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Yttrium effect on superconductor properties of Bi(Pb)-2223 compound

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Superconducting materials have many applications. These applications are performed through developing their structural characteristics and physical properties. This study presents the correlation of superconducting properties as well as its microstructural development by substitution Yttrium in Bismuth sites with different concentrations. X-ray diffraction (XRD) investigations and electrical measurements of the samples confirmed that the substitution process strongly influence the crystallite structure of the samples and consequently electrical properties. The structural analyses showed an orthorhombic structure with two phases for compound: a high-2223 phase and a low-2212 phase. The maximum T_C =123K obtained at the concentration 0.1 in optimal doping regime.

Keywords: High temperature; Superconductor; Y_2O_3; Pinning centers.

1. INTRODUCTION

The unique properties of superconducting materials have attracted many researchers and engineers to study and employ them in advanced medical technologies and most notably for magnetic resonance imaging (MRI) magnets [1-3]. The resolution of medical imaging techniques in the whole volume investigation of body needs a highly homogeneous magnetic field which can be improved by using the high-temperature superconductors BiSrCaCuO (BSCCO) [4,5]. Nanotechnology applications have become very important in various specialties, including medical. Therefore, it is very important to link superconducting materials with nanotechnology in the medical field. Recently, efforts have focused on developing nanosuperconductors which are superconducting materials at the scale of a nanometer. Nanosuperconductors are mainly employed in the field of medicine and biophysics in the form of improved imaging techniques [6]. The major restriction of BSCCO superconductor applications is the low critical current density due to the weakness of both inter-grain links and flux pinning ability. Thus, it is necessary to study their properties and then prepare them for nanotechnology applications. On other hand, to continue searching and studying different techniques to overcome the limitations of working with these materials and improve their efficiency, one of them is the doping process with different elements or oxides during the preparation of these compounds.

It is found that the electric connection between superconducting grains improved by doping with a small amount of different oxides produces effective pinning centers of the fluxes in the samples [7-11]. On other hand, the combination of stability in the different environments along with high Tc is a primary challenge in the area of applied superconductivity [12]. A series of Bi(Pb)SCCO samples doped with different oxides are prepared and investigated to elucidate the relationship between the doping process, preparation techniques, and their superconducting properties [13-17]. To complete the search for the best method and quantity of doped, we considered in our presented research study the effect of adding rare earth oxide Y_3O_2 during the preparation of BiPbSrCaCuO samples and studying its effect on their structure, pinning mechanism, and electrical properties.

2. EXPERIMENTAL TECHNIQUES

Solid-state reaction method is used to prepare $Bi_{2-x}Y_xPb_{0.3}Sr_2Ca_2Cu_3O_{10+d}$ compositions with (x= 0.1, 0.2, 0.3, 0.4 and 0.5). Powder with appropriate weight of materials Bi_2O_3, PbO, $Sr(NO_3)_2$, CaO, CuO, and Y_2O_3 are mixed and calcined in air at 800 ^{O}C for 24 h.

The powder is pressed into disk-shaped pellets and sintered in air at (840) °C for 140 hr. The structure of the samples is investigated by using an X-ray diffractometer (XRD) type Philips with the Cu-Kα radiation.

The electrical resistivity (ρ) is studied to evaluate the critical temperature T_C.

3. RESULTS AND DISCUSSION

The results of the XRD analysis performed on Y-doped samples are shown in Figure 1. (Bi, Pb)-2223 and -2212 phases in the samples; the majority of the peaks correspond to the Bi-(2223). Further, the X-ray diffraction pattern of the samples demonstrates variation in the intensity and the position of the peaks as a consequence of different Y substitution levels which is evidence of the change in phase composition of the samples and the crystalline arrangement degree.

The relative volume fractions of the high Bi-2223 phase (V2223) and low Bi-2212 phase (V2212) of the samples is calculated by using the relation in reference [18] and listed in Table 1. The lattice parameters a, b, c values, c/a ratio, and unit cell volume V of the samples are summarized in Table 1. The results are evidence that the samples have an orthorhombic structure and there are changes in the structural parameters with a variation of Y concentrations.

Table 1 and Figure 2 show that the existence of Y promotes high T_C phase V2223 growth in the samples and the highest fraction is at 0.1, but increasing doping concentration changes the reaction rate and slows down the formation of (Bi, Pb)-2223 phase. Furthermore, as can be observed from Figure 3 the higher value of the c parameter is found for the sample with x=0.1 and then decreases with increasing the yttrium concentrations. Meanwhile, the increase in the b parameter may be due to the hole carrier concentration per Cu ion introduced by the doping ions which is reduce the Cu valence and thus lead to an increase in Cu-O bond length [19].

