212 and 2201 were increased towards Sb concentration. Although the volume of 2223 phase reduced in x = 0.1 and x = 0.2 samples, the critical temperature has increased as compared to the Sb-free due to the improvement of grains interconnection.

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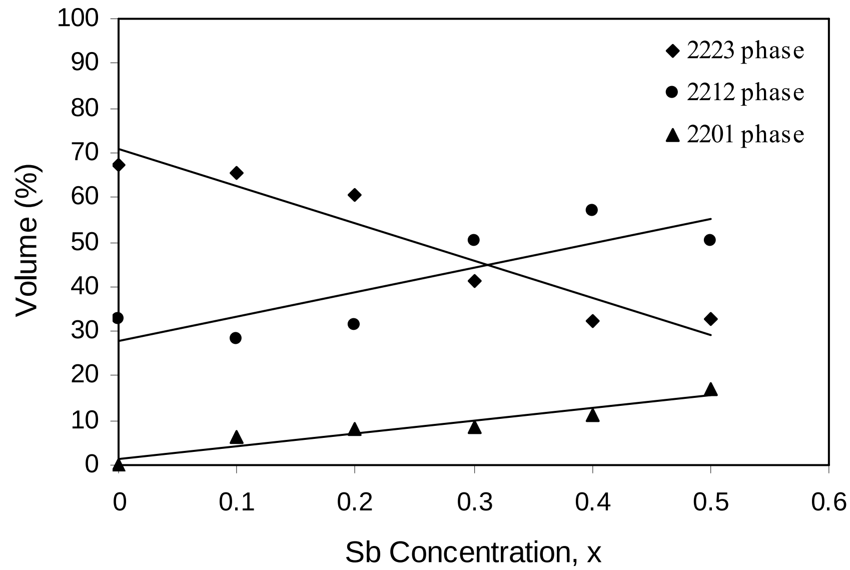

Figure 3: Volume percentage of 2223, 2212 and 2201 phases versus Sb concentrations

The relations between volume percentage of 2223 phase with the length of c-parameter is plotted in Figure 4. It shows that the volume of 2223 phase was linearly increased with the length of c-parameter. It is well known that the length of c-parameter plays an important role in order to enhance the superconducting properties. The decreased of c-parameter may caused detrimental effects on the critical temperature as previously discussed.

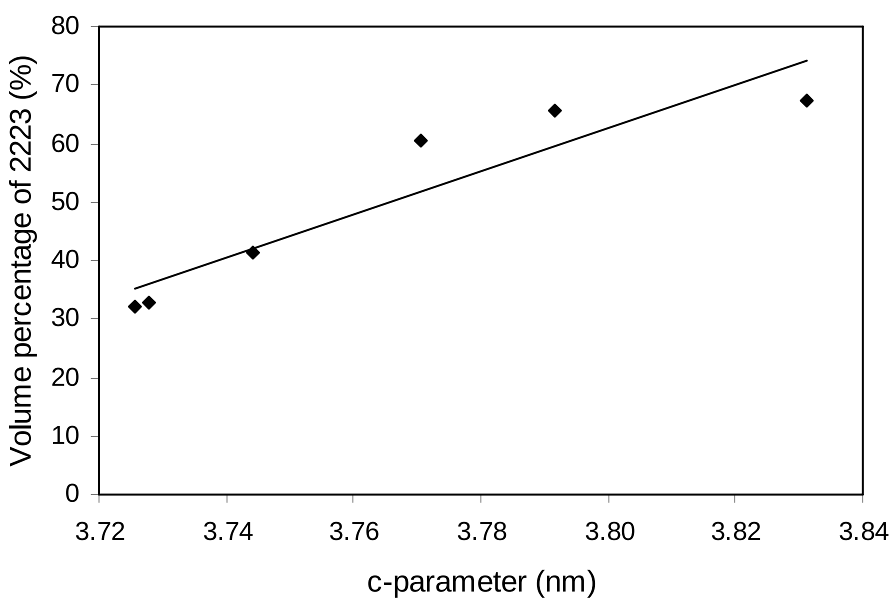

Figure 4: Volume percentage of 2223 phase versus the length of c-paramater

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CONCLUSION

The effect of Sb doping on 2223 phase of BSCCO system has been studied via XRD and resistance measurement to determine its crystalline structure and critical temperature, T_C respectively. Generally, all samples exhibit metallic behaviour above $T_{C\ onset}$. The value of zero resistance temperature, $T_{C(R=0)}$ decreased as the content of Sb increased except for sample x = 0.2 that shows the improvement of $T_{C(R=0)}$ by 4 K. This value was compared to that of the pure sample (Sb-free). The Sb_2O_3 was incorporated into the crystalline structure of BSCCO system since no peaks belong to this oxide was detected in XRD pattern. Samples with Sb content of $x \leq 0.3$ were dominated with 2223 phase while other samples ($x > 0.3$) were dominated with 2212 phase. All samples remain in tetragonal form which is $a = b \neq c$. The length of c-lattice that plays an important role of superconducting properties was found to decrease and hence contract the volume of unit cell as the content of Sb increased.

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