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The effect of Sb substitution on properties of $Bi_{1.6}Pb_{0.4}Sr_{2-x}Sb_xCa_2Cu_3O_y$ superconductors

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ABSTRACT

The effect of the partial substitution of Sr by Sb in the Bi-based superconducting materials has been investigated by X-ray diffraction (XRD), dc electrical resistivity, magnetoresistivity and critical temperature. Maximum value of the volume fraction of high-T_c phase was calculated to be 69.83 for the sample having Sb content x=0.06; the same sample has also shown the highest $T_c(0)$ value of 107.8 K amongst the samples. We estimated the transition temperature of the samples from the resistivity versus temperature measurements in dc magnetic fields up to 0.5 T. All samples exhibit metal-like behavior and appear to have a multiphase character. The lattice parameters and cell volume were found to be affected by substitution of Sb at the Sr-site.

1. Introduction

The discovery of high temperature superconductors of the LaBaCuO [1] and YBaCuO [2] families and the homologous series BiSrCaCuO [3–6], TlBaCaCuO [7] and HgBaCaCuo [8] systems has produced an explosion of interest and stimulated a great activity in the investigation of these materials. Among these, the $Bi_2Sr_2Ca_2Cu_3O_y$ (Bi-2223) phase appears to be the best suited for the practical use in superconducting devices operating at liquid nitrogen temperature ($T>77$ K) [9].

Superconductivity in the BiSrCuO system at relatively low temperatures was first reported by Michel, et al. [3]. Addition of Ca to this system led to the report of superconducting transitions between 80 and 110 K [5]. These discoveries led to frantic attempts in a number of laboratories to prepare single phase samples of the phases responsible for superconductivity. Study of single crystals revealed that these transitions are due to three different superconducting phases that are often represented by the formula $Bi_2Sr_2Ca_{n-1}Cu_nO2_{n+4}$; n=1, 2 and 3.

It has been shown that doping of BiSrCaCuO system with different elements at various amounts and adjusting preparation condition affect phase formation and physical properties in Bi-based system. Many studies of doping into superconductor oxide ceramics have been made in order to improve their superconducting, magnetic and mechanical properties [10–15].

In this work, we study the effects of the partial substitution of Sr by Sb in (Bi,Pb)SrCaCuO system; and report measurements of electrical resistivity as a function of temperature under different magnetic fields. We also reported XRD patterns to extract the lattice parameters and the relative portion of Bi-2223 and Bi-2212 phases.

2. Experimental

$Bi_{1.6}Pb_{0.4}Sr_{2-x}Sb_xCa_2Cu_3O_y$ (where x=0.00, 0.03, 0.06, 0.09, 0.15) samples were prepared by a conventional solid state reaction (SSR) method. High purity powders (purity over 99%) of Bi_2O_3, PbO, $CaCO_3$, $SrCO_3$, CuO and Sb_2O_3 were well mixed in stoichiometric proportions. The required amount of powders were weighted, mixed and ground in an agate mortar for 2 h. The mixture was pressed into pellets of about 15 mm in diameter and 2 mm in thickness with a pressure of 25 K N m^{-2} and subsequently calcined at 810 °C for 24 h in air (with one intermediate grinding) at the heating rate of 10 °C min^{-1} and then cooled to room temperature with the furnace turned off. The finely ground calcined powder was pressed at a pressure of 60 K N m^{-2} in the form of pellets having 15 mm diameter and 2 mm thickness. These pellets were sintered in air at 850 °C for 120 h with four intermediate grinding and then at 860 °C for 24 h; the heating rate was 12 °C min^{-1} and the samples were allowed the natural furnace cooling. The temperature dependence of the resistivity of samples cut from prepared pellets in the form of rectangular bars were carried out by the standard four-probe method current using OXFORD-ITC 502 closed cycle refrigerator and a Lock-in

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Amplifier at temperature between 40 and 160 K. Voltage and current leads were attached to the samples with silver paste. The structure of the samples was checked by a Philips-XPERT diffractometer with CuK_α radiation in the range $2\theta=4^\circ–70^\circ$. Phase purity and the lattice parameters were obtained from these XRD patterns.

We measured temperature and dc magnetic field(0–0.5 T) dependant of resistivity of the samples in a cryostat. The magnetic field was applied parallel to the current direction. The external dc magnetic fields for resistivity measurements were provided by an electromagnet; and we estimate stoichiometric ratio of the considered samples by using OXFORD EDX (coupled to a SEM Model LEO-1450VP).

3. Results and discussion

The substitution of Sb at Sr-site was confirmed by the energy dispersive X-ray (EDX) analyses. It was being observed that the addition of Sb into Bi-2223 system, substitutes not only strontium but also bismuth because the ionic radius of Bi^{3+} is comparable with Sb^{3+}.

