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Optimization of Synthesis Parameters for the Formation of Promising $Y_3Ba_5Cu_8O_{18}$ Compound

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Abstract

In the present work, the influence of various heat treatment conditions such as sintering temperature, duration and compacting pressure, on the structure, microstructural and electrical properties of the new $Y_3Ba_5Cu_8O_y$ (noted Y-358, YBCO family)superconducting material was investigated. Samples were produced by means of the standard solid-state reaction process. The structural and microstructural characterizations of the various synthesized products were investigated by X-ray diffraction (XRD) and scanning electron microscope (SEM). The electrical resistivity as a function of temperature was also performed and examined. The analyses show that the optimal structural formation was achieved for the product prepared at 950°C for 48 h. This sample exhibited a superconducting transition temperature (T_{co}) value around 95 K.

Key words: $Y_3Ba_5Cu_8O_y$ superconductor, Structure, Morphology, Transport properties.

1. Introduction

The high temperature superconductor (HTS) materials are one of the most intensively studied and attractive systems owing to their higher superconducting performances and diverse applications. $YBa_2Cu_3O_7$ (Y-123) is the

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first HTS material discovered with the transition temperature (T_c) of 91 K [1].One of the problems has been that the magnetic flux is not completely expelled, but rather is contained within magnetic fluxions, whose motion prevents larger super currents. To prevent the vortex motions and enhance the flux pinning strength, it is necessary to introduce artificial pinning centers (APCs) in a superconductor apart from those which occur naturally. In our previous studies, various techniques such as high energy ball milling technique [2-9] and chemical doping and additives including metal, semiconducting, insulator and magnetic nano-entities [10-15] have been employed to act as artificial pinning centers. These routes show their efficiency to enhance the superconducting properties, particularly the magnetic properties and the critical current densities.

In other hand, numerous investigations have been made on the YBCO family with various stoichiometries in the aim to enhance their superconducting properties. After the discovery of Y-123, the $YBa_2Cu_4O_8$ (Y-124) [16] and $Y_2Ba_4Cu_7O_{15}$ (Y-247) [17] are other two familiar members of the YBCO family, but with lower T_c. Like the other cuprate HTS materials, Y-123, Y-124 and Y-247 are dissimilar by their number of CuO_2 planes and CuO chains or double chains [18-19] which have a special role on the superconducting properties. Assuming that the number of atoms of Ba and Y is equal to the number of atoms of Cu, Udomsamuthirun team [20] has synthesized new numbers of the YBCO-family such as Y5-6-11, Y7-9-16, Y5-8-13, Y7-11-18, Y1-5-6, Y3-8-11 and Y13-20-33. Recently, a new Y-based superconducting material labeled Y-358, has been discovered by increasing the planes number in the unit cell [21]. Its crystalline structure is similar to that of Y-123. It was reported that Y-358 material exhibits the highest T_c among the different compounds of the YBCO family. In the literature, the value of T_c is ranging from 80 to 98 K, depending on the synthesis routes [20-29]. In the present paper, we report a study of microstructural and electrical transport properties of the Y-358 system prepared using different heat treatment conditions such as sintering temperature, duration and compacting pressure.

2. Experimental

The samples of new Y-358 compound were synthesized using the standard solid-state reaction method through a multi-heat treatment cycles. Appropriate stoichiometric ratios of high purity powders of copper oxide (CuO) and yttrium (Y_2O_3) with barium carbonate ($BaCO_3$) were mixed in an agate mortar, ground, pressed into pellets under pressure of 0.5 ton/cm² and heat treated in air at 950°C for 24 h and then cooled to room temperature within 5 h. This step of calcination was repeated twice with intermediate grinding and pelletizationin order to eliminate any remainders of carbonates. The obtained precursor powders were re-grounded, pressed uniaxially at different compacting pressures ranging from 0.5, 2 and 5 ton/cm² into pellets of 13 mm in diameter and 1 mm in thickness. Pellets have been heat treated under oxygen atmosphere at variable temperatures ranged from 930 to 970 °C and for different durations 24-96 h and finally cooled to room temperature in the furnace.

