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EFFECT OF Al DOPING ON THE MICROSTRUCTURE AND ELECTRICAL TRANSPORT PROPERTIES OF YBCO SUPERCONDUCTOR

MUHAMMAD IRFAN BIN IZHAM

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Bachelor of Applied Science (Honours) Material
Technology

Faculty of Industrial Sciences & Technology
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DECEMBER 2016

SUPERVISORS' DECLARATION

I hereby declare that I have checked the thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Bachelor of Applied Science (Honours) Material Technology.

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DEDICATION

My biggest dedication goes to my families; Izham, Shahida, Ilya, Isfahan and Imran for their supporting commends, their understanding towards my research and many more.

Next, I would like to dedicated this to Nurul Amalina. For her non-stop support from the beginning towards the end of this research. For her help. For her time spend. For her sincerity. Thanks.

Well, lastly it goes to my fellow Universiti Malaysia Pahang lecturers, classmates, friends and anyone that directly or indirectly related to my research.

THANK YOU !

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ABSTRACT

Superconductor used is $YBa_2Cu_3O_7$ (YBCO) with addition dopant element of Aluminium (Al). The Al_2O_3 doping is used to study the microstructure and electrical transport properties of YBCO superconductor. Process involved in preparation of YBCO superconductor is by using solid state reaction method. The superconductors were prepared with different composition of aluminium oxide doping which are 0.01 wt%, 0.02 wt%, 0.03 wt%, 0.04 wt%. The samples were tested with four analyses which are for phase formation; X-Ray Diffractometer (XRD) is used, for microstructure; Scanning Electron Microscopy (SEM) is used, for critical current; Four Point Probe is used, and for Meissner Effect of superconductors. The results obtained for XRD can be conclude that YBCO compound having an orthorhombic structure which shows superconducting behaviour. For SEM results, the microstructure obtain is almost the same with constant or pure YBCO superconductor although doping process were done to the samples this is due to the concentration of magnetic nanoparticles were too small to act as impurity and to cause porous structure. Next, for four point probe testing, the result obtained is the resistance value = 0 Ω when cooled at critical temperature, T_c but some errors might occur that causes some changes to the results. Lastly, Meissner Effect test shows that the critical temperature of YBCO superconductor is high when addition of Al_2O_3 element is added, compared to pure YBCO superconductor.

ABSTRAK

Superkonduktor yang digunakan adalah $YBa_2Cu_3O_7$ (YBCO) dengan elemen tambahan dopan daripada Aluminium (Al). Al_2O_3 doping digunakan untuk mengkaji mikrostruktur dan pengangkutan elektrik sifat YBCO superkonduktor. Proses yang terlibat dalam penyediaan YBCO superkonduktor adalah dengan menggunakan kaedah tindak balas keadaan pepejal. Superkonduktor telah disediakan dengan komposisi yang berbeza daripada aluminium oksida doping yang 0.01 %berat, 0.02 %berat, 0.03 %berat, 0.04 %berat. Sampel diuji dengan empat analisis iaitu bagi pembentukan fasa; X-ray Pembelauan (XRD) digunakan, untuk mikrostruktur; Mikroskop Pemindai Elektron (SEM) digunakan, untuk suhu kritikal; empat mata siasatan digunakan, dan untuk Kesan Meissner superkonduktor. Keputusan yang diperolehi untuk XRD boleh menyimpulkan bahawa sebatian YBCO mempunyai struktur otorombik yang menunjukkan tingkah laku superkonduktor. Untuk keputusan SEM, mikrostruktur mendapatkan hampir sama dengan pemalar atau tulen superkonduktor YBCO walaupun proses doping telah dilakukan untuk sampel ini adalah disebabkan oleh kepekatan nanopartikel magnet terlalu kecil untuk bertindak sebagai bendasing dan menyebabkan struktur berliang. Seterusnya, untuk empat mata siasatan ketika, keputusan yang diperolehi adalah nilai rintangan = 0 Ω apabila disejukkan pada suhu kritikal, T_c tetapi beberapa kesilapan mungkin berlaku yang menyebabkan beberapa perubahan kepada keputusan. Akhir sekali, ujian Kesan Meissner menunjukkan bahawa suhu genting superkonduktor YBCO adalah tinggi apabila penambahan Al_2O_3 elemen ditambah, berbanding YBCO superkonduktor tulen.

