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Electrical properties and crystal structure of Y123, Y358 and Y257/Y211 composite bulk superconductors

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The Y123, Y358 and Y257 bulk superconductors mixed with various ratio of non-superconducting Y211 (Y_2BaCuO_5) were synthesized by solid state reaction. The physical properties of pellets were investigated by d.c. four-probes measurement. The crystal structure was determined using powder X-ray diffraction and the characteristic peaks were determined using the Rietveld full-profile analysis method. Results showed that the $T_c$onset and $T_c$offset decreased with the increasing of Y211 doping. The samples consist of both superconducting phase and the non-superconducting phase. The lattice parameter of Y211 doped samples showed lower *c* direction than pure samples. The superconducting phase decreased with increasing Y211 content. The non-superconducting phases consists of Pccm ($Ba_2Cu_3O_6$) and Im-3m ($BaCuO_2$) respectively. According to the percentage of superconducting phase, the anisotropy increased with Y211 contents.

Key words: Y-based superconductors, Y211, Rietveld method.

INTRODUCTION

Since $YBa_2Cu_3O_7$(Y123) superconductor which has highest critical temperature at 93K was found in 1987 (Wu et al., 1987), many researchers have performed vigorously to improve its superconducting properties and the results have been applied to the fabrication of various film or bulk type superconductors. In 2009, the $Y_3Ba_5Cu_8O_{18}$(Y358) was found (Alibadi et al., 2009). This is the highest critical temperature of Y-based superconductor that has highest critical temperature at 102K. In 2013, Kruaehong (2013) could synthesize the new superconductors, $Y_2Ba_5Cu_7O_{15}$(Y257) by solid state reaction. This superconductor has highest critical temperature about 94K. Because superconducting properties of the Y123, Y358, and Y257 can be performed in liquid nitrogen, this cheap cryogenic medium makes the materials promising in many fields such as superconducting magnetic bearings (Jiqiang et al., 2012), superconducting electric motors (Hiroyuki and Yuichi, 2001), magnetic separation devices (Oka et al., 2013), non-contact transport systems (Smith and Jr. Dolan, 2013), flywheel energy storage systems (Arai et al., 2013) and permanent magnets with high trapped field (Liu et al., 2011) operating above 77K (Moon and Chang, 1990; Hull, 2001).

It is well known that Y211 (Sandiumeng et al., 1997) which is the second phase of the Y123, Y211 doping,

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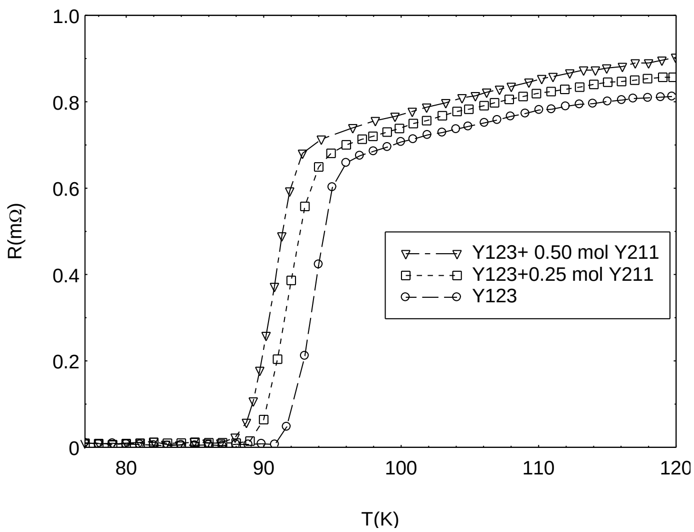

Figure 1. Graph plot between resistance and temperature of Y123 and Y211 doped.

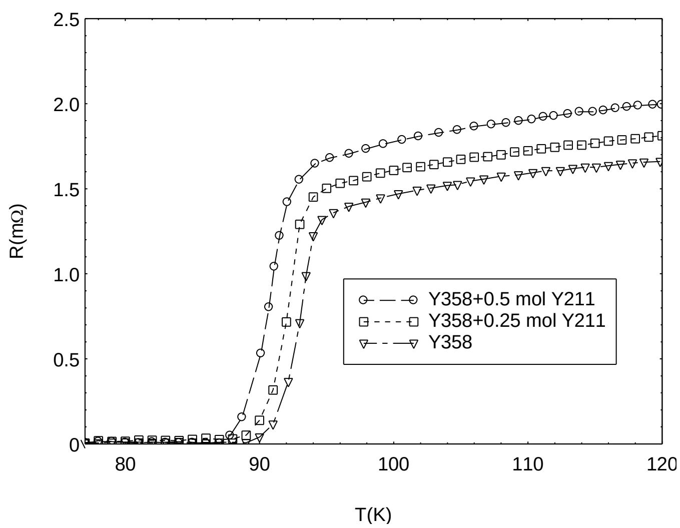

Figure 2. Graph plot between resistance and temperature of Y358 and Y211 doped.

