Current Applied Science and Technology Vol. 18 No. 3 Sep. - Dec. 2018
DOI: 10.14456/cast.2018.8

The Effect of Ti-doped on the Structure of Y134 and Y257 Superconductors

Thitipong Kruaehong[1*] Supphadate Sujinnapram[2], Pongkaew Udomsamuthirun[3], Tunyanop Nilkamjon[3] and Sermsuk Ratreng[3]

[1]Department of Physics, Faculty of Science and Technology, Suratthani Rajabhat University, Suratthani, Thailand
[2]Department of Physics, Faculty of Liberal Arts and Science, Kasetsart University, Kamphaeng Saen Campus, Nakhon Pathom, Thailand
[3]Prasanmitr Physics Research, Department of Physic, Faculty of Science, Srinakharinwirot University, Bangkok, Thailand

Received: 21 November 2017, Revised: 21 August 2018, Accepted: 9 November 2018

Abstract

The powder of Y134, Y257 and Ti composite was synthesized by solid state reaction. The crystal structure of the powder was investigated by using powder X-ray diffraction. The raw data of XRD was characterized for phase separation of composition. The samples consist of a superconducting phase with orthorhombic structure and Pmmm space group and a non-superconducting phase that have various structures and space groups. The Ti doped affected the increasing *c* lattice parameters and superconducting phase. The impurity phase had no effect on increasing the *c* lattice superconducting phase. The *c* lattice parameters and superconducting phase was increased following the Ti-doped.

Keywords: Y134 superconductor, Y257 superconductor, titanium-doped

1. Introduction

During the past thirty years, many researchers have intensively carried out experiments on the properties of Y123 as synthesized by Chu and co-workers [1] In 1987 with the critical temperature at 93 K. The Y123 superconducting material was one of the materials chosen for candidate application such as magnetic bearing [2], flywheel energy storage [3] and microwave devices [4], etc. The properties of this material were high-current density and high critical magnetic fields [5]. The development of this material requires a crystal structure. The Y123 has the orthorhombic perovskite structure with two CuO_2 planes and one Cu-O chain [6]. The superconductivity occurs in the CuO_2 plane, but the Cu-O chain is non-superconducting and acts as charge reservoirs as show in Figure 1 [7]. After the discovery of Y123, The Y124 [8] and Y247 [9] have a critical

[*]Corresponding author: Tel.: +66 851 09 0567 Fax: +66 77355 666
E-mail: kruaehong@hotmail.com

temperature of 80 K and 40 K, respectively. The critical temperature values remain in the range of Y123. In 2009, Y358 superconductors were synthesized by conventional solid state reaction by Aliabadi *et al.* [10]. The Y358 was a new Y-based high-temperature superconductor with the highest critical temperature above 100 K. In 2010, Tavana and Akhavan [11] simulated the crystal structure of Y358. The Y123 and Y358 had similar crystal structures. The Y358 has five CuO_2 planes and three Cu-O chains and the lattice parameters a=3.888 Å, b=3.823 Å and c=31.013 Å as show in Figure 1.