The structure and the phase purity were studied through powder XRD using a Philips 1710 diffractometer with CuKα radiation. The morphology was investigated using a scanning electron microscope (SEM) FEI Nano Lab 200. For the electrical measurements, the pellets were carefully cut into bar shaped samples with active cross sections for current flow of 0.3 mm. The temperature dependence of the electrical resistivity ρ(T) was measured by using the standard dc four-probe in a DMX-19 SCC cryostat system. Electrical contacts were made using silver paint and the contact resistance value was approximately 0.5 Ω. The excitation current was injected along

the length axis of the samples. The magnitude of the excitation current, I, used to measure resistivity of the samples was I = 40 μA. The values of transport critical current density (J_{ct}) were determined using a 5 μV/cm criterion.

3. Results and Discussion

Figure1 displays the temperature dependences of the electrical resistivity ρ(T) for products sintered at 930°C, 950°C and 970°C for 48 h. All products display metallic behavior in the normal state (i.e. dρ/dt>0) and a superconducting transition to zero resistance. The sample sintered at 970°C has the highest normal state resistivity. It is well-known that the absolute resistivity in the normal state could greatly depend on the porosity and the grain boundaries. Products sintered at 930°C and 950°C show a one-step superconducting transition, however for the product sintered at 970°C, the ρ(T) measurements indicated two rapid resistivity drops. The existence of a double superconducting transition can be assigned to the presence of additional phase resulting from the chemical reaction. The onset transition temperature T_c^{onset} values extracted from the ρ(T) curves are 94, 95.5 and 92 K for samples sintered at 930°C, 950 °C and 970 °C respectively. These values are higher than the values for the Y-123 superconductor. On the other hand, the zero-resistance temperature T_{co} were determined to be 88.2, 93.3 and 78.5 K for samples sintered at 930°C, 950°C and 970°C respectively.

The SEM images of the transverse cross-section morphology of the sintered products at 950°C and 970 °C are presented in Figure2. The microstructure of the sintered products exhibits a granular structure with of grains oriented randomly in all direction. The SEM photographs show a clear transformation in the grains size of samples sintered at different temperatures. The grains size increases as the sintering temperature increases. The product sintered at 970°C is consisted of large and compact grains.

The ρ(T) measurements for samples sintered at 950°C for various durations of 24 h, 48 h and 96 h are presented in Figure 3. All products exhibit a metal-like behavior at normal state. It is obvious that the sample sintered at 950°C for 48 h presents the lowest resistivity at normal state, which implies that the porosity, the disorder and the impurity scattering in the CuO_2-planes in this product are the lowest. In addition, the sample sintered at 950°C for 48 h exhibits the highest values of T_c^{onset} and T_{co}, indicating the better intra- and inter-granular properties compared to two other products.

Figure 4 shows the resistivity versus temperature curves of pellets pressed uniaxially at various compacting pressures of 0.5, 2 and 5 ton/cm² and then sintered at 950°C for 48 h. It is obvious that the sample pressed under a pressure of 2 ton/cm² presents the greatest parameters: the lowest resistivity at normal state, the closest transition to the superconducting state and the highest T_c^{onset} and T_{co}.