plays an important role in enhancing the superconducting properties of Y123 superconductors due to the increasing of high critical current density (J_c) (Fujishiro et al., 2003). Therefore, The crystal structure of Y123/Y211 composites have been attentively investigated by many research groups (Mucha et al., 2010; Endo et al., 1996; Dias et al., 2009; Yu et al., 1997; Kim and Kim, 2000).

In this present work, the influence of Y_2BaCuO_5(Y211) doping in the Y123, Y358 and Y257 superconductors were reported. Y123, Y358 and Y257 superconductors were doped with 0, 0.25 and 0.50 mol of Y_2BaCuO_5(Y211), critical temperature, phase composition and lattice parameter of the samples were compared.

Electrical measurements were carried out using d.c. four-probes technique. Structural analysis was analyzed by D8 Advance Discovery with CuK_α radiation.

MATERIALS AND METHODS

The Y123, Y358 and Y257 polycrystalline superconductors and non-superconducting (Y211) were calcined and sintered in a square furnace under air system by solid state reaction. The high-purity (99.99%) raw materials of Y_2O_3(99.99%), $BaCO_3$(99.99%), and CuO(99.99%) powders were used as start materials. Raw materials of Y123, Y358, Y257 and Y211 were mixed with different atomic ratio ranging from 1:2:3, 3:5:8, 2:5:7 and 2:1:1, respectively. Firstly, the Y123, Y358, Y257 and Y211 powders were calcined at 950°C and keep at that temperature for 24 h, then reduced to 100°C. Calcinations were repeated twice with intermediate graining to obtained the black powder of Y123, Y358, Y257 powder and the green powder of Y211 powder. The Y211 of 0 mol, 0.25 mol, 0.50 mol were mixed to Y123, Y358 and Y257. The mixed powders were calcined at 950°C and kept at that temperature for 24 h, then reground and pressed in to pellet of 30 mm in diameter and about 3 mm thickness under 2,000 psi pressure. Finally, the obtained specimens were sequentially sintered at 950°C and kept at that temperature for 24 h and annealed at 500°C for 24 h in the air.

The physical properties were analyzed by the electrical resistance and XRD diffractometer. The resistance as a function of temperature was set in a range of 77 to 120 K by using liquid nitrogen and measured by a standard d.c. four-probes method by means of a closed-cycle cryostat at low temperature down to 77K. Both voltage and current contacts were made with silver paint to minimize the contact resistance. A temperature value, where the resistance starts to increase significantly, was determined to be the onset critical temperature (T_c onset) of the sample whereas the offset transition temperature($T_c$offset) was defined as the temperature at which R=0 Ω.

The crystal structure was investigated by X-ray diffraction (XRD). Data were collected using a D8 Advance Discovery diffractometer with CuK_α target giving a monochromatic beam with wavelength 1.5416 Å in the range of 2θ =10-90^o at a scan speed of 3.4/min and step increment of 0.019° at room temperature . The lattice parameter (a, b and c) phase compositions, and space group were computed from the Rietveld full-profile analysis method (Rodriguez-Carvajai, 2001).

RESULTS AND DISCUSSION

Electrical resistance measurements

The critical temperature of the bulk samples of Y123, Y358 and Y257 and Y211 composite were investigated by aid of the dc electrical resistivity measurements using a current density of 3.82×10^{-3}A/m^2 and the temperature measured by thermocouple type K. The results are illustrated in Figures 1 to 3. The transition curves of the samples from the superconducting state to normal state exhibit the double-step behavior in all samples. Table 1 shows the onset critical temperature ($T_c$onset) and offset critical temperature (T_c offset). The samples exhibit metallic behavior above the zero resistivity transition temperature value. Moreover, it is obvious from the table that both T_c offset and T_c onset value of the Y123, Y358