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LIST OF SYMBOLS

T_c	-	Critical Temperature
%	-	Percent
J_c	-	Critical Current Density
λ	-	Penetration Depth
ξ	-	Coherence Length
ϕ	-	Permit Magnetic Flux
B	-	Magnetic Field
B_{c1}	-	Lower Critical Magnetic Field
B_{c2}	-	Upper Critical Magnetic Field
I	-	Current
V	-	Voltage
Ω	-	Resistance
wt.%	-	Weight Percentage
2θ	-	Bragg Angle

LIST OF ABBREVIATIONS

Al_2O_3	-	Aluminium Oxide
$BaCO_3$	-	Bariun Carbonate
BCS	-	Bardeen Copper Schrieffer
BSCCO	-	Bismuth Strontium Calcium Copper Oxide
CH_3CH_2OH	-	Ethanol
CH_3COCH_3	-	Acetone
CuO	-	Copper (II) Oxide
EDX	-	Energy Dispersive X-ray
FESEM	-	Field Emission Scanning Electron Microscope
SEM	-	Scanning Electron Microscopy
XRD	-	X-ray Diffraction
Y123	-	Yttrium Barium Cuprate
Y_2O_3	-	Yttrium Oxide
YBCO	-	Yttrium Barium Copper Oxide
$YBa_2Cu_3O_7$	-	Yttrium Barium Copper Oxide
$YBa_2Cu_{3-X}Al_XO_7$	-	Yttrium Barium Copper Oxide Al Doped

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Superconductors are materials that permit current to stream with no resistance. They are additionally utilized as immaculate diamagnets when presented to moderate magnetic fields. High temperature superconductor has an incredible potential to be created for high vitality transport applications. Nonetheless, the flux pinning capacity and intergrain link should be enhanced keeping in mind the end goal to reduce the quick decay of the critical current density J_c at high temperature and in magnetic fields.

The electrical resistivity of numerous metal and alloys drops abruptly to zero when the sample is cooled to adequate temperature, regularly in the fluid helium temperature range. This marvel is called superconductivity and was initially seen by Kamerlingh Onnes in 1911. At critical temperature, T_c the example experiences a phase transition from a state of ordinary electrical resistivity to superconducting state. In the superconducting state the dc electrical resistivity is zero, or so close to zero that electrical current have been seen to flow without constriction in superconducting ring.

Other vital property of superconductors was found in 1933 by Meissner and Ochsenfeld. One would expect, because of the ideal conductivity, that magnetic flux ought to be prohibited from entering a superconductor, additionally it was found that flux was ousted from the material as it was cooled through its critical temperature. This marvel is called 'Meissner' effect. Ginzburg–Landau hypothesis was created in 1950, which characterizes two parameters which are the London magnetic field penetration depth *(λ)* and the superconducting coherence length *(ξ)*. In 1957, BCS hypothesis was produced to clarify the superconductivity.

There are two types of superconductors which are Type I and Type II. In Type I, superconductors that has single critical field B_c, superconductivity is demolished by method for a first order phase transition when the nature of the associated field rises above H_c. This type of superconductivity regularly appears in metals, e.g. aluminum, lead, and mercury. Type II superconductor has two critical field, B_{c1} and higher critical field, B_{c2}. The lower critical field B_{c1} happens when appealing flux vortices invade the material however the material stays superconducting outside of these microscopic vortices. Exactly when the vortex thickness gets the opportunity to be excessively sweeping, the entire material gets, making it impossible to be non-superconducting, this identifies with the second, higher critical field B_{c2}. In a type II superconductor, the understandability length is smaller than the passage significance. Type II superconductors are ordinarily made of metal mixes or complex oxide ceramic generation. All high temperature superconductors are type II superconductors. Ginzburg-Landau proposes that for Type-I; $\frac{\lambda}{\xi} < \frac{1}{\sqrt{2}}$ while for Type-II; $\frac{\lambda}{\xi} > \frac{1}{\sqrt{2}}$.