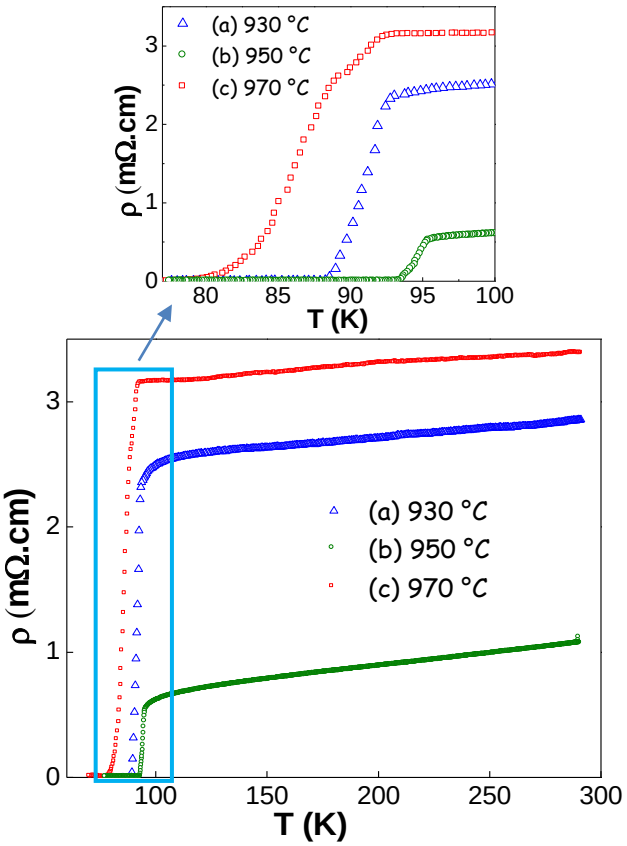


Figure 1. Temperature dependences of the electrical resistivity, ρ(T), for samples sintered at diverse temperatures: (a) 930°C, (b) 950°C and (c) 970°C. The inset shows a closer look of the superconducting transition.

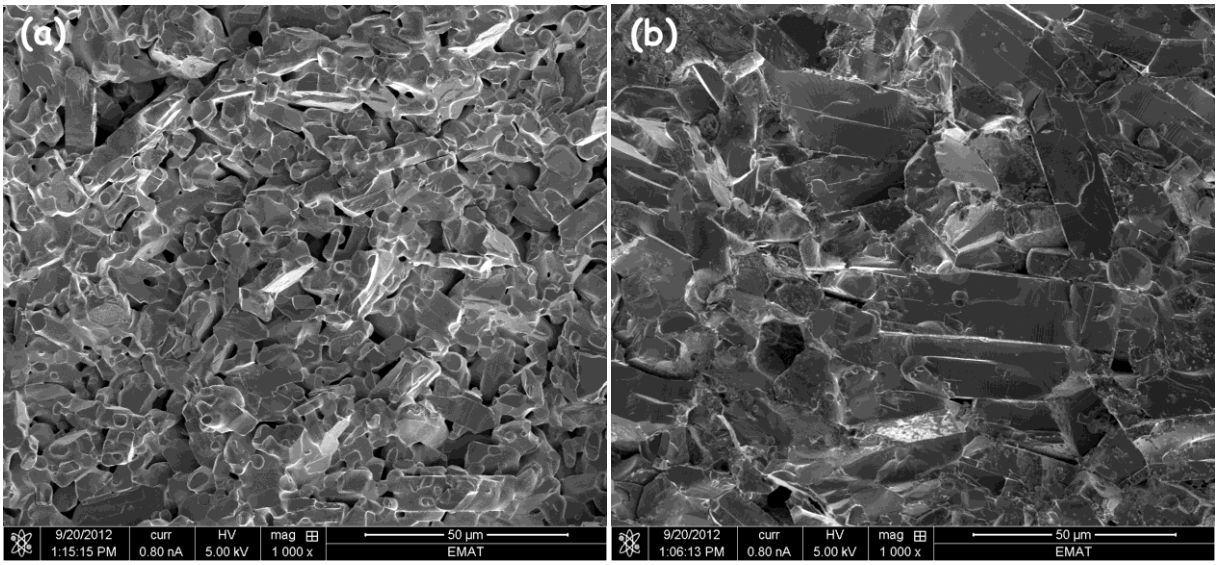


Figure 2. SEM micrographs of samples sintered at 950°C (a) and 970°C (b) for 48 h.