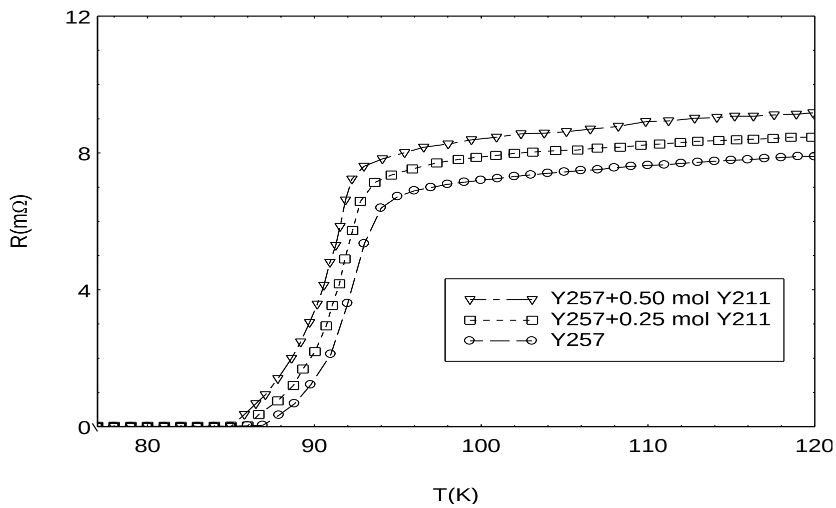

Figure 3. Graph plot between resistance and temperature of Y257 and Y211 doped.

Table 1. The T_c summation of the samples.

Samples	T_c offset (K)	T_c onset (K)
Y123	90.82	95.97
Y123+0.25molY211	89.99	94.90
Y123+0.50molY211	86.84	92.80
Y358	87.92	94.65
Y358+0.25molY211	86.98	93.00
Y358+0.50molY211	85.95	92.07
Y257	86.88	93.97
Y257+0.25molY211	85.95	93.61
Y257+0.50molY211	84.98	92.21

and Y257 doped with Y211 have lower value than the pure ones. The result is consistent with Kruaehong et al. (2013a, b). They mixed Y3-8-11 and Y7-11-18 superconductors with Y211 powder and his result showed that the critical temperature of Y3-8-11 and Y7-11-18 decreased with increasing Y211 content. This is because of poor thermal conductivity of Y211. In addition, Y211 also causes more scattering of phonon and quasi particle on the number of scattering centers (Jezowski et al., 2000).

The result of this work emphasis only on critical temperature of the sample, however, since high critical current density is considered to be one of the most important property of superconductor, thus the study on critical current density and critical magnetic field should be investigated in further study.

XRD measurement

The XRD spectra of the Y123, Y358, Y257 and Y211 composite samples are shown in Figures 4 to 12 respectively. The Rietveld full-profile analysis method was used to determine the orthorhombicity structure, phase compositions, and space groups. The difference between the experimental and calculated pattern is shown in the blue lines of the figures. Our samples exhibited the polycrystalline with the changing intensity of diffraction lines. The samples are composed of both superconducting phase and non-superconducting phases. The superconducting phase corresponds with orthorhombic structure and the non-superconducting phase shows various crystal structures. Table 2 shows percentage of the superconducting phase and non-superconducting phase in the samples. The Pmmm space group corresponds with the superconducting phase while the other space groups of the non-superconducting phase are composed of Pccm ($Ba_2Cu_3O_6$) and Im-3m ($BaCuO_2$) respectively. Additionally, Tables 3 and 4 show the lattice parameter of the superconducting phase and non-superconducting phases, respectively. The XRD pattern of the pure Y123

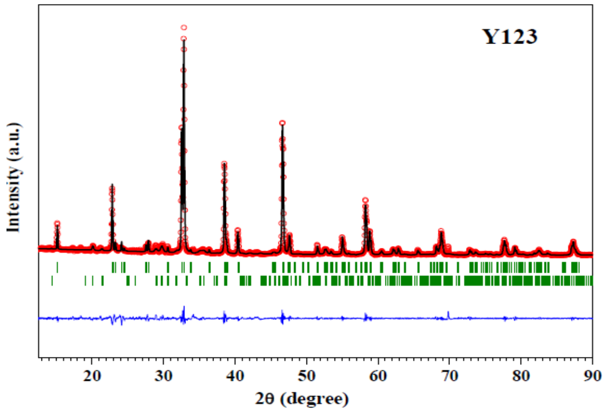

Figure 4. The XRD spectra of the pure Y123 superconductor. Experimental (o) are point on solid line, calculated (solid line) and the vertical ticks below the curve indicate the Bragg positions.

