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EFFECT OF NANO-TIO$_2$ ADDITION ON SUPERCONDUCTING PROPERTIES OF (Bi, Pb)-2223 THIN FILMS

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Abstract

Nd:YAG pulse laser system was used to fabricated $Ti_xBi_{1.7}Pb_{0.3}Sr_2Ca_2Cu_3O_y$ superconductor thin films, were x=0.1, 0.3 and 0.5. All the samples have been annealed after deposition with flow of oxygen for two hours at 800 ºC. X-ray diffraction analysis evidenced that the prepared thin films were consistent of low 2212 and high 2223 phases. Scanning electron microscopy images of the samples revealed that the addition of Ti nanoparticles into (Bi,Pb)-2223 composition would have significant effects on their grain sizes and morphologies. Electrical properties of the thin films can be associated to the modification in the holes content, the highest T_C at 114.5 K was obtained for the thin film with x=0.3.

Keywords: High temperature superconductors; (BiPb)-2223; TiO_2; nanoparticles; PLD; thin films.

1. Introduction

High temperature superconductors such BiSrCaCuO (BSCCO) have a great interest from both fundamental and practical perspectives, their electrical and magnet properties attracted considerable attention due to their chemical and thermal stability and thus they are favourable for wide applications as a bulk or thin films [1-5].

It was established that to obtain more applicable BSCCO compounds substituting or adding some nanoparticles of oxides to it during their preparation can enhances the related structural and superconducting properties. The expectance of appropriate amount of nanoparticles in BSCCO will possibly improve the inter-grain connectivity or pinning centers between grain boundaries [6-10]

Furthermore, with nanotechnology developments notable attempts have been done by researchers to synthesis high temperature superconductors thin films and enhance their potential applications. The Pulse laser deposition (PLD) combined with subsequent heat treatment cycle is required to obtain thin films with good superconductor properties. Where, it is observed that annealing step is necessary to increase the alignment of the 2223 grains which is contributed to enhance the transport current density [11-15].

The aim of this work is to investigate the effect of the Ti nanoparticles addition on the properties to BiPb-2223 superconductor thin films prepared by PLD system.

2. Material and methods

Provide $Ti_xBi_{1.7}Pb_{0.3}Sr_2Ca_2Cu_3O_y$ pellets with (x=0.1, 0.3 and 0.5 and size 50 nm) used as a target to grow a thin film on a Single crystal silicon Si n-type substrates with ordination (111). Before the deposition process the substrate were heated to a temperature of 300 ºC.

The deposition process is carried out inside a vacuum chamber by using Nd:YAG SHG Q-switching laser with 1064 nm, 500 pulses and pulse energy 700 mJ.

$Ti_xBi_{1.7}Pb_{0.3}Sr_2Ca_2Cu_3O_y$ thin films annealed at a temperature of 800 ºC in an oxygen environment for 2 hours to complete the oxidation process.

The structure of the prepared samples was obtained by using X-ray diffractometer type Philips with the Cu-Kα radiation.

The thickness of the film measured by optical interferometer and was determined to be 194 nm.

The electrical resistivity (ρ) was studied using Four-point probe DC technique to evaluate the critical temperature T_C.

Atomic force microscopy (AFM) from Angestrion Advanced Inc. USA (AA3000) was used to study the surface morphology.

Scanning electron microscopy (SEM) from (FEL Inspect S50, Netherlands) used to analyze the surface morphology and nature of the grains for all samples.

3. Results and Discussion

The crystal structure of $Ti_xBi_{1.7}Pb_{0.3}Sr_2Ca_2Cu_3O_y$ thin films with different nominal composition x=0.1, 0.3 and 0.5 studied by XRD and represented in Figure 1. The apparent change in x-ray diffraction pattern of the films due to the Ti nanoparticles addition was observed, where the analysis showed polycrystalline and correspond to orthorhombic structure consistent of low 2212 and high 2223 phases but in different intensity of diffraction lines.