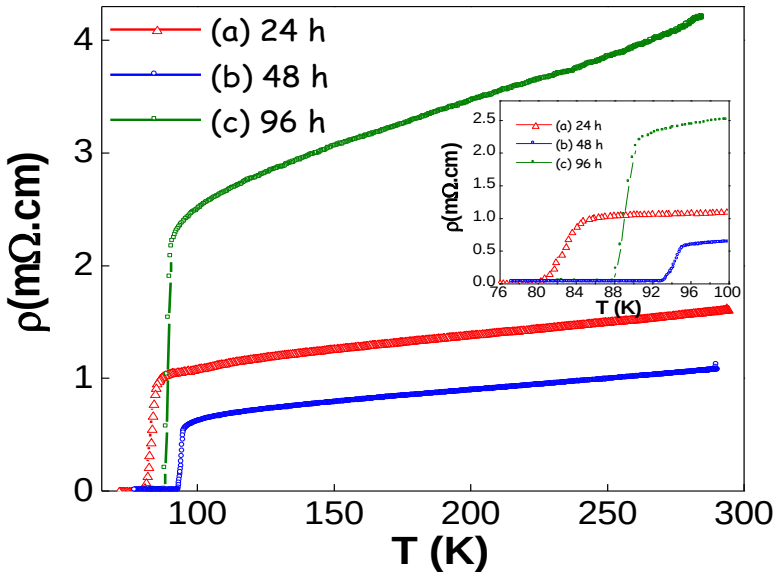


Figure 3. Variations of electrical resistivity as a function of temperature, ρ(T), for products sintered at 950 °C with different annealing durations: (a) 24, (b) 48 and (c) 96 hours.

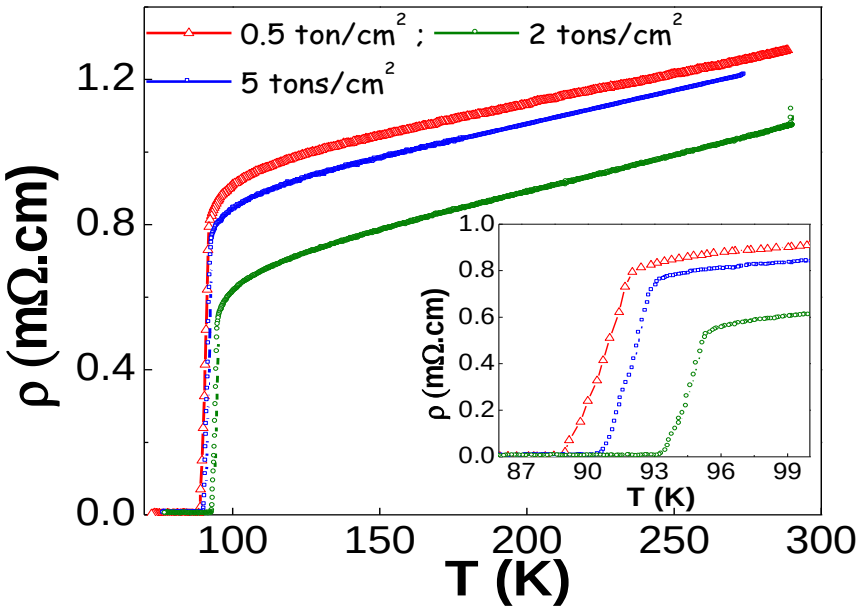


Figure 4. Measurement of ρ(T) of samples sintered at 950°C for 48 h with different compacting pressures of(a) 0.5, (b) 2 and (c) 5 ton/cm².

According to the chemical formula $Y_3Ba_5Cu_8O_y$, it is clear also that the structural and superconducting properties are related to the stoichiometry of oxygen. Therefore, another sample will be compacted into pellet form under a pressure of 2 tons/cm^2 and then sintered at a temperature of 950°C for 48 h. During this annealing, the sample is subjected under an oxygen flow. The Figure 5 shows the variations of electrical resistivity versus temperature ρ(T) of optimal $Y_3Ba_5Cu_8O_y$ products pressed into pellet under a pressure of 2 ton/cm² and then sintered at 950°C for 48 h in the absence and the presence of oxygen flow. It is clear that the sample that prepared under oxygen flow shows a little bit enhancement of the superconducting parameters compared to non-oxygenated one. The oxygenated Y-358 sample exhibits the lowest resistivity at normal state, the closest transition to the superconducting state and the highest T_c^{onset} = 96.5 K and T_{co}=95.

