Superconductivity and Structural of $ErBa_2Cu_3O_{7-\delta}$ Bulk Superconductor

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Abstract

Bulk Er123 ($ErBa_2Cu_3O_{7-\delta}$) superconducting ceramics were prepared via conventional solid state reaction. The samples were subjected to thermal treatment for 24 h calcined at 1223 K. The pelletized powder was sintered at 1223 K for 24 h. The samples showed a single step transition in the resistivity versus temperature curves. The $T_c$onset of the samples was 93 K. The XRD data showed that the superconducting compound had an orthorhombic structure with the lattice constant as a = 3.82 Å, b = 3.88 Å, c = 11.68 Å and orthorhombicity parameter as 1.69% whereas the non-superconducting compound was a cubic structure with $a = b = c$ = 18.25 Å. The simulation of atomic position in three dimensions. The SEM micrographs showed large grain sizes with a homogeneous surface. The EDX (mapping) showed a smooth distribution of Er, Ba, Cu and O bands without impurities. The heat reaction showed the endothermic curve with the peritectic temperature at 1277.980 K carried out by the DTA technique. Finally, The Cu^{2+} = 6.30×10^{-6} and Cu^{3+} = 1.82×10^{-6} Cu^{3+}/Cu^{2+} = 0.29 and oxygen deficiency have a δ value of 0.16 which were determined by a standard iodometric titration method.

Introduction

Superconductors have been the subject of intensive research since the discovery of high-temperature superconductors [1]. Superconductivity is the phenomenon where the electricity resistivity suddenly vanished when the material was cooled under a certain temperature referred to as critical temperature (T_c) [2]. The high-temperature superconductors are in the oxide form of RE123. Introduction of the chemical composition of $REBa_2Cu_3O_y$ (RE = rare earth elements such as Y, Dy and Er) [3] opens the low temperature physics to possibilities of applying a new technology to the electric power system.

The first superconductor discovered in the RE123 group was Y123 ($YBa_2Cu_3O_{7-x}$). It exhibited a critical temperature above the temperature of liquid nitrogen at 77 K, as explained by Chu and coworkers [4] in 1987.

Therefore, this material was expected to be applied with current [5] and magnetic applications [6]. RE123 has been used in transformers [7], fault current limiters [8], motors [9] and other various applications [10]. However, each application must observe the physical properties in the microstructure of this material. Since the RE123 superconductors have different critical temperatures and crystal structure [11], its crystal structure has varying numbers of the CuO_2 planes and CuO chains [12]. The difference of the plane and chain lead to various physical properties. For example, Y-based superconductors displayed the most attraction for application and consist of Y123, Y124 [13], Y247 [14] and Y358 [15 − 16]. One unit cell of Y123 has two CuO_2 planes and one CuO chain [17]. The Y124 has one CuO double chain [18].

Y247 has one CuO_2 plane and one CuO chain, and one double chain [19] while Y358 has five CuO_2 planes and three CuO chains [20]. The Y358 has a crystal structure similar to Y123. In addition, the Y-based superconductor is interesting. Er123 ($ErBa_2Cu_3O_{7-x}$) is another significant superconductor because Er123 is a Type II high-temperature superconductor similar to Y123, which is known as the RE123 system.

This type of superconductor is classified as the most stable high-temperature superconductor. In 1995, R. Abd-Shukor et al [21] synthesized the composition $ErBa_2Cu_3O_{7-\delta}$ by using the solid-state reaction method. X-ray analysis showed that the superconducting compound had an orthorhombic structure with lattice parameters a = 3.82 Å, b = 3.89 Å and c = 11.67 Å and the non-superconducting compound had a tetragonal structure with a = b = 3.85 Å and c = 11.79 Å. The electrical resistances were carried out using the four-point probes method with T_c = 90 K. T. Naito et al [22] investigated Er123 bulk superconductors and separated the two compounds. The first compound was the superconducting matrix phase of Er123 and the second compound was the non-superconducting phase of Er211(Er_2BaCuO_5) which were synthesized by the melt texture growth. The superconducting transition temperature of the samples was about 89 K. In 2002, U.C. Upreti [23] synthesized pellets of $ErBa_2Cu_{3-x}Fe_xO_{7-\delta}$ by the solid state reaction method. For x = 0, the obtained sample showed a critical temperature of 91.80 K. The crystal structure had an orthorhombic structure with the lattice constant a = 3.82 Å, b = 3.89 Å and c = 11.68 Å. The oxygen content was 6.93 characterized by standard iodometric titration. It can be seen that the Y123 and Er123 are similar in crystal structure and critical temperature value.