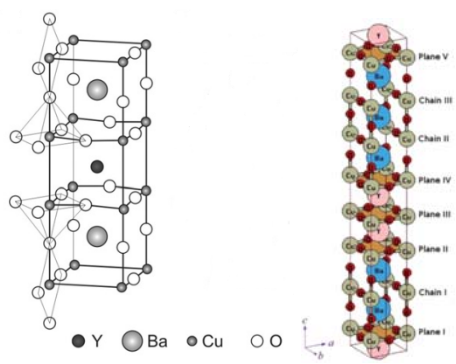

Figure 1. Crystal structures of $YBa_2Cu_3O_7$ and $Y_3Ba_5Cu_8O_{18}$

Increasing the CuO_2 planes and Cu-O chain essentially affects an increase in the critical temperature of Y-based superconductors. In 2010, Udomsamuthirun *et al.* [12] refered to the assumption that Yttrium-atoms plus Barium-atoms were equal to Cu-atoms used to synthesize the new YBaCuO superconductor by using solid state reaction. The critical temperature measurement was by standard four-probes method. The values of the critical temperature were close to Y123. In 2011, Sujinnapram *et al.* [13], characterized the crystal structure using the Reitveld refinement method [14]. Resultes revealed that, the lattice parameters of a and b are nearly equal in all samples, whereas the lattice parameter of c increases with Y-atoms. In 2015, Chainok *et al.* [15], synthesized the Y134 superconductor by conventional solid state reaction. The calcinations and sintering temperature was 950ºC. The annealing temperature was 500ºC. The lattice parameters were a=3.80665Å, b=3.88835 Å and c=15.26554 Å. In 2013, Kruaehong [16] prepared a new Y257 superconductor by solid state reaction. The calcinations and sintering temperature was 950ºC and annealing was 500ºC with the lattice parameters of a=3.81080 Å, b=3.85440 Å and c=26.49670 Å. The Y134 and Y257 were Y-based superconductors. However, the Y134 and Y257 superconductors have different Y-atoms. Y134 has one yttrium atom and Y257 has two Yttium atoms in its formula. Both superconductors show different physical properties. However, the improved superconducting material must be substitute for the constitutional element [17]. The atom radiant of element substitution should be smaller than Cu-atoms (0.730Å). Therefore, the element used in this research was Ti with the atom radius as 0.605 Å. The smaller atom radius improves the crystal structure.

This paper studies the effect of Ti doped on the crystal structure of Y134 and Y257 superconductors, The crystal structures of bulk Y134 and Y257 samples doped Ti with the various concentrations of 0, 0.05, 0.10, 0.15, 0.20, and 0.25, respectively. The space groups, lattice parameter of superconducting compound and non-superconducting compound, anisotropic parameters were carried out from Rietveld refinement method.

2. Materials and Methods

The two series of polycrystalline Y134 ($YBa_3Cu_4Ti_xO_{9-x}$) and Y257($Y_2Ba_5Cu_7Ti_xO_{15-x}$) with x=0, 0.05, 0.10, 0.15, 0.20 and 0.25 were prepared by the solid state reaction method from appropriate amounts of high-purity powder of Y_2O_3, $BaCO_3$, CuO and TiO_2. The calcinations of mixture powder were twice operated at a temperature of 950°C for 24 hrs. The result of each series was powders. Finally, the powder was pressed into pellets and sintered at 950°C for 24 hrs, annealed at 500°C for 12 hrs in an oxygen atmosphere and cooled down to room temperature with a heating rate of 2°C/min. The pellets of the each series were then reground to powder. The structural analysis was done by Powder X-ray Diffraction method(Philips, Netherlands) with a scan range(2θ) of 5°-90° . The X-ray source of Cu tube and X-ray generator at 40 kV and 30 mA is step time 3 sec/min with step size(2θ) at 0.05° and the wavelength of X-ray at λ= 1.5406 Å. The scan speed was 1°/min at room temperature. The source of the X-ray was CuK_α radiation and Ni was a filter. The Rietveld method characterized raw data of XRD for determined space groups and the lattice parameter of composition, respectively.

3. Results and Discussion

The XRD pattern of the samples is shown in Figure 2 Pure Y134 and Y257 are represented in blue. The samples with doped Ti are shown in a different color. The spectrum of our samples was similar to the Y123 spectrum [18] at the 2θ at 32°. The impurity occurred because of the increasing of Ti concentration. The planes of superconducting the Y134 ocurred at (hkl) as (0 0 3), (010) and (0 0 4) and at the 2θ at 17.414°, 22.852° and 23.289°, respectively. The (hkl) of Y257 appeared as(1 0 3), (1 1 1) and (0 0 6) and at the 2θ at 29.276°, 33.434° and 35.247°, respectively. All planes of the two samples show an orthorhombic structure.

