Some Properties of Y3-8-11/Y211 Composite Bulk Superconductors

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Abstract

In this research, we investigated the properties of Y3-8-11 superconductor formed by the mixing of the non-superconducting Y211 material and Y3-8-11 at several contents. The critical temperature, XRD and DTA were measured. The Y3-8-11 and Y3-8-11/Y211 superconductors were synthesized using solid state reaction. We found that the Y3-8-11 superconductor showed the same property as Y123 except the lattice parameter in c-direction and DTA spectra. The lattice parameter c/a ratio of Y123 and Y3-8-11 were 3.06 and 9.15, respectively. The Y3-8-11 showed two peritectic phases but Y123 has one peritectic phase. The more non-superconducting composition, the lower value of c direction of Y3-8-11 was found. As Y211 composition increasing, the critical temperature decreased.

Keywords: Y-based superconductor, Solid state reaction, Y211

1. Introduction

The first cuprate superconductor was found in La214 compound by Bednorz and Muller in 1986 [1]. And in 1987, Chu and coworker [2] found the $YBa_2Cu_3O_7$ (Y123) showed the transition temperature to around 92 K. These temperatures were high enough to be above the 77 K boiling point of liquid nitrogen. Y123 opened the possibility for more practical applications and hoped for even higher temperature superconductor. The later the other cuprate superconductors in YBaCuO were found such as $YBa_2Cu_4O_8$ (Y124) [3], $Y_2Ba_4Cu_7O_{15}$ (247) [4,5] and $Y_3Ba_5Cu_8O_{18}$(Y358) [6]. In 2010, Udomsamuthirun et al [7] synthesized the new Y-based superconductors by using the assumption that the Ba-atoms plus Y-atoms were equal Cu-atoms as Y156, Y3-8-11, Y5-6-11, Y5-8-13, Y7-11-18, Y7-9-16, and Y13-20-33. These assumptions were based on the relation between Ba-atoms to CuO_2 planes, and Y-atoms to CuO chains. In their results, the Y3-8-11 was shown the sharp transition curve at the critical temperature and synthesize by solid state reaction. It well-know that non-superconducting Y211 phase was influent on the Y123 superconductor. Critical current density (J_c) increases with the V_{211}/d_{211} ratio that V_{211} and d_{211} were the 211 volume fraction and the size of 211 particles [8, 9]. It meant that the local differences in the size and the concentration of Y211 particles cause the inhomogeneity of J_c in the Y123/Y211 system.

In this research, we investigated the characteristics of Y3-8-11 superconductor by mixed the non-superconducting Y211 material to Y3-8-11 with several contents. The critical temperature, XRD and DTA measurements were carried out.

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Manuscript received: 15 January 2013
Revised: 15 April 2013
KMITL-STJ: Regular, Part A: Material Science

2. Materials and Methods

The $Y_3Ba_8Cu_{11}O_x$ (Y3-8-11), and Y_2BaCuO_x(Y211) powders were synthesized by solid state reaction that the raw materials Y_2O_3, $BaCO_3$ and CuO of high purity (99.99%) in the desired atomic ratio as 1:2:3, 3:8:11 and 2:1:1 were used. The corresponding weight ratio was mixed, ground and reacts in the air at 950 °C for 24 hours, and then cooled to 100 °C. The calcinations process in the air was repeated twice with the intermediate grinding. The powders were reground. The black Y3-8-11 powder and the green Y211 powder were obtained. After mixing Y3-8-11 powder with 0.24 mol, and 0.48 mol of Y211 powder, these powders were reground, pressed and sintered at 950 °C. The sintering temperatures were determined by performing the differential thermal analysis (DTA) analysis.