In this work, bulk Er123 superconductor was prepared by the solid state reaction method. The critical resistivity was carried out by the conventional four-probes method. The existence of Er123 structure in our sample has been verified by powder X-ray diffraction and X-ray diffraction supported with the Rietveld refinement [24] analysis software calculation. The morphology and elementary analysis were characterized by Scanning Electron Microscope (SEM) and Energy Dispersive X-ray Spectroscopy EDXS (mapping techniques). The onset temperature, endset temperature and oxygen contents were investigated by Differential Thermal Analysis (DTA) and standard iodometric titration.

Materials and Methods

The purity of 3N (99.999%) Er_2O_3, $BaCO_3$ and CuO were used to produce bulk ceramic $ErBa_2Cu_3O_{7-\delta}$ by the solid state reaction technique. The appropriate amount of chemicals were mixed in the ratio of 1 : 2 : 3. The mixed powder was placed in an alumina crucible cup, then calcined twice in ambient pressure at a constant temperature of 1223 K for 24 h in atmosphere (Eurothem Controller, Lenton box Furnace), and then slowly cooled at a rate of 275.50 K min^{-1} to room temperature. The resulting powders were thoroughly ground to achieve powder homogeneity and pressed by hydraulic machine into pellets 30 mm in diameter and 3 mm thick. The pellets were sintered at 1223 K for 24 h. Finally, the box furnace was cooled down for 24 h at a rate of 275.50 K min^{-1} to 773 K for annealing and doped oxygen.

The obtained samples were investigated for crystal structure by powder X-ray diffraction (Bruker D8-Discovery) using $CuK_{\alpha1}$ radiation (λ = 1.55 Å) at 40 kV and 30 mA with a step of 0.023° over the angle range 10° − 90°. The Rietveld refinement software program was used to identity phase compositions and lattice parameters for each compound. The electrical resistivity of the sample was carried out by using the standard four-probes measurement within the range temperature of 77 − 120 K. Nanovoltmeter Fluk 8845A 6.50 digit, constant current source HY3005, and Fluk thermometer controller 51Π were used for the measurement. The Scanning Electron Microscope (SEM, FEI, Quanta400) system was used to study surface morphology and Energy Dispersive X-ray Spectroscopy (EDXS) operated with the mapping techniques attached to the SEM was used to determine the chemical composition analysis and distributed elements. The peritectic temperature of Er123 powders was measured using a specially designed differential thermal analysis (DTA) system (NETZSCH449) model. Ten milligrams of the synthesized Er123 powder was placed directly in a high-purity alumina pan with dimensions of 5.00 mm in diameter and 2.50 mm in height for DTA measurement performance. Another alumina pan with the same dimensions was used as a reference. All the experiments were carried out under ambient pressure. Idometric titration was used to determine the Cu^{2+}, Cu^{3+}, Cu^{2+}/Cu^{3+}, ratio, oxygen content and chemical formulae, respectively.

Results and Discussion

The electrical resistivity and normalized resistivity as a function temperature from 77 K – 120 K is shown in Fig. 1. and Fig. 2., respectively. The sample exhibited normal behavior in the pellets above onset critical temperature ($T_c$onset) displaying good grain and a homogeneous surface of the sample. All critical temperatures are shown in Table 1. The various T_c including $T_c$offset, $T_c$middle and $T_c$onset values. The resistivity measurement versus temperature used the lowest current density at 2.55×10^{-3} A m^{-2}. The values of current density were 3.18×10^{-3} A m^{-2} and 3.82×10^{-3} A m^{-2}, respectively. The current density at 2.55×10^{-3} A m^{-2} showed the $T_c$offset, $T_c$middle and $T_c$onset at 89.98 K, 90.89 K and 93 K, respectively. When the current density increased, T_c values were reduced. It was found that current density affects the critical temperature of this superconductor. The various T_c shifted down when the current density increased. In 2007, I. Hamadneh [3] synthesized Y123, Dy123 and Er123 superconductors using the coprecipitation (COP) method. The critical temperature of the samples in the range of 50 K – 300 K was measured by the standard four-probes technique with the constant current of 30 mA. The result revealed that the Er123 superconductor exhibited a critical temperature value of 91 K. The different values between our sample and Hamadneh 's sample was 2 K. The values of 2.55×10^{-3} A m^{-2} converted in mA unit approximately 200 mA. Our experiment used high current density to measure the critical temperature. Thus, lower current density caused higher critical temperatures.