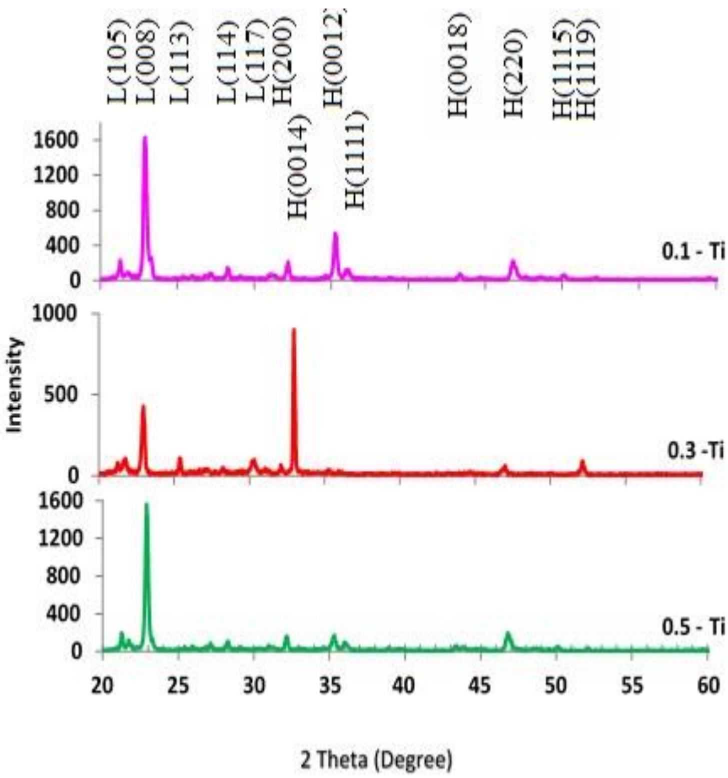

Figure 1. X-ray diffraction patterns of $Ti_xBi_{1.7}Pb_{0.3}Sr_2Ca_2Cu_3O_y$ thin films for different Ti content

The relative volume fractions (V. F.) of the high Bi-2223 and low Bi-2212 phases were estimated using formulas in [16] and listed in Table 1, obviously high-T_C phase dominates over the low-T_C phase. Variation the intensity and position of the peaks with increasing Ti content indicating the change in phase composition and the la (Bi-2223) obtained for sample with 0.3 concentrations. This could be owes to the changing of crystalline lattice parameters of the samples, a pronounced Bragg intensities belonging to the high-T_C phase arraignment degree with increasing Ti.

As seen in Table 2, upon Ti addition unsystematic variation of lattice parameters noticed. This variation is thought to be related to the several combinations of different reasons. Where, Pb doping on Bi2223 has a bond-ordering effect and depress the structure modulation [17]. Moreover, it alters the holes concentration in CuO_2 planes, it also produce an oxygen vacancies by being dominantly in a 2^+ oxidation state [18-19]. On other hand the increase in lattice constant c indicate that cations of the, Ca^{2+} in addition to Bi^{3+} may partly be substituted by Ti^{+4} ions; while the shortened could be to the increasing of oxygen with increasing the Ti nanoparticles in BSCCO system, similar behavior has been noticed by [20].

Table 1. Values of volume fraction of phase of $Ti_xBi_{1.7}Pb_{0.3}Sr_2Ca_2Cu_3O_y$ thin films for different values of x

x	**Volume fraction of phases formed (%)**	
	Bi-2223 phase	Bi-2212 phase
0.1	80.000	20.000
0.3	71.428	28.571
0.5	77.777	22.222

Table 2. Values of lattice parameters, volume of unit cell and c/a of $Ti_xBi_{1.7}Pb_{0.3}Sr_2Ca_2Cu_3O_y$ thin films for different values of x

x	**a (Å)**	**b (Å)**	**c (Å)**	**V(Å)^3**	**c/a**
0.1	5.425	5.401	37.382	1095.308	6.89
0.3	5.449	5.458	37.621	1118.872	6.90
0.5	5.275	5.365	37.275	1054.896	7.06

The behavior of electrical resistance as a function of temperature for $Ti_xBi_{1.7}Pb_{0.3}Sr_2Ca_2Cu_3O_y$ thin films were x=0.1, 0.3 and 0.5 are studied and illustrated in Figure 2.

All thin film exhibited superconductor and showed metallic behavior above T_C (onset) value, evidencing that Bi-2223 phase is still the major one, in agreement with the XRD analysis. The T_C were found to be 114, 114.5 and 113 K for x=0.1, 0.3 and 0.5 respectively.

As can be seen from the Figure 2, in spite the room temperature resistances decreases towards lower values, two steps with broadening transition obtained for superconductor 0.1 Ti sample due to the presence of impurities grains or from the porosity, grain boundary resistivity and grain boundary weak-links in the sample.

While increasing Ti to 0.3 and 0.5 yield a well-defined one step with a small width transition reveled decreasing impurity phases and decreasing the grain boundary defects which should achieve the electrical properties.

The alter of the electrical properties the thin films can be associated to the modification in the holes content; weak coupling between BiO–BiO layers in the BSCCO compound allows the substitution of the different oxides for Bi^{3+} site which changes the carrier concentration due to the different cation doping levels [21].