Our samples were analysis and characterized the critical temperature by the standard four-probes method was used to measure the resistance of our samples with current density of 2.55×10^{-3} A/m^2 and varied the temperature from 77 K to 120 K with the temperature measurement by thermocouple type K. The crystal structure by powder X-Ray Diffraction (XRD) was using a Bruker X-ray diffractometer (D8) with CuK$_\alpha$ radiation (λ= 1.5416 Å). The 2-theta (2θ) range 10° to 90° was scanned in step 0.02 degree per second. The power condition was 40 kV at 40 mA. We analyzed the XRD patterns using FULLPROF program. The refinements were done using the orthorhombic space group Pmmm and Pmm2. The peritectic temperature determined by heating samples in air. When the temperature was equal to or higher than the peritectic, the superconducting compound decomposed to liquid phase which could be identified by Differential Thermal Analysis (DTA) NETZSCH 409. The temperature collected at 940° C to 1,190° C with rate 2° C/min, respectively.

3. Results and Discussion

The resistance versus temperature of our samples is shown in Fig 1. And the summation of the onset, middle and offset transition temperature read from curves were in Table 1. Our previous results [7] on pure Y3-8-11 were $T_c$offset = 89 K, $T_c$middle = 91 K, $T_c$onset = 94 K and the present samples had the same critical temperature as T_c onset about 94 K.

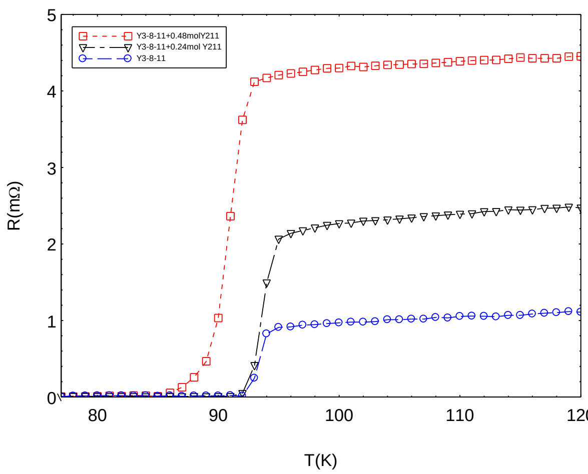

Figure 1. Resistance versus temperature of pure Y3-8-11 and Y3-8-11/Y211superconductors.

TABLE I. THE CRITICAL TEMPERATURE OF PURE Y3-8-11 AND Y3-8-11/Y211 SUPERCONDUCTORS.

Samples	$T_c$offset (K)	$T_c$middle (K)	$T_c$onset (K)
Y3-8-11	92.0	93.4	94.5
Y3-8-11+ 0.24 mol Y211	91.0	93.5	94.5
Y3-8-11+ 0.48 mol Y211	85.0	90.8	93.0

According to results shown in Fig 1 and Table 1, one can notice the influence of non-superconducting Y211 on the critical temperature of Y3-8-11 superconductors. The more composite of Y211, the lower critical temperature of Y3-8-11/Y211 composite was found. These results were agreed with the property of Y123 material.

The measured and calculated XRD spectra of our samples were shown in Figs. 2-4. The main peaks of our sample obtained were the ones which existed in Y123 and Y358. The FULLPROF [10] software program was used to determine the crystal structures. We found that the Pmmm and Pmm2 space group were fitted well with some impurity peaks. However, the Pmm2 space group was better fit on Y3-8-11 and Y211 spectra. The lattice parameters were calculated and shown in Table 2.

TABLE II. THE LATTICE PARAMETERS OF PURE Y3-8-11, Y3-8-11/Y211 SUPERCONDUCTORS AND Y211.