The XRD pattern is shown in Fig. 3. The red cycle from experiment data and the black solid line calculated from simulated data correspond with experimental data. The vertical green band tics is Bragg diffraction [25]. The blue solid line in the bottom pattern was different in the experiment data from the calculated data. The ER123 sample can be separated into the superconducting compound and the non-superconducting compound. The percentage of the superconducting compound was 91% with the lattice constant $a = 3.81863$ Å, $b = 3.88354$ Å and $c = 11.68209$ Å. The first compound corresponds to orthorhombic structure with Pmmm symmetry. The second compound $BaCuO_2$ was non-superconducting with 9% and it showed a cubic structure and lattice constant $a = b = c = 18.24617$ Å with a Im-3m space group. Orthorhombicity of the sample from lattice parameters of the superconducting compound was calculated by using the formula $200(b-a)/(a+b)$ giving 1.69%. AS expected, this low orthorhombicity value displayed a homogeneous surface morphology which was found by SEM.
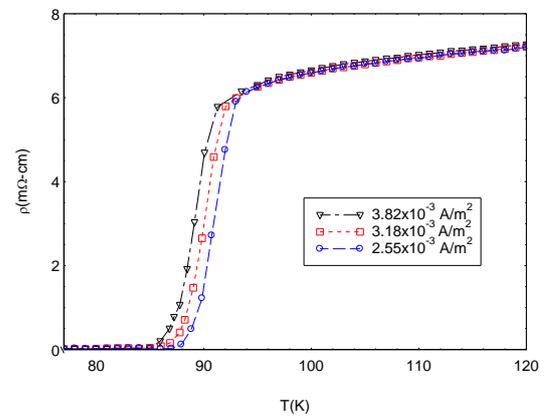

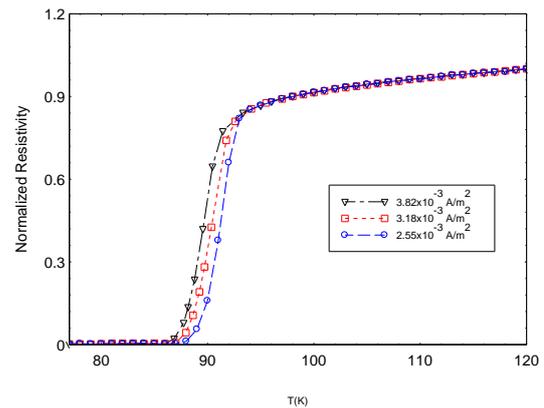**Fig. 1** Electrical resistivity versus temperature of the Er123.

Fig. 2 Normalized resistivity versus temperature of the Er123.

Table 1 Critical temperature values of the sample at different the critical current density.

Current Density ($\times 10^{-3}$ A m^{-2})	$T_c$offset (K)	$T_c$middle (K) (50% ρ)	$T_c$onset (K)
2.55	89.98	90.89	93.00
3.18	84.98	89.99	92.03
3.82	84.01	88.99	91.24

Research of Er123 superconductors have been conducted by many groups. In 2009, A.R. Jurelo et al [26] synthesized polycrystalline $ErBa_2Cu_3O_{7-\delta}$ doped-Pr by conventional solid state reaction using Er_2O_3, Pr_6O_{11}, $BaCO_3$ and CuO as starting materials. The XRD pattern resulted from the Er123 structure compared with JCPDS files. Pure Er123 showed an orthorhombic structure with the lattice constant $a = 3.8236$ Å, $b = 3.8792$ Å and $c = 11.6778$ Å with Pmmm symmetry [27] and small impurity of $BaCuO_2$. The c lattice was reduced by increasing the Pr concentration. In 2013, A. Sedky and S.B. Mohamed [28] studied Er123 superconductors with Zn and Fe doped. These samples were synthesized by solid state reaction using the ingredients of Er_2O_3, $BaCO_3$, CuO, ZnO and Fe_2O_3. The c lattice parameter was increased when Zn doped, but decreased with Fe doped characterized by XRD.
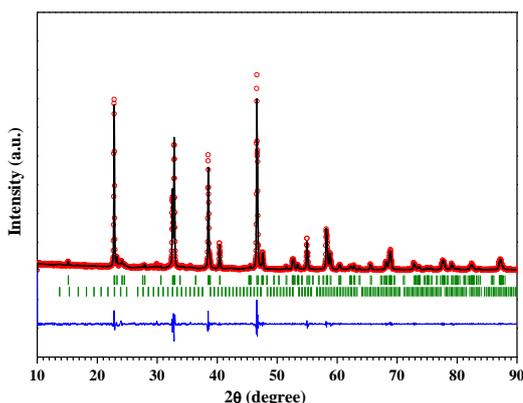

Fig. 3 The X-ray diffraction pattern of Er123.

The raw data of the XRD was used to calculate and refine the atomic position of elements in three dimension (x, y, z) structure consisting of Ba-atoms, Er-atoms, Cu(1)-atoms, Cu(2)-atoms, and O(1)-O(5)

