Studying the Addition Effect of Nano WO₃ on the Biₓ₋ₓPbₓSrₓCaᵧCu₂O₇₋ₓ Superconductors

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Abstract: Different concentrations of WO₃ nanoparticles were added to Biₓ₋ₓPbₓSrₓCaᵧCu₂O₇₋ₓ, composite its superconducting properties as well as its microstructural development were studied. Powder pellets made-up using method of solid-state reactions. Critical transition Temperatures Tc of samples measured by technique of four-point probe. It found that addition of nanoparticles WO₃ up to the 0.2 wt.% enhances the Tc, the highest Tc was exhibited at 120 K while excessive addition suppressed it. WO₃ nanoparticles introduced effective pinning centers. The gross structural characteristics of synthesized High-Tc Superconductors (HTSc) was investigated through X-ray diffractions. The results showed both high and low phases exist in models with orthorhombic structures for all samples. Grains shape and their connectivity studied with SEM. EDX analysis used to test the chemical compositions of the Biₓ₋ₓPbₓ,WₓSrₓCaᵧCu₂O₇₋ₓ superconductor. XRD, SEM and electrical measurements were done on the samples to deduce the best properties desired for the superconductor.

Key words: BSCCO superconducting system, WO₃ addition, high-2223 phase, pinning center, (HTSc), grains shape

INTRODUCTION

Superconductivity is an interesting wonder recognized by transitions phases at a Tc where both conducting and the superconducting phases are in equilibrium. Discovering the High-Tc Superconductors (HTSc) is in great demand for technological development and industrial applications (Luiz, 2010; Rahman et al., 2015).

Material sciences and engineering researchers concerned in the prediction and the clarification of the HTSc properties from the standpoint of structure (Rasheid et al., 2011). One of the most special features of the HTSc layered superconductors is the correlation between superconductivity and the lattice structure. The Bi₁₋ₓSrₓCa₋ₓCu₂O₇₋ₓ system the most promising HTSc has general chemical formula Biₓ₋ₓSrₓCa₋ₓCu₂O₇₋ₓ (n = 0-2) (Kharisssova et al., 2014). Tc is mainly determined by the structure and the chemical composition; the chemical compositions of the materials within the grains also at the grains boundaries of a superconductor consumes a considerable result above it’s properties. It is known that inter-grain regions behave like nonconducting area, thus, grain connectivity becomes more important for the sharpness of transition and other critical parameters.

Considerable effort has been made on the possibility of modifying the structure (Al-Bermany, 2017) and the superconducting chattels of Bi-based compound by increasing the number of charge carriers chemically by cation substitution change the number of oxygen atoms (Parinov, 2013).

Recently, remarkable progress in the development of nanotechnology materials has led to a continuous studying of the influences of doping with various nanoparticles on the properties of the BSCCO such as AlₓGaₓZrO₃, TiO₂, NdₓO₃, CoₓO₃, SrOₓ, Y₂O₃ (Parinov, 2013; Abbas et al., 2018; Hamid, 2009; Ajjarujana and Shaya, 2015; Saratekin et al., 2016; Jannmah et al., 2013; Garnier et al., 2002; Oboudi, 2017). These studies showed that doping the layered HTS materials with nanoparticles has different effects, the dopants formulate innovative phase by reaction vigorously with Bi. 2223 and 2212 phases which adversely affect the properties of superconductor or the nanoparticles could doing like pinning centres, improve inter-granular contacts, so, improving the superconducting critically parameter. Furthermore, BSCCO actual delicate to carriers doping and are superconductors only for the particular range of doping levels.

In this research, samples of (Bi. 2223) dissimilar concentrations of added WO₃ nanoparticles (0, 0.1, 0.2 and 0.3 wt.%) set by technique of the solid state reaction. The electrical and structural results were assumed together to investigate the role of tungsten over the superconductor properties.

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MATERIALS AND METHODS

Experimental: Bi$_3$Pb$_{2.3}$W$_4$Sr$_3$Ca$_2$Cu$_3$O$_{12-x}$ structures with (x = 0, 0.1, 0.2 and 0.3%) set by the process of the solid state reactions. To make this an correct molar ratio of high purities powder of the Bi$_2$O$_3$, PbO, Sr(NO$_3$)$_2$, CaO, CuO with WO$_3$ nanoparticles with size 20 nm were mixed. The mixture was grounded to a fine powders, calcined in air for 24 h at 820°C. This was following by intermediates grinding. The powder hard-pressed into disc-shaped pellets, 3 mm thickness and 13 mm in diameter with the manually hydraulic press (type speke) that was under pressure 0.6 GPa. These pellets were sintered for 140 h in air at 845°C.