AFM images and data collected from $Ti_xBi_{1.7}Pb_{0.3}Sr_2Ca_2Cu_3O_y$ thin films is illustrate Figure 3 and list in Table 3. It can be noticed that the highest average diameter of grains and lowest roughness values found for samples with 0.3 Ti, there is a remarkable grain growth for the thin film on the substrate with assistance presence oxygen and Ti.

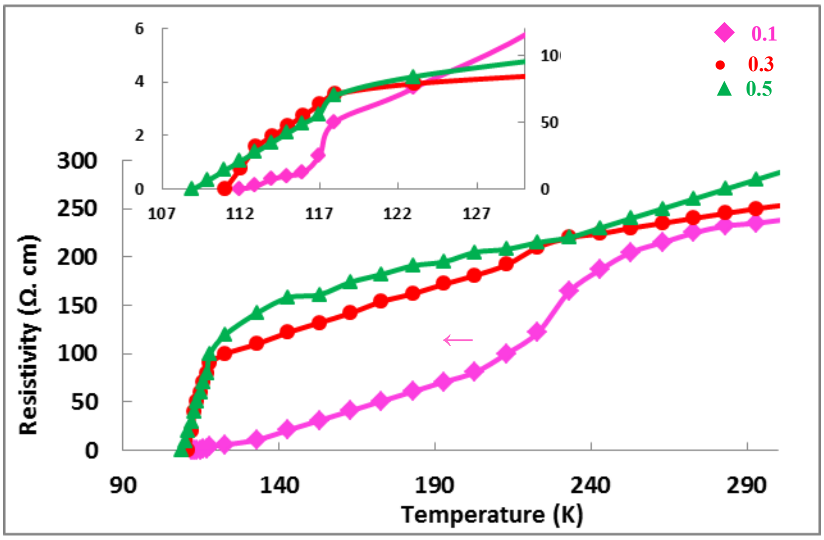

Figure 2. Temperature dependence of resistivity of $Ti_xBi_{1.7}Pb_{0.3}Sr_2Ca_2Cu_3O_y$ thin films for different Ti content

While sample of composition x=0.5 has more roughness and less average diameter than the other, this could be attributed for two reasons first the grains grow horizontally rather than vertically with small diameter similar conclusion reported by Abbas *et al.* [20], second presents of Ti oxide nanoparticles on the surface of the grains which causes the increasing roughness of the film.

The SEM photographs for 0.1, 0.3, and 0.5 samples are shown in Figure 4.

Table 3. Values of average grains diameter and roughness of $Ti_xBi_{1.7}Pb_{0.3}Sr_2Ca_2Cu_3O_y$ thin films for different values of x

x	Average Roughness	Average Grain diameter (nm)
0.1	2.70	110.0
0.3	2.39	112.5
0.5	4.70	92.3

It is obviously seen that formations of the surface morphology of the samples were changed with different Ti concentration; they are mainly composed by randomly oriented plate-like grains with different sizes. It can be seen that thin films present randomly dispersed small grains together with bigger ones. The microstructure found in the thin film with 0.3 Ti, increasing the size of these small grains and reducing their number and showed much larger pores in the near surface area. On other hand a part from the faceted thin film also it could be notice a crack due to the stress of the grain growth during the annealing process.

Further increasing addition of TiO_2 leads to the decreasing the grains size and dispersed of the Ti nanoparticles between the thin film matrix grains.