As grown samples of $Bi_{1.6}Pb_{0.4}Sr_{2-x}Sb_xCa_2Cu_3O_y$ having various Sb concentration were subjected to structural characterization employing X-ray diffraction (XRD) technique. Fig. 1 shows XRD patterns of samples (A1–A5). All peaks were indexed as "H" for high-T_c Bi-2223 phase and "L" for low-T_c Bi-2212 phase. There is a consistence variation in the intensity and position of the peaks indicating the change in phase composition and lattice parameters of the samples. The peaks position and the intensities of the diffraction data reveal that the all samples consisted of a mixture of Bi-2223 and Bi-2212 phases as the major constituents. For the Bi-2223 phase the highest intensity peak for the samples A1–A5 were found to be 653, 759, 945, 792 and 503 count per second (CPS), respectively. As can be seen from Fig. 1 a sharp and intense peak corresponding to the Bi-2223 phase appearing at 2θ value of nearly 5°, gradually increase in its intensity with increasing in antimony content from $x=0.00$ to 0.09 and for further increase in antimony content this peak intensity decrease. The peak of low-T_c Bi-2212 phase obtained at $2\theta=34.01$ for sample A2 with $x=0.03$ is converted to the peak of high-T_c Bi-2223 phase with increase in antimony content, i.e. $x=0.06$, 0.09 and 0.15, respectively. It can be inferred from these results that addition of an optimum level of antimony enhances the formation of Bi-2223 phase and also helps in conversion of low-T_c phase to the high-T_c phase. The relative volume fraction of Bi-2223 phase were determined from (0 0 2), $(0\,0\,\underline{10})$, (1 1 5), (1 1 9), (2 0 0), $(1\,1\,\underline{11})$, $(2\,0\,\underline{12})$, (2 2 0) and $(0\,0\,\underline{22})$ peaks and the relative proportions of Bi-2212 phase were

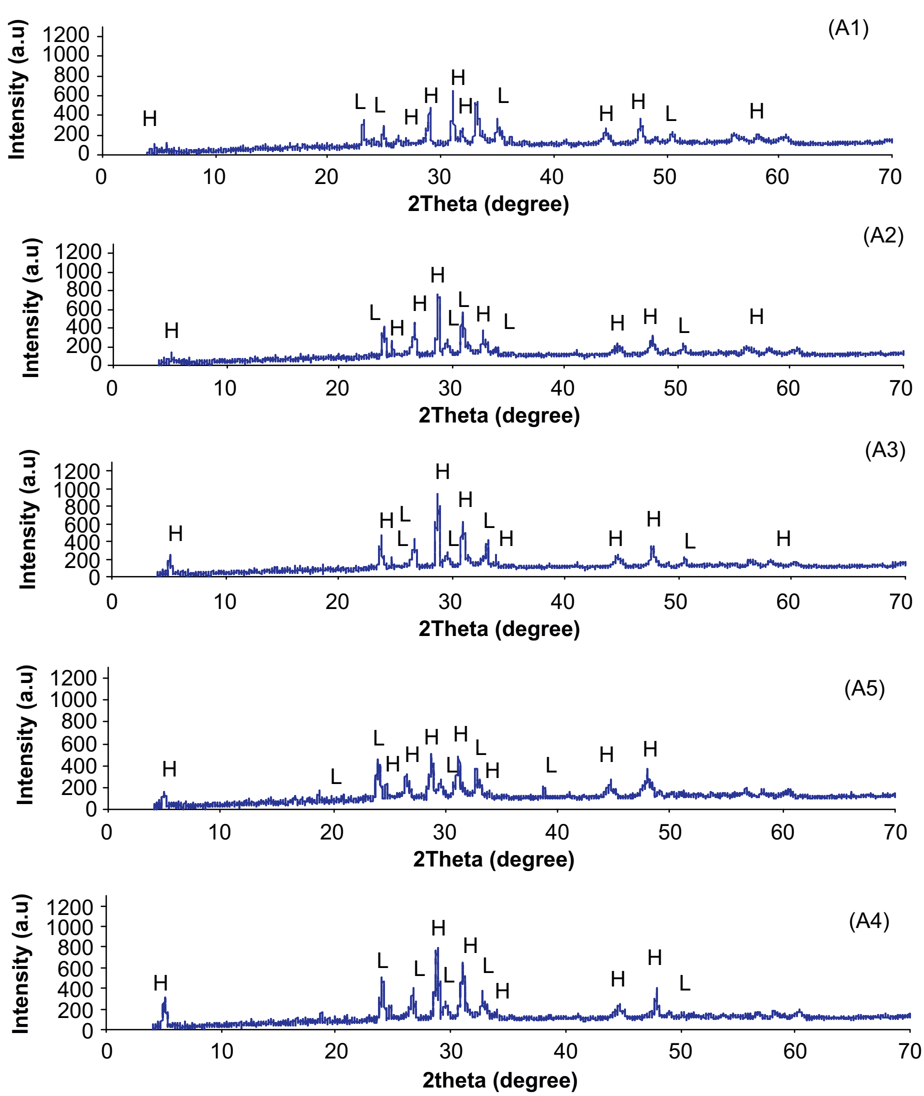

Fig. 1. The XRD patterns of samples [A1(x=0.00), A2(x=0.03), A3(x=0.06), A4(x=0.09), A5(x=0.15)].