The prepared samples structure was obtained applying X-ray diffraction meter (Philips with the Cu-Kα radiation). The electrical resistivity (•) was studied to evaluate the critical Temperature $T_c$.

The nature of the grains and the surface morphology for some samples were analyzed using FEI Inspect S50 Scanning Electron Microscope (SEM) (Netherlands). The compositional information of the elements in Bi$_3$Pb$_{2.3}$W$_4$Sr$_3$Ca$_2$Cu$_3$O$_{12-x}$ sample were achieved by FEI-SEM Model Inspect-S50, Energy Dispersive X-ray spectrometer (EDX).

RESULTS AND DISCUSSION

XRD results of the analysis achieved on WO$_3$ added to samples shown in Fig. 1, both (Bi, Pb)-2223 and -2212 phases coexist in the samples, the majority of the peaks correspond to the Bi-(2223). This shows that the addition of WO$_3$ supports growth of high $T_c$ phase. According to the model suggested by Abbas et al. (2017), Abbas and Abdulridha (2017) the (Bi,Pb)-2223 phase is formed through a growth process and distinct nucleation. Therefore, the slightly larger volume fraction of the (Bi, Pb)-2223 phase exist in the Bi$_3$Pb$_{2.3}$W$_4$Sr$_3$Ca$_2$Cu$_3$O$_{12-x}$, composition may be the reason of the faster conversion rate for this composition.

Additionally, the X-ray result of these samples demonstrates that there is a difference the position of the

Fig. 1: The X-ray diffraction patterns of the Bi$_3$Pb$_{2.3}$W$_4$Sr$_3$Ca$_2$Cu$_3$O$_{12-x}$ samples
Table 1: The values of lattice parameters, volume of unit cell and phase volume fraction for Bi$_x$Pb$_{1-x}$Sr$_2$Ca$_2$Cu$_3$O$_{y\mu}$ superconductors

<table>
<thead>
<tr>
<th>X (%)</th>
<th>a (Å)</th>
<th>c (Å)</th>
<th>V (Å$^3$)</th>
<th>c/a</th>
<th>Tc (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0</td>
<td>5.472</td>
<td>37.151</td>
<td>1112.4050</td>
<td>6.968</td>
<td>114</td>
</tr>
<tr>
<td>0.1</td>
<td>5.454</td>
<td>37.148</td>
<td>1085.7949</td>
<td>6.811</td>
<td>116</td>
</tr>
<tr>
<td>0.2</td>
<td>5.321</td>
<td>37.110</td>
<td>1084.6435</td>
<td>6.781</td>
<td>120</td>
</tr>
<tr>
<td>0.3</td>
<td>5.288</td>
<td>37.095</td>
<td>1085.5347</td>
<td>6.923</td>
<td>115</td>
</tr>
</tbody>
</table>

Fig. 2: Temperature dependence of resistance of the Bi$_x$Pb$_{1-x}$W$_x$Sr$_2$Ca$_2$Cu$_3$O$_{y\mu}$ superconductors

peaks and in the intensity with the variation of WO$_3$ concentration which is evidence of the change in phase composition of the samples and the crystalline arrangement degree.

However, there is no substantiation that WO$_3$ may react actively with the Bi$_x$Pb$_{1-x}$W$_x$Sr$_2$Ca$_2$Cu$_3$O$_{y\mu}$ compounds to form new phases which as a rule, degrades the properties of superconducting material. The additions may act to stabilize the 2223 phase to increase its volume in the compounds.

The parameters a, b, c and c/a values proved an orthorhombic structure for all samples. Table 1 summarizes the lattice parameters of Bi$_x$Pb$_{1-x}$W$_x$Sr$_2$Ca$_2$Cu$_3$O$_{y\mu}$ superconductors for various WO$_3$ concentrations. It was important to mention that the addition concentration increases, the cell volume decreases due to both the oxygen vacancies and the cations arrangements acting at the same time (Al-Bermany, 2017; Xu et al., 1987).