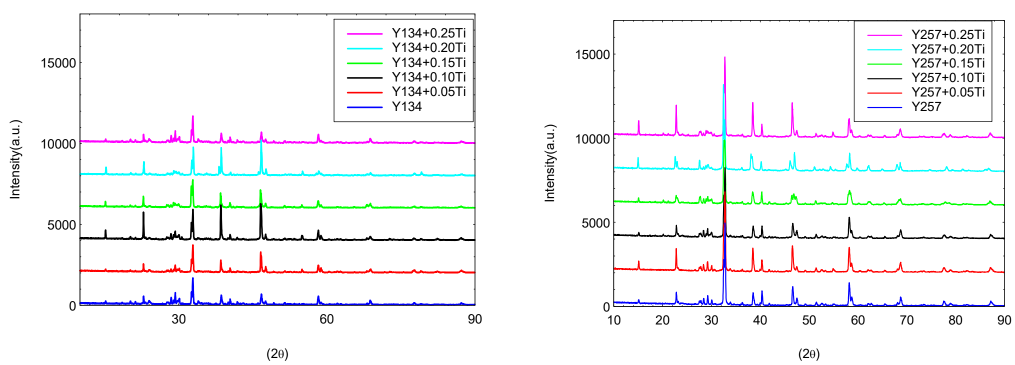

Figure 2. XRD pattern of Y134+Ti and Y257+Ti superconductors

The samples consist of two phases. The first was a superconducting phase with an orthorhombic structure and Pmmm space group symmetry and the second was a non-superconducting phase with various space groups as shown in Table 1. The Y134+0.25 and Y257+0.25 show the highest superconducting phase in Y134 and Y257. Thus, increasing the Ti concentration also increased the superconducting phase. The lattice parameters of the superconducting phase is shown in Table 2. The *c* lattice parameter of Y257 with Ti composite was twice as long as Y134. Increasing the superconducting phase also causes a in longer *c* lattice parameter. The Y134 and Ti composite does not have the non-superconducting phase of Y211.

Table 1. The percentage of superconducting and non-superconducting compounds

Samples	Superconducting Compound	Non-superconducting Compounds		
		(Y_2BaCuO_5), Pbnm	$BaCuO_2$, Im-3m	$Ba_2Cu_3O_6$, Pccm
Y134	60	-	20	20
Y257	70	30	-	-
Y134+0.05Ti	72	-	18	10
Y257+0.05Ti	76	24	-	-
Y134+0.10Ti	74	-	16	10
Y257+0.10Ti	80	20	-	-
Y134+0.15Ti	79	-	11	10
Y257+0.15Ti	85	-	10	5
Y134+0.20Ti	82	-	15	3
Y257+0.20Ti	90	-	5	5
Y134+0.25Ti	88	-	10	2
Y257+0.25Ti	95	-	5	-

Table 2. The lattice parameter of superconducting compounds

Samples	Lattice constant		
	***a*(Å)**	***b*(Å)**	***c*(Å)**
Y134	3.80926	3.86889	15.13311
Y257	3.81974	3.88374	26.49670
Y134+0.05Ti	3.80924	3.86598	15.15486
Y257+0.05Ti	3.82896	3.88965	26.50630
Y134+0.10Ti	3.82172	3.88705	15.18759
Y257+0.10Ti	3.81917	3.88797	26.51320
Y134+0.15Ti	3.80939	3.88326	15.24488
Y257+0.15Ti	3.82412	3.87321	26.52132
Y134+0.20Ti	3.80918	3.88134	15.31448
Y257+0.20Ti	3.82432	3.88542	26.53212
Y134+0.25Ti	3.82451	3.88123	15.35231
Y257+0.25Ti	3.81596	3.86231	26.54321