atoms. The position of the Er-atom and Cu(1)-atom in the structure were fixed at (0.5, 0.5, 0.5) for the Er-atom and at (0, 0, 0) for the Cu(1) atom as shown Fig.4. The other atoms were invariant depend on refinement process as shown in Table 2.
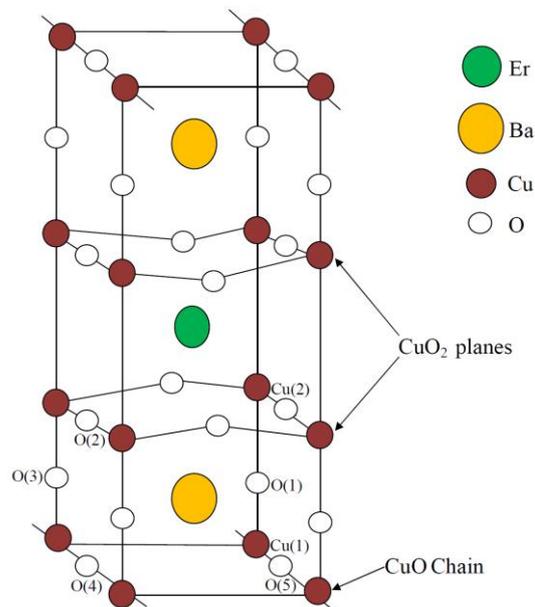

Fig.4 Sketch of the structure of Er123 model consisting of the CuO_2 plane and CuO chain.

The SEM and EDX analysis of the sample showed the essential physical morphology and microstructure properties. The sample with gold (Au) coated on the surface improved the electron conduction at the surface and high contrast the SEM image can be observed in Fig.5. The Au peak appearance in the EDX is shown in Fig.6. The samples showed large grain size with high compaction and a homogeneous surface.

From EDX mapping, the bands of elementary analysis consist of Er, Ba, Cu and O

Table 2 Crystallographic detail of Er123 orthorhombic cell $a = 3.82$ Å, $b = 3.88$ Å and $c = 11.68$ Å. Space group Pmmm (No.47). $d_{cals} = 7.15$ g cm^{-3}, Volume = 173.24 Å^3.

Atoms	x	y	z
Ba	0.50	0.50	0.18
Er	0.50	0.50	0.50
Cu(1)	0.00	0.00	0.00
Cu(2)	0.00	0.00	0.3_6
O(1)	0.00	0.00	0.1_8
O(2)	0.00	0.00	0.3_8
O(3)	0.50	0.00	0.3_7
O(4)	0.00	0.50	0.00
O(5)	0.50	0.00	0.00

without impurity. The bands of Er, Ba, Cu and O are dark yellow, red, light blue and green, respectively. All elementaries were evenly distributed. It be can seen that the Er band has the lowest intensity in color since the Er_2O_3 has minimal concentration. The Ba, Cu, and O bands have a similar intensity. These samples were prepared by the standard solid state reaction to provide even distribution of all elements.

The EDX showed element composite details of the synthesized ceramic bulk sample of Er123. This technique generally is attached with SEM. The energy of the electron beam at intervals of 10 − 20 keV interacted with the surface of the sample. The energies of the X-ray are different based on material investigation. The results revealed the EDX spectra where the Er, Ba, Cu, O and Au peak with various energies in keV unit as shown in Fig.8. The EDX spectra have five prominent peaks at the energy level of O = 0.53 keV, Cu = 8.04 keV, Er = 6.95 keV, Ba = 4.46 keV and Au = 9.71 keV corresponding with the EDX international chart [29]. The elements can be separated into two groups. In the first group, the lower energy levels have O and Cu elements which exhibited the $K\alpha_1$. For the second group, the higher energy levels have Er and Ba elements which exhibited the $L\alpha_1$. Both

$K\alpha_1$ and $L\alpha_1$ showed characteristic X-rays for the elements.

Differential Thermal Analysis (DTA) is an inexpensive and rapid method to measure heat capacities of condensed phases. From this measurement, the sample changes for phase transitions can be easily determined, including the onset temperature, peritectic temperature and endset temperature from a room temperature of 298 − 1252 K with a heating rate of 293 K min⁻¹. A heating rate of 2 K min⁻¹ was used from 1253 − 1323 K. Differential Thermal Analysis (DTA) monitors heat effects associated with phase transitions and chemical reactions as a function of temperature. The results of the DTA show the onset temperature, peritectic temperature and endset temperature. The onset temperature, peritectic temperature and endset temperature were 1261.59 K, 1292.63 K, and 1227.98 K, respectively.

Our Er123 had a higher peritectic temperature than the Er123 reported by M. Muralidhar et al [30]. The area under the curve was the energy of the reaction. The results revealed that, the energy of the reaction is 1,610 J. The sample showed an endothermic reaction, such as in most phase transitions, where heat is absorbed. Therefore, heat flow to the sample is higher than to the