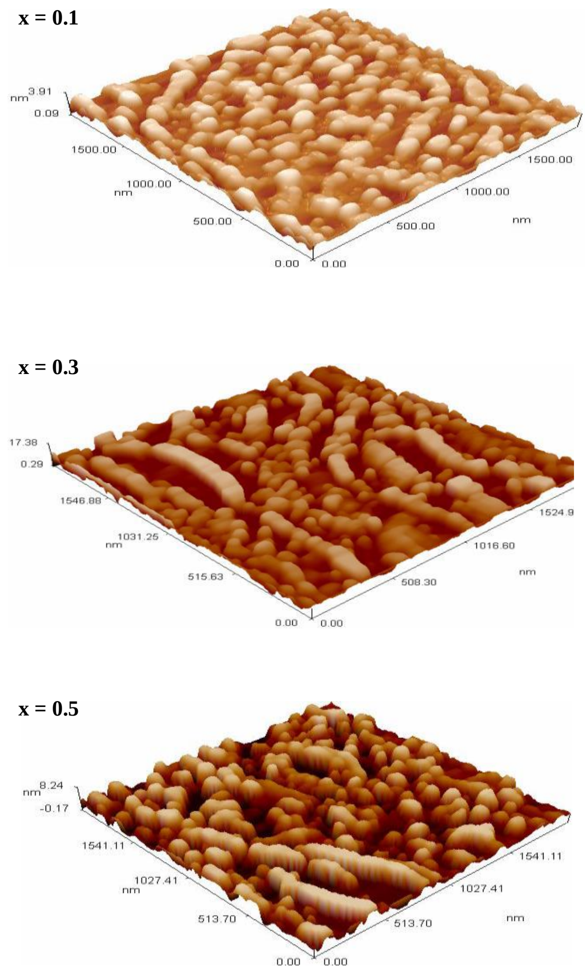

Figure 3. AFM images of the fracture surface of the $Ti_xBi_{1.7}Pb_{0.3}Sr_2Ca_2Cu_3O_y$ thin films for different Ti content

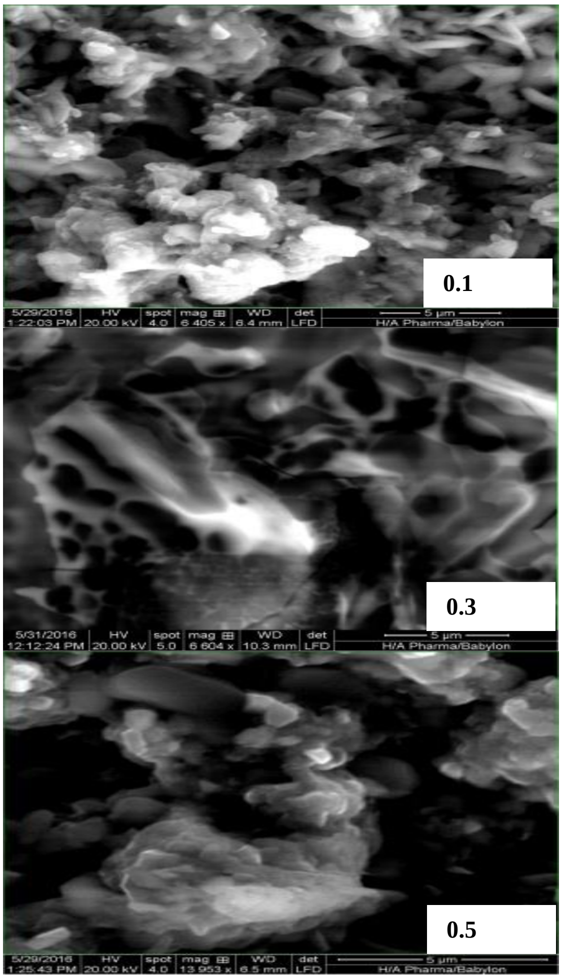

Figure 4. SEM surface micrographs of the $Ti_xBi_{1.7}Pb_{0.3}Sr_2Ca_2Cu_3O_y$ thin films for different Ti content

4. Conclusions

XRD analysis showed that $Ti_xBi_{1.7}Pb_{0.3}Sr_2Ca_2Cu_3O_y$ superconductor thin films were x=0.1, 0.3 and 0.5 the dominance of the high-T_C phase over the low-T_C phase.

Scanning electron microscopy images of the samples revealed that the addition of TiO_2 nanoparticles into Bi(Pb)-2223 composition would have significant effects on their grain sizes and morphologies and confirmed by the XRD. Electrical properties of the thin films can be associated to the modification in the holes content, the highest T_C at 114.5 K was obtained for the thin film with x = 0.3. The enhancement of the samples was attributed to the improvement of grain connectivity and flux pinning with the assistance of present oxygen which strengths links and increases the contact areas between the grains. This improvement of the superconductivity properties opens wide range for practical applications such as electronic devices which are dependent on the fabrication of high quality thin films.

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References

[1] Luiz A. Superconductor, Published by Sciyo 2010, Janeza Trdine 9, 51000 Rijeka, Croatia;

[2] Kharissova O, Kopnin E, Maltsev V, N Leonyuk, Leon-Rossano L, et al. Recent advances on bismuth-based 2223 and 2212 superconductors: synthesis, chemical properties, and principal applications, Crit Rev Solid State Mater Sci, 2014;39:253-76;

[3] Fujino H, Kume E, Sugimata E, Zhao X, Sakai S. Characteristics of intrinsic Josephson junctions using a $Bi_2Sr_2CaCu_2O_x$ thin film estimated overall in a chip, Physica C Supercond, 2004; 412-414: 1410-3;