In this study the physical properties and crystal structure of the high-temperature superconductor were investigated the impurity phase was present and important for analysis of the experiment data. The impurity phase was related to precursors of the materials. However, generally the impurities phase occured during the heat treatment. Table 3 shows each of the impurities in the samples in 3 catetories. The first impurity was Y211 (Y_2BaCuO_5). The Y211 influenced the microstructure of the superconducting properties of the samples. It is well known that the samples with a Y211 inclusion raised the critical current density (J_c) [19] and critical magnetic field [20]. However, Y211 inclusion exceeded 40 mol% [21] in the samples [22]. Additionally, the Y211 had a positive effect on the magnetic properties as a good pinning center [23]. One phase of the impurities appeared as a result of the samples in $BaCuO_2$ where the physical properties have not been often reported. The appearance of $BaCuO_2$ is highly inhomogeneous to the surface of the samples. The oxygen content of $BaCuO_2$ varies between 1.8-2.5 in the chemical formula [24]. The variation of the oxygen content of $BaCuO_2$ changes following the Cu^{2+} [25] ion in the crystal structure. Small amounts of $Ba_2Cu_3O_6$ in the last phase of the impurity can be detected. The $Ba_2Cu_3O_6$ and $BaCuO_2$ that appear in the samples showed a defective crystal structure.

Table 3. The lattice parameter of non-superconducting compounds

Samples	Non-Superconducting Compounds								
	Y_2BaCuO_5, Pbnm			$BaCuO_2$, Im-3m			$Ba_2Cu_3O_6$, Pccm		
	a(Å)	*b*(Å)	*c*(Å)	*a*(Å)	*b*(Å)	*c*(Å)	*a*(Å)	*b*(Å)	*c*(Å)
Y134	-	-	-	18.31372	18.31372	18.31372	13.05722	20.63098	11.39764
Y257	7.25231	12.23212	5.54890	-	-	-	-	-	-
Y134+0.05Ti	-	-	-	18.30035	18.30035	18.30035	13.02788	20.63243	11.39855
Y257+0.05Ti	7.21762	12.07321	5.63210	-	-	-	-	-	-
Y134+0.10Ti	-	-	-	18.29048	18.29048	18.29048	13.00549	20.60827	11.37064
Y257+0.10Ti	7.24030	12.15212	5.65223	-	-	-	-	-	-
Y134+0.15Ti	-	-	-	18.29277	18.29277	18.29277	13.00968	20.61089	11.37079
Y257+0.15Ti	-	-	-	18.27230	18.27230	18.27230	13.02557	20.64878	11.39420
Y134+0.20Ti	-	-	-	18.35385	18.35385	18.35385	13.07883	20.68951	11.44247
Y257+0.20Ti	-	-	-	18.29818	18.29818	18.29818	13.01123	20.67820	11.48885
Y134+0.25Ti	-	-	-	18.23412	18.23412	18.23412	13.05234	20.68235	11.45685
Y257+0.25Ti	-	-	-	18.31958	18.31958	18.31958	13.02392	20.67834	11.40198

Y134 and Y257 with Ti composites were synthesized by using solid state reaction and used the temperature to powder calcined and sitered at 950 ºC. The powders samples were investigated to study the crystal structure by using powder X-ray Diffraction. The characterized and lattice parameters of phases composition used the Reitveld refinement method. The samples divided into two phases, The superconducting phase had an orthorhombic structure and Pmmm symmetry. The non-superconducting phase had 3 categories. The Y211 had the orthorhombic structure with Pbnm space group. The $BaCuO_2$ had the cubic structure with Im-3m space group. The final phase of the non-superconducting sample was $Ba_2Cu_3O_6$ had an orthorhombic structure with Pccm space group. The effect of the Ti doped on the Y134 and Y257 showed a more superconducting-phase and longer c lattice parameter. The Y134 and Y134 with Ti composite does not have the impurity of Y211.