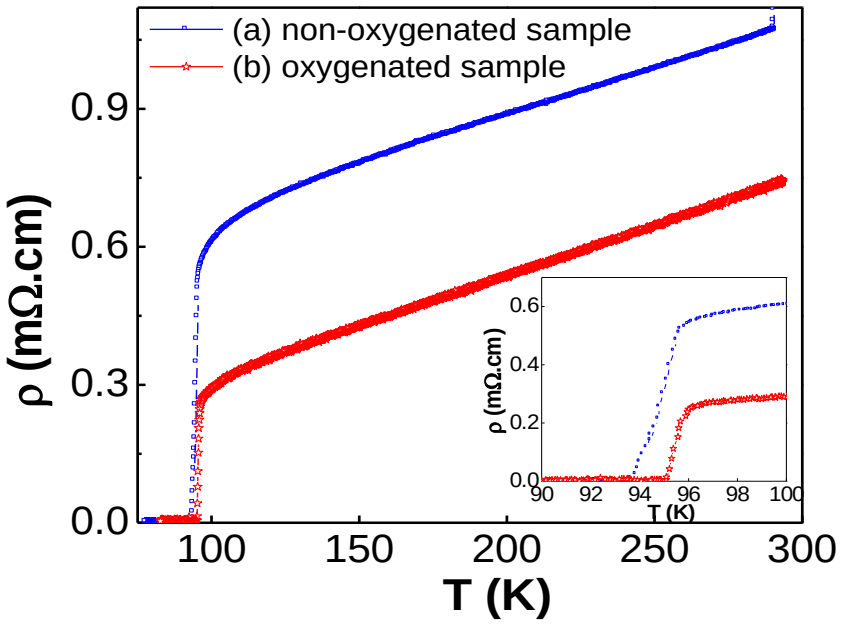


Figure 5. Variations of electrical resistivity as a function of temperature ρ(T) of optimal $Y_3Ba_5Cu_8O_y$products sintered in the absence and the presence of oxygen flow.

The XRD pattern of the optimal $Y_3Ba_5Cu_8O_y$ products sintered in the presence of oxygen flow is shown in Figure 6. All observed peaks are belonging to the $Y_3Ba_5Cu_8O_y$ orthorhombic phase with Pmm2 symmetry beside very small amount of impurity phases. The lattice parameters of Y-358 were calculated using High Score program and are found to be a = 3.8167 Å, b = 3.8825 Å and c = 31.1397 Å. The deduced "a" and "b" parameters are almost equal to those of Y-123 compound, however the parameter "c" of Y-358 is approximately three times that of Y-123, which is compatible with the results reported in the literature for these compounds [21]. Additionally, the energy dispersive X-ray spectroscopy (EDXS) spectrum is performed for the optimal Y-358 sample and is shown in Figure 7. The EDX spectrum indicates the presence of Y, Ba and Cu elements and the

quantitative analysis confirms that the compound has principally the expected composition with ratio of Y/Ba/Cu ≈ 3/5/8 (inset of Figure 7).