The superconductor utilized as a part of this study is a type II superconductor YBCO ($YBa_2Cu_3O_7$) which was found by Maw-Kuen Wu and Chu Ching-Wu in 1987. YBCO has T_c higher than the breaking point of fluid nitrogen. A few nanoparticles have been included $YBa_2Cu_3O_7$ superconductor to go about as pinning centers with a specific end goal to enhance flux pinning capacity. As indicated by Lyuksyutov (1999) nanoparticles with size bigger than superconducting coherence length, ξ and smaller than London magnetic field penetration depth, λ of YBCO have been recommended to build J_c.

Figure 1.1 *Type I superconductor*

(Sources: hyperphysics.phy-astr.gsu.edu)

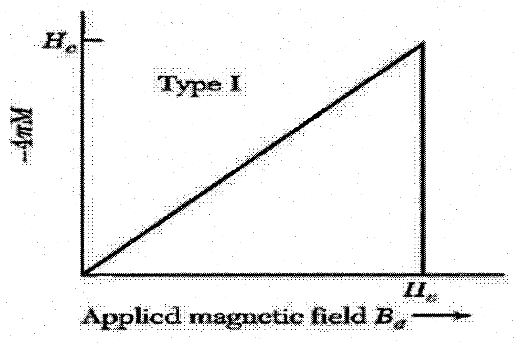
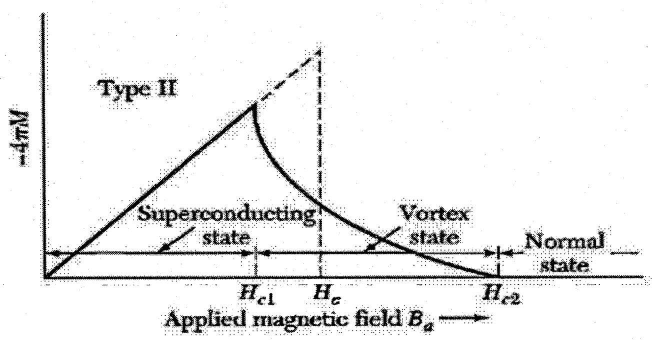


Figure 2 *Type II superconductor*

(Sources: hyperphysics.phy-astr.gsu.edu)



1.2 PROBLEM STATEMENT

Superconductors consist of two types, commonly known as Type-I and Type-II superconductor. Type-II superconductor has the upper hand when comparing the critical temperature, T_c of material due to its capability to achieve and operate at higher T_c. Although it possess the outstanding leading material to be the new advanced technology, but it has a certain limitation due to multiple factors. As discussed above, the ability of the superconductor to maintain its critical temperature for optimization of 0 resistances, is one of the limitations that superconductor facing nowadays. A step to overcome this problem is, by adding dopant that will definitely change the characterization of original YBCO superconductor. By doping, the transition temperature of YBCO will increased and the result is increasing in critical current density, porosity in microstructure and variation in crystal structure. (Abd-Ghani, et al. 2012)

1.3 OBJECTIVES OF RESEARCH

Objectives of this research are:

1. To study the effect of Al doping on the microstructure of YBCO superconductor.
2. To determine the effect of Al doping on electrical transport properties of YBCO superconductor.
3. To develop a laboratory scale method in determining the critical temperature of YBCO superconductor.

1.4 SCOPE OF STUDY

In this research, YBCO with an addition of different Al_2O_3 weight ratio as the dopant material will be fabricated using solid state reaction method. The process includes grinding, pelletizing and sintering at 900 °C. The grinding is done intermediately. Moreover, by using SEM and XRD, the microstructure and phase formation of the Al_2O_3 doping YBCO is observed respectively. A fast and easy method to measure the DC resistance in FIST Laboratory is developed to characterize the pellets at 77 K using four point probe apparatus in Universiti Malaysia Pahang (UMP).