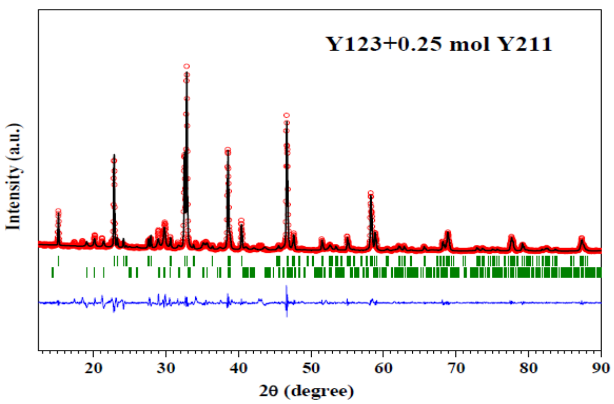

Figure 5. The XRD spectra of Y123+0.25 mol Y211 composite superconductor. Experimental (o) are point on solid line, calculated (solid line) and the vertical ticks below the curve indicate the Bragg positions.

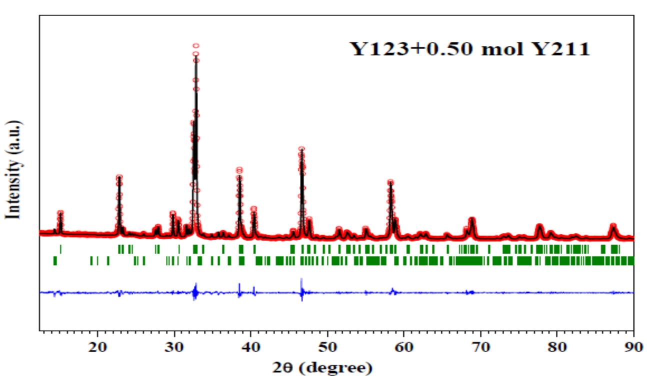

Figure 6. The XRD spectra of Y123+0.50 mol Y211 composite superconductor. Experimental (o) are point on solid line, calculated (solid line) and the vertical ticks below the curve indicate the Bragg positions.

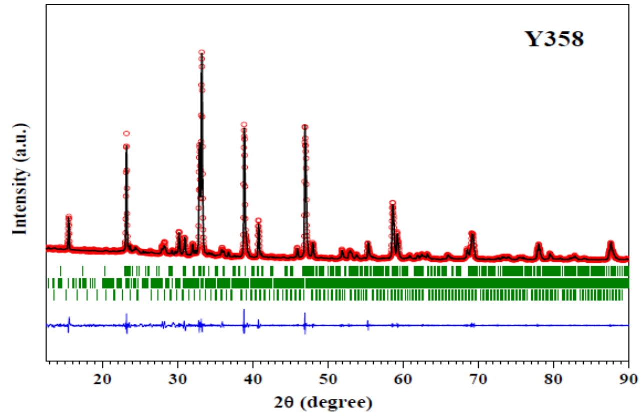

Figure 7. The XRD spectra of the pure Y358 superconductor. Experimental (o) are point on solid line, calculated (solid line) and the vertical ticks below the curve indicate the Bragg positions.

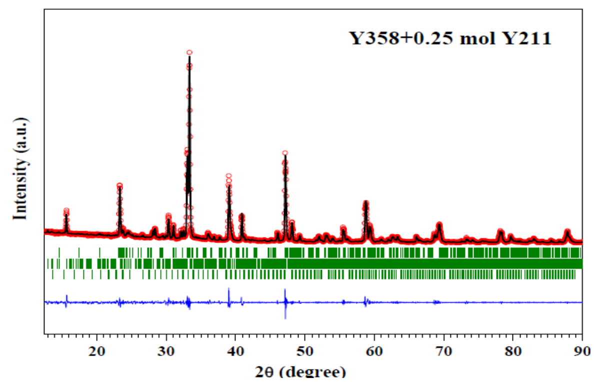

Figure 8. The XRD spectra of Y358+0.25 mol Y211 composite superconductor. Experimental (o) are point on solid line, calculated (solid line) and the vertical ticks below the curve indicate the Bragg positions.