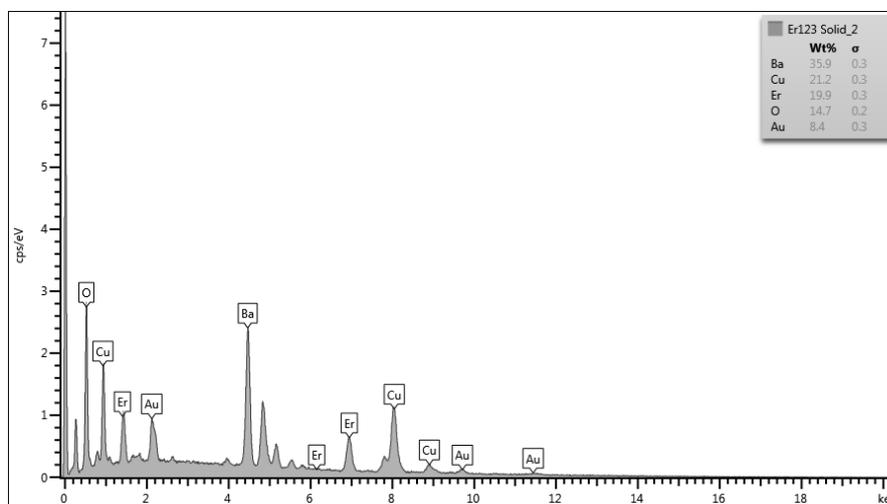**Fig. 5** SEM and EDX mapping image of the Er123.

Fig. 6 The elementary analysis spectra of the Er123.

reference material. Hence dH/dt is positive. In an exothermic process, such as crystallization, dH/dt is negative. In DTA data, the difference in heat flow between the sample and the reference of the same temperature were recorded as a function of temperature. The reference is an inert material such as alumina. The temperature of both samples and reference were increased at a constant rate, since the DTA is at constant pressure and heat flow is equivalent to enthalpy changes. RE123 has a complex crystal structure and various oxygen content values depending on the kind of compound. A change in the oxygen content is caused by a variation in physical properties. For example, in Y-based superconductors, Y123 has the chemical formula $YBa_2Cu_3O_{7-\delta}$. The highest critical temperature was 93 K [31] for the composition formula $YBa_2Cu_3O_{6.92}$. However, the oxygen content of $7-\delta$ is lower than 6.4 [31]. The Y123 compound is not a superconducting material and δ is the deficiency of samples. It was difficult to control the oxygen content because the stoichiometry of oxygen content was in a wide range. The Y123 decomposition under high oxygen pressure was $Y247(Y_2Ba_4Cu_7O_{15-\delta})$. The Y247 mixed crystal structures of Y123 and Y124 and showed various critical temperatures intervals from 30 K − 95 K depended on the oxygen content [32]. The $Y124(YBa_2Cu_4O_8)$ showed a single critical temperature at 80 K. Finally, Y-based superconductors displayed the highest critical temperature at 102 K of $Y358(Y_3Ba_5Cu_8O_{18})$. It is seen that the chemical formula of each Y-based superconductor is different. Additionally, the critical temperature of Y-based superconductors depends on the CuO_2 planes and CuO chain [33]. The oxygen content for Er123 superconductors are similar to the Y123 superconductors. The standard iodometric titration method is a popular investigation method to determine the oxygen content. For example, U.C. Upreti [23] synthesized Er123 superconductors with Fe doping in 2004. Pure Er123 had the highest critical temperature at 91.8 K with δ = 0.74. In 2013, A. Sedky and S.B. Mohamed [29] prepared Er123 by doping Zn and Fe. The δ at 0.74 showed the highest critical temperature at 90 K. For our experiment, the δ value was 0.164, hence $7 - 0.164$ = 6.84. The obtained chemical formula was $ErBa_2Cu_3O_{6.8363}$. The critical temperature at the lowest current density is 93 K, equal to the highest critical temperature of Y123. Additionally, this study used standard iodometric titration to determine the Cu^{2+} and Cu^{3+} and Cu^{3+}/Cu^{2+}. Cu^{2+} and Cu^{3+} caused the anisotropy of RE123 superconducting material to correspond

to an orthorhombic distortion and asymmetric distribution of oxygen. The results revealed that the Er123 has Cu^{2+} = 6.30 × 10^{-6} and Cu^{3+} = 1.8202× 10^{-6} and Cu^{3+}/Cu^{2+} = 0.29. The ratio of Cu^{3+}/Cu^{2+} affect the critical temperature. In 199, Choy et al [34] investigated the ratio of Cu^{3+}/Cu^{2+} in Y123 by using standard iodometric titration. The ratio of Cu^{3+}/Cu^{2+} = 0.18 has a T_c = 60 K and ratio of Cu^{3+}/Cu^{2+} = 0.30 with T_c = 90 K. The ratio of Cu^{3+}/Cu^{2+} = 0 affected the non-superconducting material. In 2015, Chainok et al [35], synthesized Y123 by solid state reaction and used Cu^{3+} and Cu^{2+} as standard iodometric titration processes. Conventional sintering at 1,223 K had a ratio of Cu^{3+}/Cu^{2+} = 0.28. Thus, the ratio of the value Cu^{3+}/Cu^{2+} of Y123 and Er123 are closely related due to the highest critical temperature in this material. It was found that the Cu^{3+} and Cu^{2+} are important in the crystal structure of RE123. The Cu^{3+} showed pyramid geometry while Cu^{2+} showed a distorted pyramid. The Cu^{3+} and Cu^{2+} are mixed valence [36].