CHAPTER 2

LITERATURE REVIEW

2.1 HISTORY OF YBCO SUPERCONDUCTOR

Yttrium barium copper oxide (YBCO) is a high temperature superconducting materials. It is firstly found by Georg Bednorz and Karl Müller in April 1986, where at that time their work at IBM, had revealed that some semiconducting oxides shows superconductivity behavior at almost high temperature. The first material found that shows superconducting behavior above the boiling point of liquid nitrogen which is 77 K while having 90 K as the critical temperature, T_c, was YBCO. The general formula for YBCO in Y123 is $YBa_2Cu_3O_{7-x}$. According to Wu, et al. (1987), the first discovery of Y123 was made in 1987 by Chu and coworker with T_c of 93 K. The crystal structure of YBCO is in perovskite structure and having a penetration depth, λ of 120 nm in the ab plane and 800 nm along the c-axis while the coherence length, ξ is 2 nm in the ab plane, 0.4nm along the c-axis.

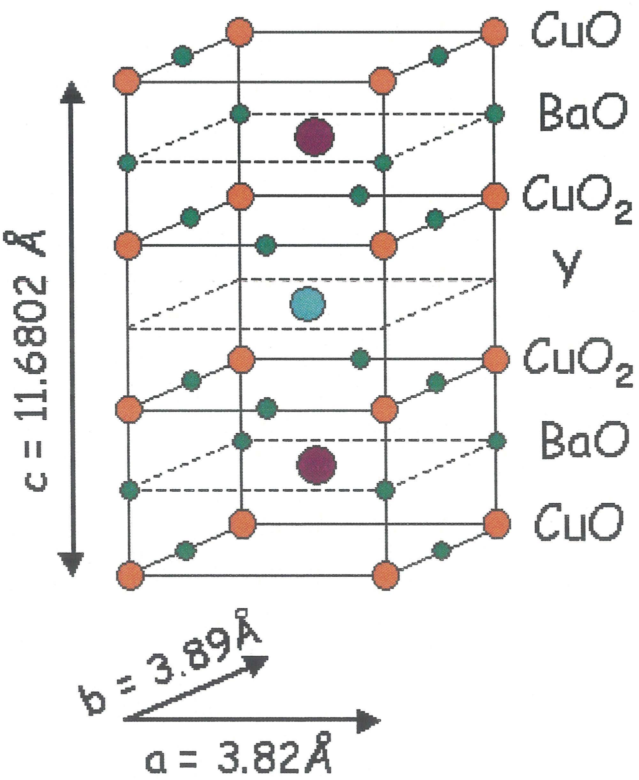
According to Earnshaw and Greenwood (1997), they stated that the value of oxygen content in the $YBa_2Cu_3O_{7-x}$ is very sensitive where $0 \leq x \leq 0.65$ shows superconducting behavior below T_c and $x \sim 0.07$ shows superconducting behavior with the highest critical temperature at 95 K.

Discovery of YBCO is that, it is the first material that break the 77 K (liquid nitrogen) temperature boundary. Now, the optical T_c is more than 90 K. YBCO might be the most highly studied material due to it cleanest and most ordered crystal. But the study of YBCO can be quite confusing because of presence of CuO planes; the square plane and the chain plane. By analogy with other HTSC families, it is thought the superconductivity originates in the square plane, but it is difficult to isolate the behaviors of the plane.

YBCO has typically been used in nuclear magnetic resonance (NMR) studies. It probe the spatial distribution of magnetic field. The reason of all these things to happen is because of YBCO is so well ordered that all the atoms are a particular species will live in the same electronic environment. The newest research on YBCO is that it is used for quantum oscillation experiments, to map out the size of the Fermi pockets.