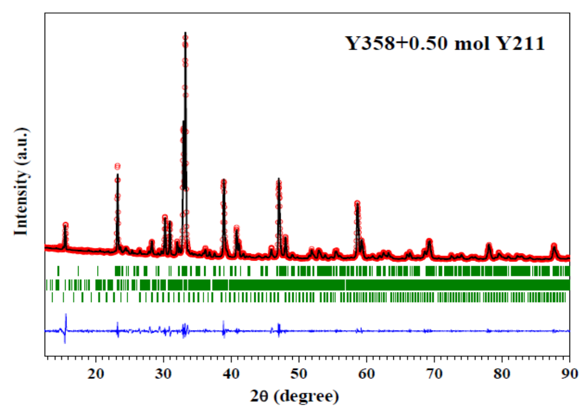

Figure 9. The XRD spectra of Y358+0.50 mol Y211 composite superconductor. Experimental (o) are point on solid line, calculated (solid line) and the vertical ticks below the curve indicate the Bragg positions.

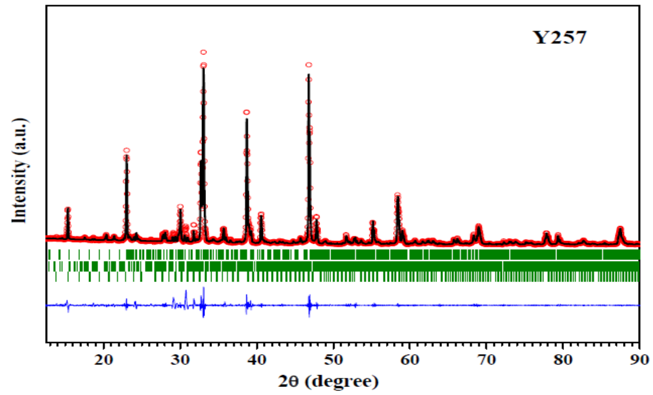

Figure 10. The XRD spectra of pure Y257 superconductor. Experimental (o) are point on solid line, calculated (solid line) and the vertical ticks below the curve indicate the Bragg positions.

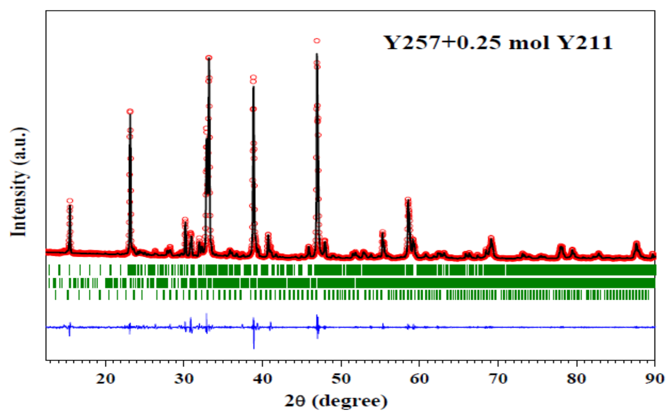

Figure 11. The XRD spectra of pure Y257+0.25 mol Y211 superconductor. Experimental (o) are point on solid line, calculated (solid line) and the vertical ticks below the curve indicate the Bragg positions.

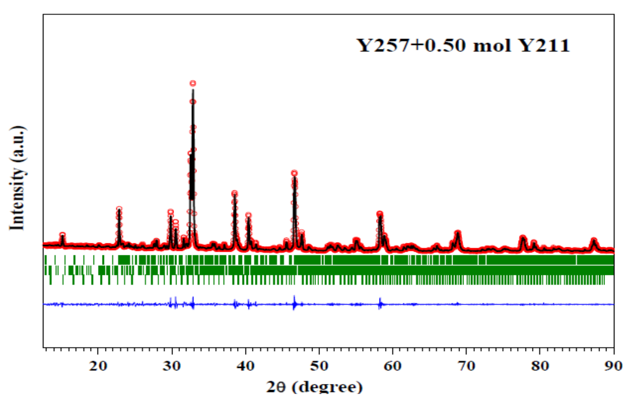

Figure 12. The XRD spectra of pure Y257+0.50 mol Y211 superconductor. Experimental (o) are point on solid line, calculated (solid line) and the vertical ticks below the curve indicate the Bragg positions.

Table 2. The percentage phase composition.

Samples	Percentage phase composition (%)		
	Superconducting phase,	Non-superconducting phase	
	Pmmm	$Ba_2Cu_3O_6$, Pccm	$BaCuO_2$, Im-3m
Y123	90	6	4
Y123+0.25molY211	82	7	11
Y123+0.50molY211	80	12	8
Y358	25	55	20
Y358+0.25molY211	20	40	40
Y358+0.50molY211	15	35	50
Y257	14	36	50
Y257+0.25molY211	12	40	48
Y257+0.50molY211	10	45	45

Table 3. The lattice parameters of the superconducting phase.