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structures of Y123 and Y124 showed various critical temperatures intervals from 30 – 95 K depended on the oxygen content [32]. The Y124($YBa_2Cu_4O_8$) showed a single critical temperature at 80 K. Finally, Y-based superconductors displayed the highest critical temperature at 102 K of Y358($Y_3Ba_5Cu_8O_{18}$). It is seen that the chemical formula of each Y-based superconductor is different. Additionally, the critical temperature of Y-based superconductors depends on the CuO_2 planes and CuO chain [33]. The oxygen content for Er123 superconductors are similar to the Y123 superconductors. The standard iodometric titration method is a popular investigation method to determine the oxygen content. For example, U.C. Upreti [23] synthesized Er123 superconductors with Fe doping in 2004. Pure Er123 had the highest critical temperature at 91.8 K with δ = 0.74. In 2013, A. Sedky and S.B. Mohamed [29] prepared Er123 by doping Zn and Fe. The δ at 0.74 showed the highest critical temperature at 90 K. For our experiment, the δ value was 0.164, hence 7 − 0.164 = 6.84. The obtained chemical formula was $ErBa_2Cu_3O_{6.8363}$. The critical temperature at the lowest current density is 93 K, equal to the highest critical temperature of Y123. Additionally, this study used standard iodometric titration to determine the Cu^{2+} and Cu^{3+} and Cu^{3+}/Cu^{2+}. Cu^{2+} and Cu^{3+} caused the anisotropy of RE123 superconducting material to correspond to an orthorhombic distortion and asymmetric distribution of oxygen. The results revealed that the Er123 has Cu^{2+} = 6.30 × 10^{-6} and Cu^{3+} = 1.82× 10^{-6} and Cu^{3+}/ Cu^{2+} = 0.29. The ratio of Cu^{3+}/ Cu^{2+} affect the critical temperature. In 1988, Choy et al [34] investigated the ratio of Cu^{3+}/ Cu^{2+} in Y123 by using standard iodometric titration. The ratio of Cu^{3+}/ Cu^{2+} = 0.18 has a T_c = 60 K and ratio of Cu^{3+}/Cu^{2+} = 0.30 with T_c = 90 K. The ratio of Cu^{3+}/Cu^{2+} = 0 affected the non-superconducting material. In 2015, Chainok et al [35], synthesized Y123 by solid state reaction and used Cu^{3+} and Cu^{2+} as standard iodometric titration processes. Conventional sintering at 1223 K had a ratio of Cu^{3+}/Cu^{2+} = 0.28. Thus, the ratio of the value Cu^{3+}/ Cu^{2+} of Y123 and Er123 are closely related due to the highest critical temperature in this material. It was found that the Cu^{3+} and Cu^{2+} are important in the crystal structure of RE123. The Cu^{3+} showed pyramid geometry while Cu^{2+} showed a distorted pyramid. The Cu^{3+} and Cu^{2+} are mixed valence [36].

Conclusion

Bulk Er123($ErBa_2Cu_3O_{7-\delta}$) was synthesized by using the conventional solid state reaction method. The sample was calcined and sintered at 1223 K. The physical properties of the obtained sample were characterized by the four-probes technique, powder X-ray diffraction, SEM and EDX (mapping method), DTA and standard iodometric titration method, respectively. The highest critical temperature exhibited was 93 K with a current density of 2.55 × 10^{-3} A m^{-2}. The superconducting compound was orthorhombic in structure and Pmmm space group. The lattice parameters of RE123 were a = 3.82 Å, b =3.88 Å, c = 11.68 Å and the orthorhombicity parameter was 1.69%. The second compound was a non-superconducting compound ($BaCuO_2$), a cubic structure with the lattice parameters of $a = b = c$ = 18.25 Å. The percentage of superconducting compound and non-superconducting compound was 91% and 9 %, respectively. The atomic position consisted of a Ba-atom, Er-atom, Cu(1)-Cu(2) atoms, O(1)-O(5) atoms and a 3-dimensional simulation. The sample having high compact large grain size and homogeneity was identified. The EDX (mapping) showed the regular distribution of Er, Ba, Cu and O bands without impurities. The DTA curve showed an endothermic curve with the onset temperature, peritectic temperature and endset temperature at 1261.59 K, 1277.98 K, and 1292.63 K, respectively. The absorption energy of the heat reaction was 161 J. Finally, the standard iodometric titration method was used to determine ions of copper Cu^{3+}, Cu^{2+}, Cu^{3+}/Cu^{2+} ratio and deficiency parameter. The Er123 has Cu^{2+} = 6.30 × 10^{-6} and Cu^{3+} = 1.82 × 10^{-6} and Cu^{3+}/ Cu^{2+} = 0.29. The oxygen deficiency was δ value 0.1637. The oxygen content was 6.84. Thus, the chemical formula of obtained samples was $ErBa_2Cu_3O_{6.8363}$.