4. Conclusions

Y134 and Y257 with Ti composites were synthesized by using solid state reaction and used the temperature to powder calcined and sitered at 950ºC. The powders samples were investigated to study the crystal structure by using powder X-ray Diffraction. The characterized and lattice parameters of phases composition used the Reitveld refinement method. The samples divided into two phases, The superconducting phase had on orthorhombic structure and Pmmm symmetry. The non-superconducting phase had 3 categories. The Y211 has an orthorhombic structure with Pbnm space group. The $BaCuO_2$ has a cubic structure with Im-3m space group. The final phase of the non-superconducting phase was $Ba_2Cu_3O_6$ which had an orthorhombic structure with Pbnm space group. The $BaCuO_2$ has a cubic structure with Im-3m space group. The final phase of the non-superconducting phase was $Ba_2Cu_3O_6$ which had an orthorhombic structure with Pccm space group. The effect of the Ti doped on Y134 and Y257 showed the more superconducting-phase and the longer *c* lattice parameter, While Y134 and Y134 with Ti composite did not have the impurity of Y211.

5. Acknowledgements

The authors thank the Research and Development Institute of Suratthani Rajabhat University, Faculty of Science and Technology, for financial support.

References

[1] Wu, M.K., Ashburn, J.R., Torng, C.J., Hor, P.H., Meng, R.L., Gao, L., Huang, Z.J., Wang, Y.Q. and Chu, C.W., 1987. Superconductivity at 93 K in a new mixed-phase Y-Ba-Cu-O compound system at ambient pressure. *Physical Review Letter*, 58, 908-910.

[2] Han, Y.H., Lee, J.S., Sung, T.H., Han, S.C., Kim, Y.C. and Kim, S.J., 2002. Design a hybrid high T_c superconductor bearings for flywheel energy storage system. *Physica C*, 372-376, 1457-1461.

[3] Koshizuka, N., Ishikawa, F., Nasu, H., Murakami, M., Matsunaga, K., Saito, S., Saito, O., Nakamura, Y., Yamamoto, H., Takahata, R., Itoh, Y., Ikezawa, H. and Tomita, M., 2003. Progress of superconducting bearing technologies for flywheel energy storage systems. *Physica C*, 386, 444-450.

[4] Saini, S., Mele, P., Mukaida, M. and Kim, S.-J., 2015. Microwave irradiation on a-axis oriented Y123/Pr123 two-stacked Josephson Junctions device. *Current Applied Physics*, 15, 569-573.

[5] Tallouli, M., Sun, J., Chikumoto, N., Otabe, E.S., Shyshkin, O., Charfi-Kaddour, S. and Yamaguchi, S., 2016. Observation of self-magnetic field relaxations in Bi2223 and Y123 HTS tapes after over-current pulse and DC current operation. *Cryogenics*, 77, 53-58.

[6] Alecu, G., 2004. Crystal structure of some high-temperature superconductors. *Romanian Reports in Physics*, 56, 404-412.

[7] Huijben, M., Koster, G., Blank, H.A. and Rijnders, G., 2008. Interface engineering and strain in $YBa_2Cu_3O_{7-\delta}$ thin film. *Phase Transition*, 81, 703-716.

[8] Marsh, P., Fleming, R.M., Mandich, M.L., DeSantolo, A.M., Kwo, J., Hong, M. and Martinez- Miranda, L.J., 1988. Crystal structure of the 80 K superconductor $YBa_2Cu_4O_8$. *Nature*, 334, 141-143.

[9] Bordet, P., Chaillout, C., Chenavas, J., Hodeau, J.L., Marezio, M. and Kaldis, J.E., 1988. Structure Karpinski determination of the new high temperature superconductor $Y_2Ba_4Cu_7O_{14+x}$. *Nature*, 334, 596-598.

[10] Aliabadi, A., Farshchi, M. and Akhavan, M., 2009. A New Y-based HTSC with T_c above 100 K *Physica C*. 469, 2012-2014.

[11] Tavana, A. and Akhavan, M., 2010. How T_c can go above 100 K in the family. *Euro Physics Journal B*, 73, 79-83.