Lattice parameters c decreases with the increments of W concentrations to $x = 0.2$ afterward c decreases as shown in Fig. 2. The increases of c tells that, Cu$^{2+}$, Cu$^{+}$ in addition, to Bi$^{3+}$ may partly be substituted by W$^{4+}$ ions, comparable performance observed by Nihal et al. (Türk et al., 2014). Though the decreasing in c attributed to the charges organization phenomena, also, changes in the oxgens contented, the attractive interactions among the added band created by adding WO$_3$, crossing level of Fermi pulls from CuO bands some holes and causes the distance reduction among planes of Cu-O$_2$ which resulting in reduction in c axis (Azhan et al., 2009).

Fig. 3: The SEM surface micrographs of the Bi$_x$Pb$_{1-x}$W$_x$Sr$_2$Ca$_2$Cu$_3$O$_{y\mu}$ samples for different W content: a) X = 0; b) X = 0.1; c) X = 0.2 and d) X = 0.3

Furthermore, the existence of Pb in the Bi-system is supposed to reduce the modulation by affecting charges equilibrium, the oxgens contented and the structure of the related sheets (Ikedo et al., 1988).

Temperature dependence of the electrical resistivity ($\sigma$-T) of WO$_3$-doped samples ($0 \leq x \leq 0.3$) have been studied in (Fig. 2). The resistivity exhibited well defined metallic behavior and superconducting transitions to zero resistance for all compositions with narrow superconducting transition widths. Another feature can be observed: the superconducting transition of all the samples is composed of only one-step transition. This reveals that the sample consists predominantly of (2223) phase. This tendency is also, a good evidence of the homogeneity of the (2223) phase (Iqbal and Mehmood, 2009). The T$_c$ values measured from the $\sigma$-T curve of the samples were 114, 116, 120 and 115 K for $x = 0.0$, 0.1, 0.2 and 0.3%, respectively.

The SEM images of the Bi$_x$Pb$_{1-x}$W$_x$Sr$_2$Ca$_2$Cu$_3$O$_{11+}$ samples ($0 \leq x \leq 0.3$) obtained Fig. 3. Surface was composed of plate like grains of different orientation, indeed is the characteristic grains structures of (Bi-2223) (Abbas et al., 2018). The porous are formed on the grains during the sintering process.

Increasing the W nanoparticles content in the samples achieves densification by decreasing the porosity. Thus, these surface becomes distinctly composed of thick small and large grains. The reason for this significant improvement is that WO$_3$ nanoparticles fill
Fig. 4: The EDX spectra of the Bi$_2$Pb$_{1.5}$Ti$_{1.5}$Sr$_2$Ca$_2$Cu$_3$O$_{10.5}$ superconductor resulting in a smoother and denser surface. This is in good agreement with the studies reported by Yazici et al. The EDX spectra of the Bi$_2$Pb$_{1.5}$W$_{0.5}$Sr$_2$Ca$_2$Cu$_3$O$_{10.5}$ superconductor are demonstrated in Fig. 4, authorizes the wanted element in the chemicals compositions presented. There are no unwanted element in the sample, proving that there is no contamination during the preparation process. A crowning of carbon elements distinguished, perhaps due to tiny carbons layer evaporated above samples through the combination procedure. Some peaks Pb, Bi with similar energy values detected, representing the ions of Bi substituted incompletely by ions of Pb in structure. Same crowning can observed for W ions for both Bi and Cu ions.

A significant standpoint got from the research is that WO$_3$ additions support and stabilize the creation of Bi high phase. Besides, it reduces the sintering temperature, since some kind of a liquid phase was present in the samples beyond X ~ 0.2 concentration.

Hence, it is possible to control the grain growth and tailor the microstructure hence the T$_c$ values, flux pinning properties of (Bi, Pb)$_0$ superconductors by the appropriate choice of the W addition.

CONCLUSION

Investigation the superconducting properties and understanding the mechanism of the superconductivity by the addition of WO$_3$ additions but it is essential to control the amount of addition. Minor concentration of W on the Bi high phase lattice could useful. The Bi$_2$Pb$_{1.5}$W$_{0.5}$Sr$_2$Ca$_2$Cu$_3$O$_{10.5}$ superconductor yields the highest T$_c$ value of 120 K at the high Bi-2223 phase formation. The improvement is attributed to the shift in hole concentration of the system from the underdoped to the optimal doped state. Oxide additions did not display solid propensity for substitution straight in superconductor lattices.

It is worth noting that increasing the W concentrations decreasing T$_c$ values but it's not prevent the creation of (Bi high phase). It increases the possibility of occupying the positions of W nanoparticles (interstitially or in substitutional site).

REFERENCES