Samples	Lattice Parameters		
	a(Å)	b(Å)	c(Å)
Y3-8-11	3.8261	3.8931	35.0101
Y3-8-11+ 0.24 mol Y211	3.8311	3.8931	35.0211
Y3-8-11+ 0.48 mol Y211	3.8152	3.8846	34.9006
Y211	12.1852	5.6611	7.1351

In Fig 2, the pure Y3-8-11's XRD patterns were shown that they were in the same space group of Y358 with the difference in c direction of lattice parameters. The lattice parameters of Y3-8-11 were a = 3.8261 Å, b = 3.8931 Å, and c = 35.0110 Å and lattice parameters of Y358 were a = 3.8880 Å, b = 3.8230 Å and c = 31.0313 Å [5]. By comparing lattice parameters of Y123 [11], a = 3.8227 Å, b=3.8872 Å and c = 11.6802 Å, we found that the c/a ratio of Y123, Y358 and Y3-8-11 were 3.06, 7.98 and 9.15 respectively. These materials had almost the same value in a direction, then the Y3-8-11 had the c-values about three times of Y123, and Y358 has about 2.6 times of Y123. The XRD patterns of Y3-8-11/Y211 composite were shown in Fig 3. and 4 that the more composition of Y211, the lower value of c direction of Y3-8-11 occurred. Although, the XRD spectra of Y3-8-11 was shown the same space group of Y358 (Pmm2) and nearly the same of Y123 (Pmmm), the space group of the other superconductors in this family such as Y124 and Y247 (Ammm) [12] were different. The orthorhombicity of the Y3-8-11 was equal to 200(a- b)/(a + b) = 1.74%.

In Fig 5, the differential thermal analysis (DTA) of our samples were shown. The pure Y3-8-11 had the two peritectic phase as 1008 °C and 1017 °C, and the Y3-8-11+0.24 mol Y211 and Y3-8-11+0.48 mol Y211 had only one dominate peritectic phase as 1014 °C and 1012 °C, respectively. We knew that the pure Y123 has one peritectic temperature in the range 1010 °C to 1020 °C [13] depending on many conditions such as annealing temperature, doping concentration, etc. While we added Y211 the peritectic temperature increased during our sample of Y3-8-11. However, the Y3-8-11+Y211 had the same as Y123. The reason may be that the Y211 could fulfill the Y-atom missing in Y3-8-11 structure. The influence of Y211 on Y3-8-11 was dominated in DTA spectra. The composition of pure Y3-8-11 should be difference to Y123 because there were two peritectic phase in pure Y3-8-11.

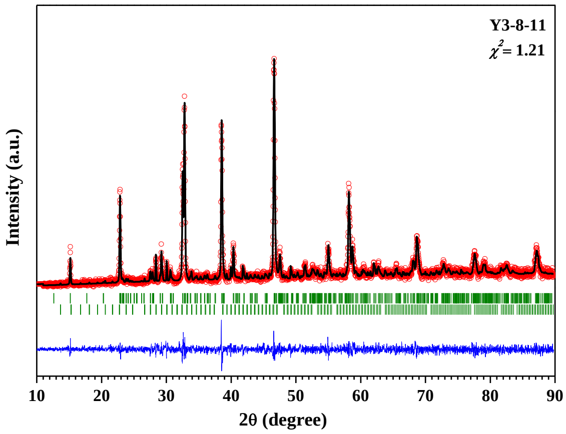

Figure 2. The XRD patterns of the Y3-8-11 were shown. Experimental (o), calculated (solid line) and the vertical tics below the curve indicate the Bragg positions

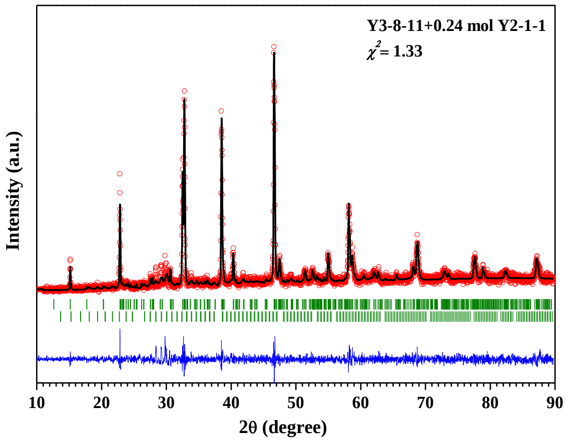

Figure 3. The XRD patterns of the Y3-8-11+ 0.24 mol Y211 were shown. Experimental (o), calculated (solid line) and the vertical tics below the curve indicate the Bragg positions.