Acknowledgement

References

[1] J.G. Bednorz, K.A. Muller, Possible High Tc Superconductivity in the Ba-La-Cu-O System, Z. Phys. B. 64 (1986) 189 − 193.

[2] S. Murase, K. Itoh, H. Wada, K. Noto, Y. Kimura, Y. Tanaka, K. Osamura, Critical Temperature Measurement Method of Composite Superconductors, Physica C. 357 (2001) 1197 − 1200.

[3] I. Hamadneh, A.M. Rosli, R.A. Shukor, N.R.M. Suib, S.Y. Yahya, Superconductivity of $REBa_2Cu_3O_{7-\delta}$ (RE = Y, Dy, Er) Ceramic Synthesized via Coprecipitation Method. J. Phys.: Conf. Ser. 97 (2008) 1 − 5.

[4] K. Wu, J.R. Ashburn, C.J. Torng, P.H. Hor, R.L. Meng, L. Gao, Z.J. Huang, Y.Q. Wang, C.W. Chu, Superconductivity at 93 K in a New Mixed-Phase Y-Ba-Cu-O Compound System at Ambient Pressure, Phys. Rev. Lett. 58 (1987) 908 − 910.

[5] K. Rogacki, B. Dabrowski, Increase of critical currents in chemically substituted Y123, Physica C. 460 (2007) 406 − 407.

[6] J.-H. Lee, B.-H. Jun, S.-D. Park, B.J. Park, S.C. Han, S.H. Lee, C.-J. Kim, Suppression of samarium diffusion in top seeded melt growth processed Y123 superconductors using a Sm123 seed, Physica C. 471 (2011) 863 − 866.

[7] T. Tsutsumi, A. Tomioka, M. Iwakuma, H. Okamoto, Y. Gosho, H. Hayashi, Y. Iijima, T. Saito, T. Ohkuma, A. Tagomori, T. Izumi, Y. Shiohara, Development of REBCO superconducting transformers with current limiting function, Phys. Procedia. 36 (2012) 1115 − 1120.

[8] J.D. Hodge, H. Muller, D.S. Applegate, Q. Huang. A, Resistive Fault Current Limiter Based on High-Temperature Superconductors, Appl. Supercond. 3 (1995) 469 − 482.

[9] T. Oka, K. Yokoyama, K. Noto, Construction of a strong magnetic field generator with wide magnetic poles by bulk superconductors, Physica C. 412 (2004) 761 − 765.

[10] Y. Iijima, S. Fujita, M. Igarashi, M. Daibo, N. Nakamura, S. Hanyu, R. Kikutake, Y. Sutoh, H. Tobita, H. Fuji, K. Kakimoto, M. Nagata, M. Itoh, Development of Commercial RE123 Coated Conductors for Practical Applications by IBAD/PLD Approach, Phys. Procedia. 58 (2014) 130 − 133.

[11] K. Ogasawara, N. Sakai, M. Murakami, Subgrain structures and their effects on critical current properties in large single-domain RE123 bulk superconductors, Physica C. 378 (2002) 727 − 731.

[12] H. Khosroabadi, M. Rasti, M. Akhavan, Structural analysis of $Y_3Ba_5Cu_8O_{19-\delta}$ high-Tc superconductor by ab initio density functional theory, Physica C. 497 (2014) 84 − 88.

[13] P. Marsh, R.M. Fleming, M.L. Mandich, A.M. Desantolo, J. Kwo, M, Hong, L.J. Martinez-Miranda, Crystal Structure of the 80 K Superconductor $YBa_2Cu_4O_8$, Nature. 334 (1988) 141 − 143.

[14] P. Bordet, C. Chaillout, J. Chenavas, J.L. Hodeau, M. Marezio, J. Karpinski, E. Kaldis, Structure Determination of the New High Temperature Superconductor $Y_2Ba_4Cu_7O1_{4+x}$, Nature. 334 (1988) 596 − 598.

[15] A. Alibadi, Y.A. Farschi, M. Akhavan, A new Y-based HTSC with Tc above 100 K, Physica C. 469 (2009) 2012 − 2014.

[16] A. Tavana, M. Akhavan, How Tc can go above 100 K in the YBCO Family, Eur. Phys. J. B. 73 (2010) 79 − 83.

[17] K. Srinivasan, G. Thomas, P. Padaikathan, Fluorine Doping Effect in the New Superconducting $Y_3Ba_5Cu_8O_y$ Compound, J. Miner. Mater. Character. Eng. 10 (2011) 1277 − 1283.

[18] M. Verma, V.S. Tomar, Comparison of Co and Ni Doping at Copper Site in Y-124 High Temperature Superconductor, Physica C. 272 (1996) 335 − 341.