2.2 YBCO GENERAL STRUCTURE

Figure 2.1 *Structure of YBCO*
Source : (http://hoffman.physics.harvard.edu/materials/CuprateIntro.php)



YBCO having a perovskite structure that consist of layers. Each layer's boundary is defined by planes of square planar CuO_4 units that sharing 4 vertices. Perpendicular to these CuO_2 planes are CuO_4 ribbons sharing 2 vertices each. On the other hand, yttrium atoms are found between CuO_2 planes, when barium atom are situated between the CuO_4 ribbons and CuO_2 planes.

2.3 ALUMINIUM DOPING

According to Wildad (2013) by doping, the electric state of the superconductivity will be more clarified and understood. Effect if Al_2O_3 substitution on the superconducting properties of high -T_c superconductors (HTSCs) may enhance the understanding of several unusual normal state and superconducting properties of these materials.

Previous study shows that Al_2O_3 doping was possible in Y123 and that Al_2O_3 substitutes Cu in the CuO chains net. The substitution was more effective for the enhancement of the critical current density, J_c of YBCO at 77 K than the substitution of Cu in the CuO_2 plane.

2.4 FABRICATION OF YBCO

In the case of YBCO bulk superconductors, it is fabricated by the top seeded melt-growth (TSMG) process, most difficult issue is to push the particles below some critical size which is about 500 nm for Y_2BaCuO_5 particles during the crystal growth. Nanosized non-superconducting regions can be introduced into YBCO bulk superconductor by neutron irradiation or buying chemical substitution of atoms for $YBa_2Cu_4O_{7-\delta}$ lattice mainly carbon chains. These artificially created pinning centers can be effective for enchanced flux pinning in YBCO intermediate magnetic fields and high temperatures.

CHAPTER 3

MATERIALS AND METHODS

3.1 INTRODUCTION

This chapter details the research methodology employed in the present research, comprising preparation of YBCO superconductor. It is fabricated using solid state reaction which containing grinding, sintering and pelletizing. YBCO superconductor is prepared by mixing Yttrium Oxide (Y_2O_3), Barium Carbonate ($BaCO_3$) and Copper Oxide (CuO) together and grind. Thus, my research is about doping Al_2O_3 into the superconductor, small amount of Aluminium Oxide (Al_2O_3) is added into the compound before grinding process takes place. Solid state reaction method involves intermediate grinding the compound and sintering the grinded compound for 24 h at 900 ^{o}C. According to Sozeri et al. (2007) the grain sizes will increases and some grain surfaces become more visible though the grain shapes were uneven when the superconductor are sintered at 900 ^{o}C. After two times of intermediate grinding and sintering, the compound is pressed for pelletizing using hydraulic pump with pellet 13 mm diameter and 2 mm thickness mold. Then, two pellets were made using pelletizing method and sintered. The first pellet is checked for Scanning Electron Microscopy (SEM) and the other pellet is used for checking Meissner Effect, four point probe testing for critical temperature, T_c

3.2 RESEARCH METHODOLOGY

Table 3.1

Table of weight percent ratio of material used to fabricate Al_2O_3 doped YBCO superconductor with Al_2O_3 compositon of (0.01, 0.02, 0.03 and 0.04) wt.%

X (%)	Weight Y_2O_3 (g)	Weight $BaCO_3$ (g)	Weight CuO (g)	Weight Al_2O_3 (g)
0	1.5130	5.2890	3.1980	0.0000
0.01	1.5136	5.2910	3.1885	0.0068
0.02	1.5142	5.2930	3.1791	0.0137
0.03	1.5148	5.2951	3.1696	0.0205
0.04	1.5154	5.2971	3.1602	0.0274

The molecular formula of Al_2O_3 doped YBCO superconductor is $YBa_2Cu_3O_{(7-x)}Al_x$, material is produced according to its percentage of Al_2O_3 in it. After calculated, based on aboved table the sample is weigh and fabricated. When X = 0, the total amount of Al_2O_3 used is zero, this sample act as the control for this research to make a comparison throughout the research.