[12] Udomsamuthirun, P., Kruaehong, T., Nilkamjon, T. and Ratreng, S., 2010. The new superconductors of YBaCuO materials. *Journal of Superconductivity and Novel Magnetism*, 23, 1377-1380.

DOI: 10.14456/cast.2018.8

[13] Sujinnapram, S., Udomsamuthirun, P., Kruaehong, T., Nilkamjon, T. and Ratreng, S., 2010. XRD Spectra of New YBaCuO Superconductors. *Bulletin Material Science*, 5, 1053-1057.

[14] Rodriguez-Carvajal, J., 2000. Fullprof. Laboratoire Leon Brillouin (CEACNRS).

[15] Chainok, P., Khuntak, T., Sujinnapram, S., Tiyasri, S., Wongphakdee, W., Kruaehong, T., Nilkamjon, T., Ratreng, S., and Udomsamuthirun, P., 2015. Some properties of $YBa_mCu_{1+m}O_y$ (m= 2, 3, 4, 5) superconductors. *International Journal of Modern Physics B*, 29, 1-14.

[16] Kruaehong, T., 2013. Preparation and characterization of the new Y257 superconductors. *Advanced Materials Research*, 770 22-25.

[17] Sahoo, M. and Behera, D., 2014. Effect of Ti doping on structural and superconducting property Of $YBa_2Cu_3O_{7-y}$ high T_c superconductor. *Journal of Superconductivity and Novel Magnetism*, 27, 83-93.

[18] Guner, S.B., Gorur, O., Celik, S., Dogruer, M., Yildirim, G., Varilici, A. and Terzioglu, C., 2012. Effect of zirconium diffusion on the microstructure and superconducting properties of $YBa_2Cu_3O_{7-\delta}$ superconductors. *Journal of Alloys and Compounds*. 540, 260-266.

[19] Ouerghi, A., Moutalbi, N., Noudem, J.G. and M'chirgui, A., 2017. The influence of slow cooling on Y211 size and content in single-grain YBCO bulk superconductor through the infiltration-growth process. *Physica C*, 534, 37-44.

[20] Dias, F.T., Vieira, V.N., Wolff-Fabris, F., Kampert, E., Gouveac, C.P., Campos, A.P.C., Archanjo, B.S., Schaf, J., Obradors, X., Puige, T., Roa, J.J. and Sahoo, B.K., 2016. High-field paramagnetic Meissner effect up to 14 T in melt-textured $YBa_2Cu_3O_{7-\delta}$. *Physica C*, 525, 105-110.

[21] Wu, X.D., Xu, K.X., Qiu, J.H., Pan, P.J. and Zhou, K., 2016. Effect of Y_2BaCuO_5 content and initial temperature of slow-cooling on the growth of YBCO bulk. *Physica C*, 468, 435-441.

[22] Dogan, F., 2005. Continuous solidification of $YBa_2Cu_3O_{7-x}$ by isothermal undercooling. *Journal of the European Ceramic Society*, 25, 1355-1358.

[23] Abdelhalim, H.T.A., B.A., E. Hassan., Ahmed, T., Brahim, L. Mustapha, B., Habiba, E.H., E.H. and Youssef, E.H., 2018. Angular dependence of the critical current density and the temperature scaling of the flux pinning force in YBCO thin film. *Chinese Journal of Physics*, 56, 754–759.

[24] Diaz-Guerra, C., Piqueras, J., Garcia, J.A., Remon, A. and Opagiste, C., 1997. Cathodoluminescence and photoluminescence studies of sintered $BaCuO_2$. *Journal of Luminescence*, 71, 299-304.

[25] Supadanaison, R., Panklang, T., Wanichayanana, C., Kaewkao, A., Nilkamjon, T., Udomsamuthirun, P., Tiyasri, S., Wongphakdee, W. and Kruaehong, T., 2018. Determination of Cu^{2+} and Cu^{3+} by titration in Y134 and Y145 superconductor. *Materials Today: Proceedings*, 5(7 Part 1), 14896-14900.