[19] J. Karpinski, S. Rusiecki, B. Bucher, E. Kaldis, E. Jilek, The nonstoichiometry of high-Tc Superconductor $Y_2Ba_4Cu_7O_{15 \pm x}$(14 ≤Tc≤68 K), Physica C. 161 (1989) 618 − 625.

[20] M. Mazaheri, S. Ghasemi A. Heidarpour, An Approach to Synthesis a New Superconducting Belonging to the YBCO Family: $Y_2Ba_5Cu_7O_x$. J. Supercond. Nov. Magn. 28 (2015) 2637 − 2640.

[21] R.A. Shukor, S.S. Lee, M. Yahya, Ultrasonic Velocity Studies on Superconducting and Non- superconducting $ErBa_2Cu_3O_{7-\delta}$, Physica C. 243 (1995) 134 − 138.

[22] T. Naito, H. Fujishiro, K. Iida, M. Murakami, Anisotropic Thermal Conductivity of Er-Ba- Cu-O bulk Superconductors, Physica C. 468 (2008) 1428 − 1430.

[23] U.C. Upreti, Fe content Variation and Superconducting Order Parameter Dimensionality in $ErBa_2Cu_{3-x}Fe_xO_{7-\delta}$, Indian J. Pure Appl. Phys. 42 (2004) 38 − 42.

[24] H.M. Rietveld, A profile refinement method for nuclear and magnetic structures, J. Appl. Crystallogr. 2 (1969) 65 − 71.

[25] P. Nisha Santha Kumaria, S. Kalainathanb, Comparative Study of Pure and Magnesium Doped Cadmium Mercury Thiocyanate Single Crystals – Gel Technique, J. Miner. Mater. Character. Eng. 7(4) (2008) 317 − 330.

[26] A.R. Jurelo, R. Menegotto Costa, A.V.C. de Andrade, P.R. Junior, G.K. da Cruz, C.S. Lopes, M. dos Santos, W.T.B. de Sousa, Analysis of Fluctuation Conductivity of Polycrystalline Er_{1-x} $Pr_xBa_2Cu_3O_{7-\delta}$ Superconductors, Brazilain J. Phys. 39(4) (2009) 667 − 672.

[27] Th. Hahn, International Tables For Crystallography. Springer Publication, Netherland, 2005.

[28] A. Sedky, S.B. Mohamed, Paraconductivity Study in $ErBa_2Cu_{3-x}M_xO_{7-\delta}$(M = Zn, Fe) Superconductors, Chinese J. Phys. B. 22(11) (2013)117401.

[29] Table For EDS Analysis , http:www.jeol.com/Energy, 6 June 2018.

[30] M. Muralidhar, N. Sakai, M. Jirsa, S. Tanaka, Solid Phase (RE_2BaO_4)-Liquid Phase $(BaCuO_2)$ Reaction: The Way to Highly Oriented $Er_2Ba_3CuO_y$ Superconducting Thick Films on Commercial Silver Substrates, Cryst. Growth. Des. 9(5) (2009) 2404 − 2408.

[31] K. Conder, Oxygen Diffusion in the Superconductors of the YBaCuO family: Isotope Exchange Measurement and Models. Mat. Sci. Eng. R. 32 (2001) 41 − 102.

[32] S. Gholipor, V. Daadmehr, A.T. Rezakhani, H. Khosroabadi, F. Shahbaz Tehrani R. Hosseini Akbarnejad, Structural Phase of Y358 Superconductor Comparison with Y123, J. Supercond. Nov. Magn. 25 (2012) 2253 − 2258.

[33] P. Udomsamuthirun, T. Kruaehong, T. Nilkamjon, S. Ratreng, The New Superconductors of YBaCuO Materials. J. Supercond. Nov. Magn. 23 (2010) 1377 − 1380.

[34] J.H. Choy, S.Y. Chol, S.H. Byeon, S.H. Chun, S.T. Hong, D.Y. Jung, W.Y. Choe, Y.W. Park, Determination of the Copper Valency and Oxygen Deficiency in the High-Tc Superconductor, $YBa_2Cu_3O_{7-\delta}$, Bull. Korean Chem. Soc. 9(5) (1988) 289 − 291.

[35] P. Chainok, T. Khuntak, S. Sujinnapram, S. Tiyasri, W. Wongphakdee, T. Kruaehong, T. Nilkamjon, S. Ratreng, P. Udomsamuthirun, Some properties of $YBa_mCu_{1+ m}O_y$ (m = 2, 3, 4, 5) superconductors, Int. J. Mod. Phys. B. 29 (2015) 1 − 12.

[36] J.G. Bednorz, K.A. Muller, Perovskite-type oxide-The New Approach to High-Tc Superconductivity, Rev. Mod. Phys. 60(3) (1988) 585 − 600.