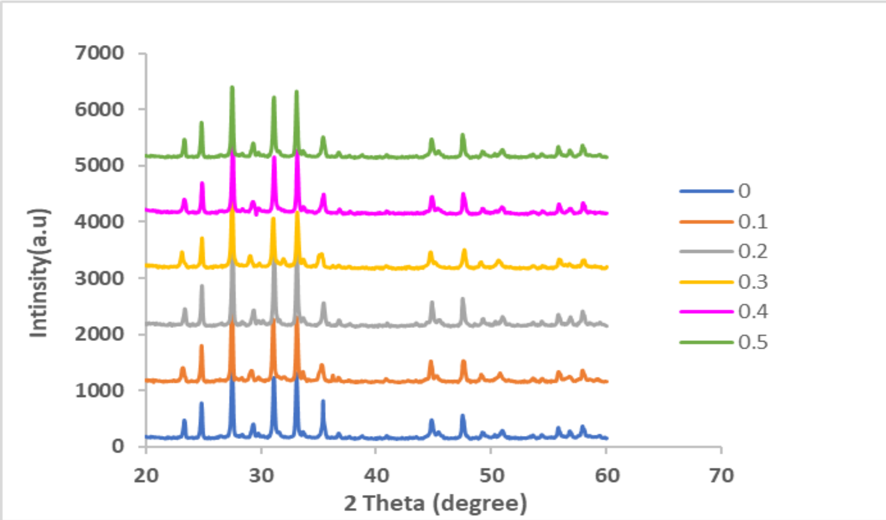

Figure 1 This figure depicts XRD pattern of samples for different Y concentrations.

Table 1 Values of lattice parameters a, b, c, c/a, V, V-2223 phase, V-2212 and T_C for different compositions of $Bi_{2-x}Y_xPb_{0.3}Sr_2Ca_2Cu_3O_{10+d}$ with $0 \leq x \leq 0.5$.

x	a(Å)	b (Å)	c (Å)	c/a	V(Å)^3	Volume fraction of phases (%)		T_C (K)
						V-2223	V-2212	
0.0	5.388	5.394	37.324	6.927246	1084.743	58.2	41.8	105
0.1	5.271	5.278	37.642	7.141339	1047.213	77.2	22.8	123
0.2	5.331	5.339	37.337	7.003752	1062.693	74.5	25.5	110
0.3	5.342	5.344	37.323	6.986709	1065.484	68.7	31.3	105
0.4	5.422	5.420	37.243	6.868868	1094.469	60.8	39.2	104
0.5	5.480	5.478	37.243	6.796168	1118.014	59.4	40.6	103

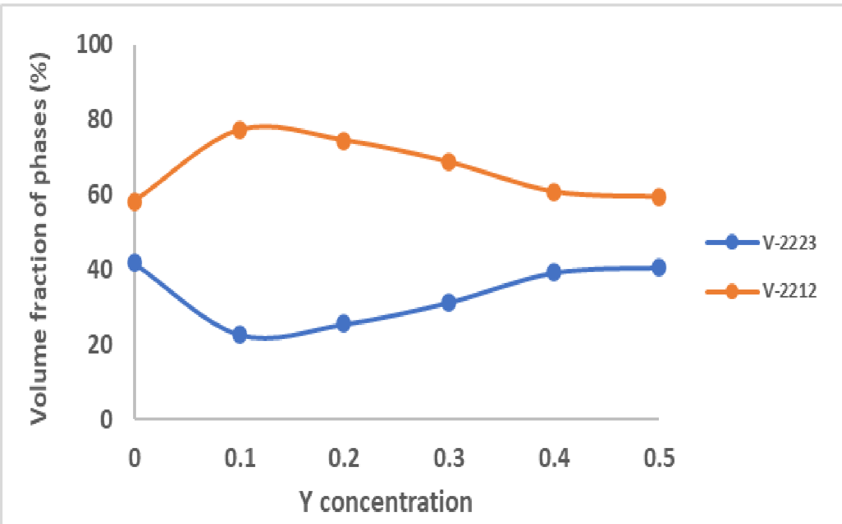

Figure 2 Volume phases of samples for different substitution concentrations.