3.3 MATERIAL AND APPARATUS

Table 3.2 shows the material and apparatus used in fabricating Al_2O_3doped YBCO superconductor with different Al_2O_3 percentage. Also the apparatus needed in throughout the research, including all the testing especially four point probe testing which is fabricated in the lab itself. Some materials are used from the past research, examples solder and wire.

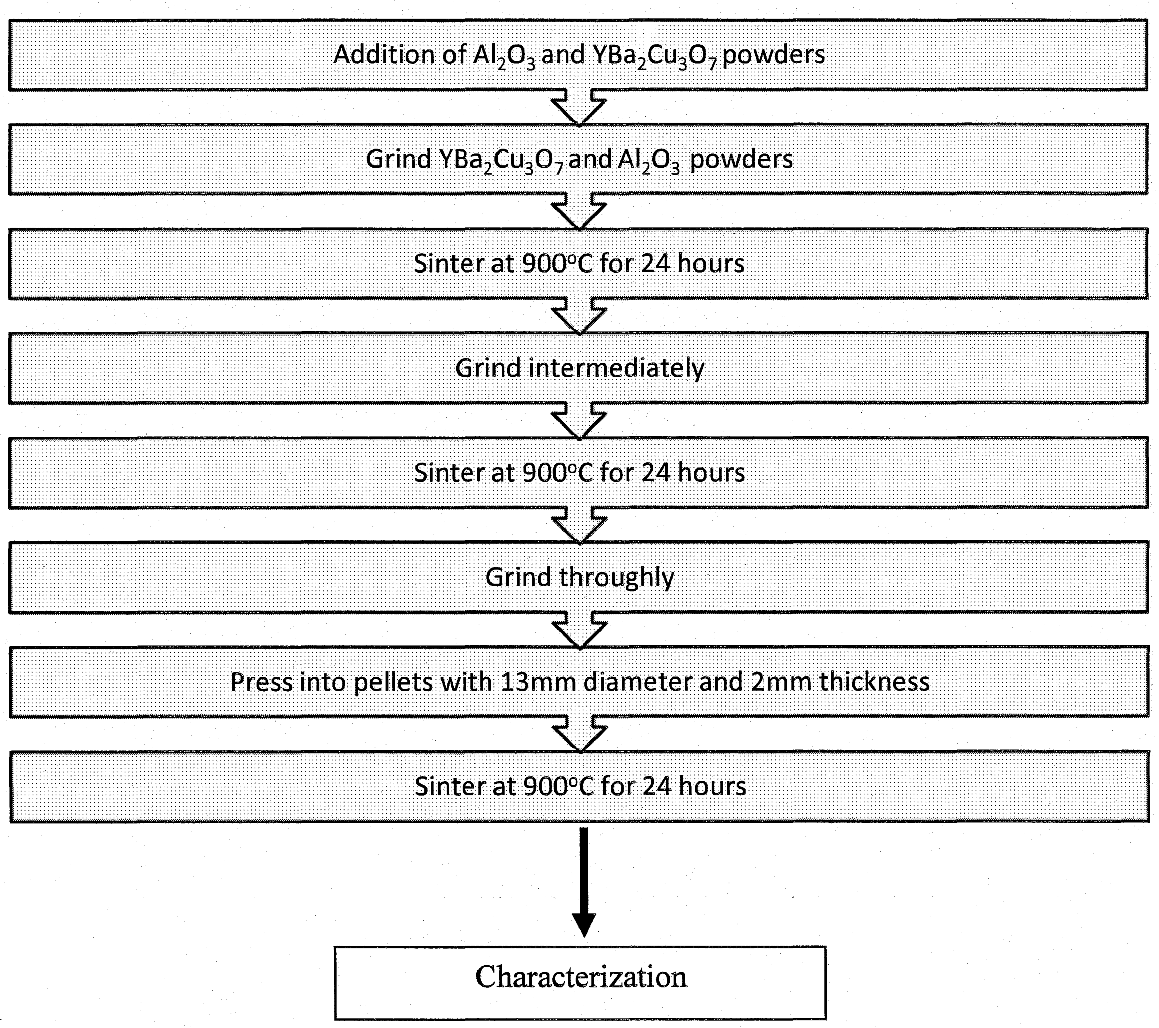
Table 3.2

List of minimum materials and apparatus in fabricating Al_2O_3 doped YBCO superconductor