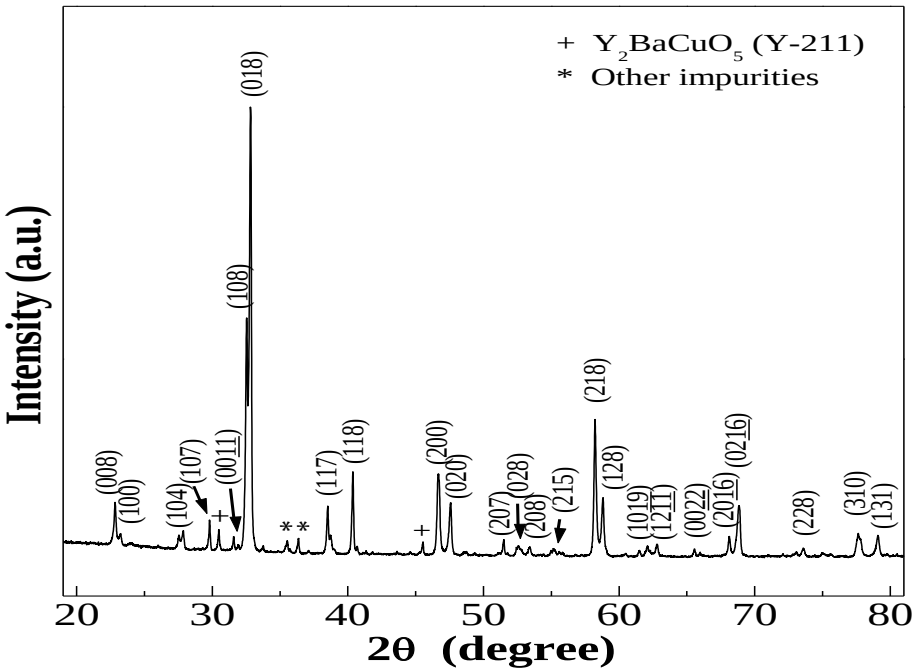
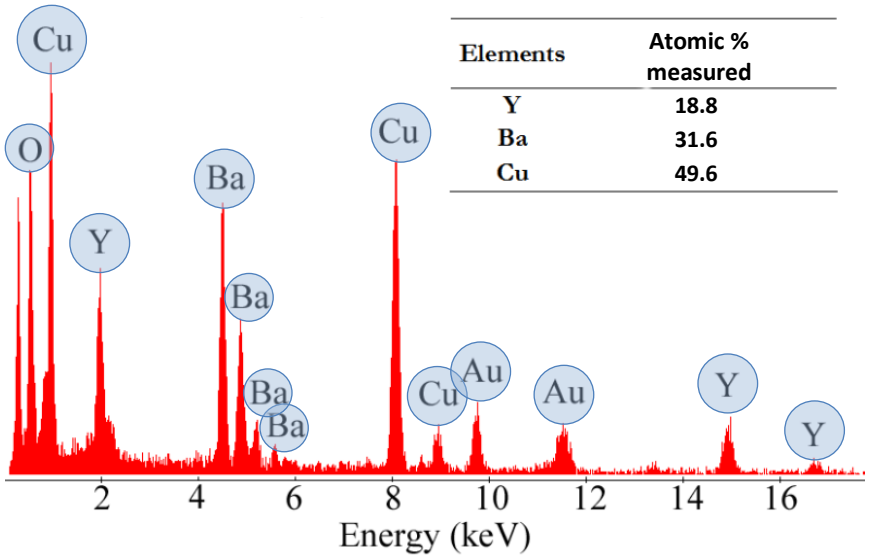


Figure 6. X-ray powder diffraction (XRD) patterns of Y-358 samples prepared at 950°C for 48 h in (a) the absence and (b) the presence of oxygen flow.



Elements	Atomic % measured
Y	18.8
Ba	31.6
Cu	49.6

Figure 7. EDX spectrum of the optimal synthesized $Y_3Ba_5Cu_8O_y$compound indicating the presence of the expected elements. Inset: quantitative chemical composition.

The critical current density J_c for the optimal Y-358 compound was calculated and found to be around 190 A/cm². This value is very interesting especially when compared to the values reported in the literature in the case of $Y_3Ba_5Cu_8O_1y$ compounds.

4. Conclusion

In summary, we have successfully produced and optimized the different synthesis conditions, particularly the sintering temperature, the duration and the compacting pressure. The best superconducting parameters were obtained for the sample compacted into pellet under a pressure of 2 ton/cm² and then sintered at 950 °C for 48 h. For this sample, the superconducting T_c^{onset}started at 95.5K and the value T_{co} was reached at 93.3 K. After that, it is found that the preparation of this optimal Y-358 sample in the presence of oxygen flow leads to enhance a little bit the values of T_c^{onset} and T_{co} to be equal 96.5 and 95 K, respectively. Furthermore, this sample showed the lowered resistivity in the normal state. Besides, the critical current density J_c was calculated and found to be around 190 A/cm². The obtained superconducting parameter are very interesting especially when compared to the values reported in the literature, better than obtained by many researchers and very comparable to the best values (T_{co} = 98 K and T_c^{onset} = 100 K) reported by Aliabadi and team [21].

5. Conflicts of Interest

The author(s) report(s) no conflict(s) of interest(s). The author along are responsible for content and writing of the paper.

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