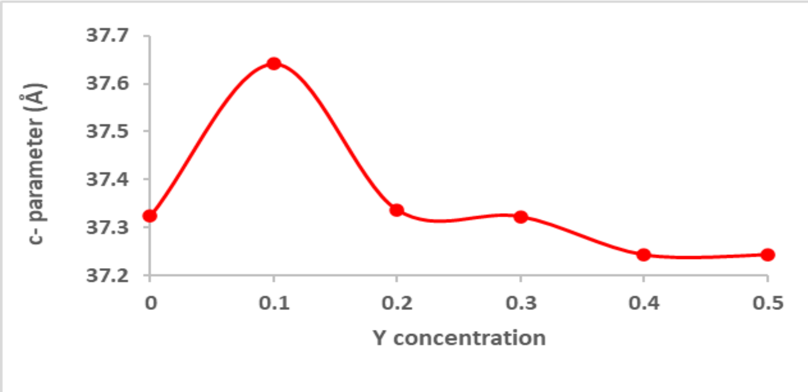

Figure 3 c- parameter of samples for different substitution concentrations.

Superconducting transitions have been detected on the curves of normalized resistivity ρ_N as a function of temperature of the samples in the range of (0.0≤ x≤ 0.5) as shown in Figure. 4. The samples show metallic behavior and a superconducting transition to zero resistance by one step. This reflects the decrease in both impurity phases and grain boundary defects. The T_C determined for those samples are (105, 123, 110, 105, 104, and 103) K for x = 0, 0.1, 0.2, 0.3 0.4, and 0.5 respectively as listed in Table 1. The highest T_C is determined for $Bi_{1.9}Y_{0.1}Pb_{0.3}Sr_2Ca_2Cu_3O_{10+d}$ composition which has the highest V2223 and c-parameter as mentioned before. The results confirm that the appropriate amount of doping acts as the effective pinning centers for the current in the samples. Y and Pb can fill the inter-grain spaces, and thereby reinforce the coupling between granules.

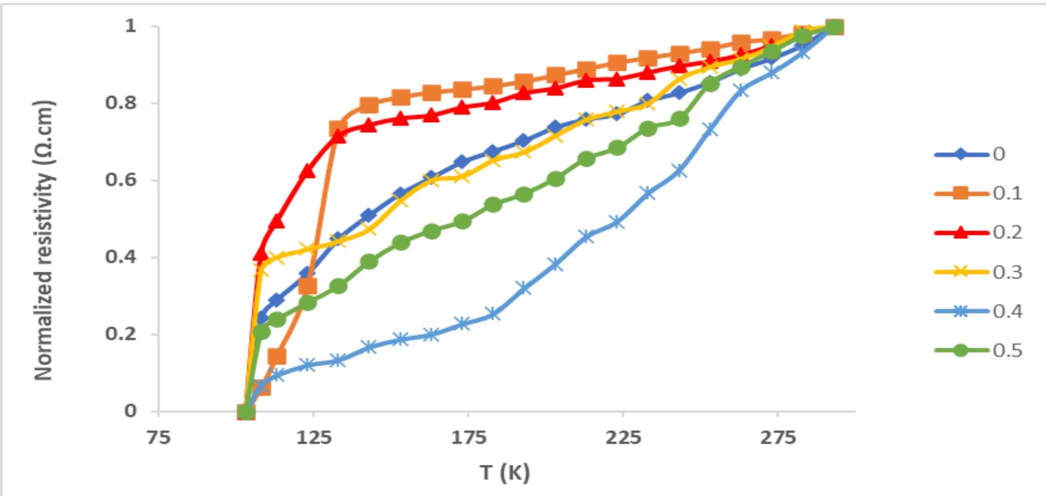

Figure 4 Normalized resistivity as a function of temperature of samples for different Y concentrations.

On other hand, it indicates that the sample is in optimal doping regime while a decrease of T_C with increasing the substitution concentrations because the shift of this sample towards the overdoped region. This agrees with the model studied by Emery *et al.* which is concerned with alternating two CuO2 sheets of multilayer cuprates and indicated the strong correlation between under and over-doped planes obtained in Bi-2223 phase [20-23].

4. CONCLUSIONS

Substitution of Y and Pb distorted the electronic structure of the BSCCO system and simultaneously influenced the superconducting critical temperature, based on the parabolic dependence between the number of holes per CuO2 and T_C. However, the substitution process leads to the prominent enhancement of T_C and the high Bi-2223 phase formation. The structural and electrical resistivity results of BPSCCO samples revealed that the Y substitution in combination with Pb addition induced alteration in lattice parameters and superconductivity behavior as result of the structural distortion and charge ordering phenomenon. The maximum T_C = 123 K was found at the concentration of 0.1 in the optimal doping regime.

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