[4] Yildirim G, Varilic A, Terzioglu C. Anisotropic nature and scaling of thermally activeted dissipation mechanism in Bi-2223 superconducting thin film. J. Alloys Comp. 2013; 8(554): 327-34;

[5] Tretyakov Y, Oskina T., Thermal stability and oxygen nonstoichiometry of BSCCO superconductors, Physica C Supercond 1991; 185–189(1): 471–2;

[6] Oboudi S. Synthesis and Magnetic Properties of $Bi_{1.7}Pb_{0.3}Sr_2Ca_2$ Cu_3O_{10+d} Added with Nano Y, J Supercond Nov Magn, 2017; 30(6):1473–82;

[7] Nabil A Yahya, Abd-ShukorR. Effect of different nano-sized MgO on the transport critical current density of $Bi_{1.6}Pb_{0.4}Sr_2Ca_2$ Cu_3O_{10} superco-nductor. J Supercond Nov Magn. 2013; 27(2):329–35;

[8] Mawassi R, Marhaba S, Roumie M, Awad R, Korek M, et al. Improvement of superconducting parameters of $Bi_{1.8}Pb_{0.4}$ $Sr_2Ca_2Cu_3O_{10+\delta}$ added with nano-Ag. J Supercond Nov Magn. 2013;27(5):1131-42;

[9] Kong W, Abd-Shukor R. Enhanced electrical transport properties of nano $NiFe_2O_4$ added $(Bi_{1.6}Pb_{0.4})Sr_2Ca_2Cu_3O_{10}$ superconductor. J. Supercond. Novel Mag. 2010; 23(2): 257–63;

[10] Oboudi S, Mustafa M. Synthesis and Characterization of Ag nanoparticles addition on BPSCCO Superconducting thin films. Adv Nanopart, 2016; 5: 75-82;

[11] Oboudi S, Mustafa M. Gold nanop-articles effect on (Bi,Pb)-2223 supercon-ducting Thin Films, Applied Physics Research, 2016; 8(5): 64-74;

[12] Díaz-Valdés E, Jergel M, Falcony-Guajardo C, Morales F, Araujo-Osorio J. Statistical preparation and characterization of Bi-based superconducting thin films, Superficies, 2000; 10: 9-14;

[13] Aksan M, Altin S, Yakinci M, Guldeste A, Balci Y. Effect of Bi deficiency on grain alignment of BiPb-2223 thin film fabricated using rf sputtering process and on critical current density properties, Mat Sci Technol, 2011; 27(1): 314-9;

[14] Guldeste A. Bismuth based thin film superconductors, Pembroke College, A thesis submitted for the degree of Doctor of Philosophy in the University of Oxford. Hilary Term 1994;

[15] Takahira S, Ichino Y, Yoshida Y. Fabrication of High Jc (Bi,Pb)2223 thin films by PLD and Post-annealing process. Physics Procedia, 2015; 65: 153–6;

[16] Bilgili O, Selamet Y, K ocabas K. Effects of Li substitution in Bi-2223 superconduc-tors. J. Supercond Nov Magn, 2008; 21: 439-49;

[17] Huong P, Wang H , Verma A, Kim S, Lee D, Kim K. Effect of selective substitution on the microstructure and properties of $Bi_2Sr_2Ca_2Cu_3O_{10}$ superco nductor, Chinese J. Phys, 1993 ;31,(6-11): 1151-6;

[18] Karppinen M, Lee S, Lee J, Poulsen J, Nomura T, et al. Hole doping in Pb free and Pb-substituted $(Bi,Pb)_2Sr_2Ca_2Cu_3O_{10+d}$ superconductors, Phys. Rev. B., 2003; 68 (5): 54502-7;

[19] Paulose P, Patil S, Frank H, Guntherodt G. Influence of Pb and Nb substitution on pinning and irreversibility behavior of Bi2212, Physica C.1993;208(1-2):11-7;

[20] Abbas M, Bahedh H, Abbas L. Superconductivity in $Bi_{2-x}Sb_xPb_{0.3}Sr_{2-y}Ba_yCa_2Cu_3O_{10+d}$ thin films, Asian Academic Research J. Multidiscplinary, 2015;2(7):126-35;

[21] Ozkurt B, Ekicibil A, Aksan M, Ozcelik B, Yakinci M, et al., Structural and physical properties of Nd substituted bismuth cuprates $Bi_{1.7}Pb_{0.3-x}Nd_xSr_2Ca_3Cu_4O_{12+y}$, J. Low Temp Phys. 2007;149 (1): 105-18.