Samples	Lattice parameters			Anis=200
	a(Å)	b(Å)	c(Å)	[(b-a)/(b+a)]
Y123	3.81710 0.00008	3.88430 0.00009	11.68000 0.00021	1.73
Y123+0.25molY211	3.81590 0.00017	3.88540 0.00090	11.67590 0.00023	1.78
Y123+0.50molY211	3.81660 0.00015	3.88670 0.00038	11.67390 0.00029	1.80
Y358	3.82257 0.00009	3.87603 0.00004	30.66149 0.00044	1.38
Y358+0.25molY211	3.82884 0.00027	3.88363 0.00026	30.52480 0.00176	1.42
Y358+0.50molY211	3.77715 0.00009	3.84602 0.00012	30.39207 0.00070	1.80
Y257	3.80225 0.00008	3.86696 0.00009	26.38292 0.00129	1.68
Y257+0.25molY211	3.81932 0.00006	3.89151 0.00004	25.86840 0.00095	1.87
Y257+0.50molY211	3.81011 0.00009	3.88957 0.00009	25.70966 0.00133	2.06

revealed that it is composed highest content of superconducting phase comparing to the doped samples. Besides, in case of increasing non-conducting phase the lower c direction was occurred. The main peaks of Y358 and Y257 were similar with Y123 superconductor. The anisotropic of the samples are equal to 200(b-a)/0.5(b-a). Moreover, the more content of Y211 doping causes more anisotropic of the samples (Table 3).

It is important to note that the XRD could not detect Y211 in the final samples. This may be due to the

Table 4. The lattice parameter of the non-superconducting phase.

Samples	Non-superconducting phase								
	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)
Y123	7.13074 0.00157	12.27472 0.00314	5.61281 0.00101	-	-	-	-	-	-
Y123+0.25molY211	7.13609 0.00134	12.27148 0.00186	5.60504 0.00086	-	-	-	-	-	-
Y123+0.50molY211	7.13139 0.00018	12.17139 0.00045	5.65701 0.00017	-	-	-	-	-	-
Y358	-	-	-	18.44041 0.00157	18.44041 0.00157	18.44041 0.00157	13.07853 0.00019	20.72125 0.00029	11.44339 0.00019
Y358+0.25molY211	-	-	-	18.31984 0.00030	18.31984 0.00030	18.31984 0.00030	12.94864 0.00023	20.51307 0.00032	11.33181 0.00015
Y358+0.50molY211	-	-	-	18.37572 0.00091	18.37572 0.00091	18.37572 0.00091	13.05474 0.00021	20.71643 0.00040	11.42290 0.00018
Y257	-	-	-	18.23857 0.00047	18.23857 0.00047	18.23857 0.00047	12.97630 0.00017	20.56757 0.00026	11.38094 0.00017
Y257+0.25molY211	-	-	-	18.41250 0.00169	18.41250 0.00169	18.41250 0.00169	13.04191 0.00017	20.71064 0.00032	11.43900 0.00012
Y257+0.50molY211	-	-	-	18.47248 0.00086	18.47248 0.00086	18.47248 0.00086	13.02902 0.00019	20.63760 0.00027	11.42583 0.00016

preparing process that the samples were calcined at 950°C. Such high temperature may transform the Y211 to be other substances such as $BaCuO_2$ and $Ba_2Cu_3O_6$.

Conclusion

The Y123, Y358 and Y257 superconductors and non-superconducting of Y211 were synthesized by solid state reaction. The black Y123, Y358 and Y257 and the green Y211 were obtained. The Y211 of 0, 0.25 and 0.50 mol were mixed with Y123, Y358 and Y257 to their superconductors. The mixed powders were calcined and sintered. The critical temperature of the T_c onset and T_c offset of samples were investigated by d.c. four-probes method and crystal structure were carried out by powder X-ray diffraction with Rietveld full-profile analysis method for determining the phase composition, lattice parameters of the superconducting phase, non-superconducting phase and space group. The results indicated that the $T_c$onset and $T_c$offset of the samples lower with increasing Y211 doping. The samples consist of both superconducting and non-superconducting phase. The lattice parameter of pure samples has longer *c* direction than Y211 doped samples. The superconducting phase decreased with increasing Y211 doping. There are three types of non-superconducting phases in the samples, Y211, $BaCuO_2$ and $Ba_2Cu_3O_6$ with Pbnm, Im-3m and Pccm, respectively. According to the percentage of superconducting phase, the anisotropy increased with more Y211 contents.

Conflict of Interest

The author has not declared any conflict of interest.

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