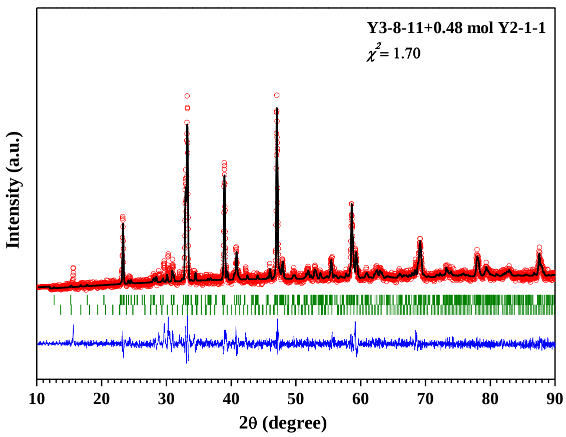

Figure 4. The XRD patterns of the Y3-8-11+ 0.48 mol Y211 were shown. Experimental (o), calculated (solid line) and the vertical tics below the curve indicate the Bragg positions.

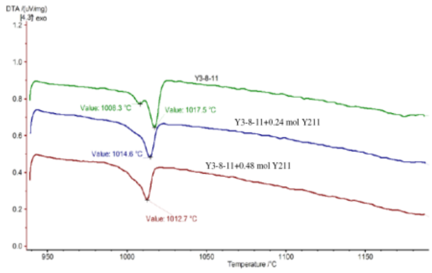

Figure 5. The DTA of our samples

According to our data, the Y3-8-11 superconductor showed the same property as Y123 except the lattice parameter in c-direction and DTA spectra. The longer of lattice parameter in c-direction did not affect to T_c. There were many parameters that enhanced the T_c such as apical oxygen [14], the number of CuO_2 planes, CuO chains, and CuO double chains. Nakajima et al. [15] claimed that the system with three CuO_2 planes had the highest T_c in the cuprates. There were one and three CuO_2 planes in Y123 and Y358 [6]. respectively, but they shown the same T_c in our measurement. However, the T_c onset of Y358 give in [6] is above 100 K. The Y3-8-11 was synthesized based on the assumption that there might be about three CuO_2 planes in unit cell. The T_c should be in the same of Y358 that we found these result. The apical oxygen had an important role in the superconductivity mechanism. To higher T_c in YBaCuO compound, one should pump more holes from the chains to the oxygen sites of the planes-tending to diagonal charge order. The application of the pressure and doping condition in the synthesized process should be done to achieve the higher T_c.

4. Conclusions

Within the Udomsamuthirun et al's assumption [7], we synthesized the Y3-8-11 and Y3-8-11/Y211 composite superconductors and investigated the effect of Y211 on properties of Y3-8-11 superconductors. The critical temperature, XRD and DTA were measured. The non-superconducting Y211 showed an influence on the critical temperature of Y3-8-11 superconductors. The more concentration of Y211, the lower critical temperature of Y3-8-11/Y211 composite was found. The c/a ratio of Y123, Y358 and Y3-8-11 were 3.06, 7.98 and 9.15 respectively. The Y3-8-11 and Y358 had the value of c direction about 3.0 and 2.6 times of Y123. We also found that the more composite of Y211 was the lower c-parameter of Y3-8-11 found. The differential thermal analysis was shown that the pure Y3-8-11 had two peritectic phases.

ACKNOWLEDGMENT

The author would like to thank to Professor Dr.Suthat Yoksan for a useful suggestion. The financial support of the Office of the Higher Education Commission, Srinakharinwirot University and ThEP Center were acknowledged.

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