Material And Apparatus	Quantity
Yttrium Oxide (Y_2O_3)	6.0579 g
Barium Carbonate ($BaCO_3$)	21.1762 g
Copper Oxide (CuO)	12.6975 g
Aluminium Oxide (Al_2O_3)	0.0684 g
Ethanol (C_2H_6O)	1 Liter
Acetone (C_3H_6O)	1 Liter
Silver Paint	15 g
Liquid Nitrogen (Aq. N_2)	3 Liter
Solder	1 unit
Mortar and Pestle	1 unit
Crucible	4 unit
Crucible Boat	1 unit
Spatula	2 unit
Aluminium Foil	1 roll
Strong Magnet (Neodyminium Magnet)	8 unit
Copper Wire	3 meter
Multimeter	1 unit
Thermocouple	1 unit
Sand Paper (400 and 800)	1 unit
Plastic Tweezer	1 unit

3.4 MATERIAL SYNTHESIS METHODS

Figure 3.1 *Flowchart for preparation of Al doped YBCO superconductor.*



3.4.1 GRINDING

During grinding process, the apparatus used is mortar and pestle. At the beginning of the grinding, the mixture of YBCO and Al_2O_3 in powder form is pour inside the pestle and ready for grinding. Be cautious to wear gloves and mask during this synthesis. This is due to the odour and grinded particle might be hazardous to our body. Averagely the grinding process takes around 30 minutes to homogenized the powder. Earlier the powder mixture containing white and black powder with large granules but after grinding, after homogenizing the powder, a black-grey powder is form with composition of fine granules. Grinding process occurs three times for each sample. The first grinding is for homogenizing the compound, next is after the first sintering process and the last grinding occur, after the second sintering process; which is before pelletizing of powder.

3.4.2 SINTERING

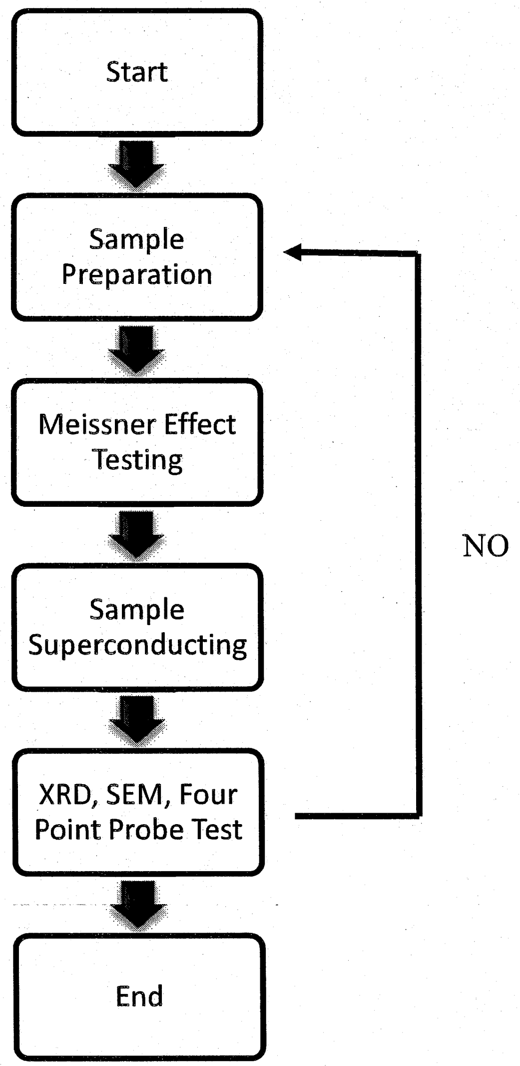
Sintering process of these Al_2O_3 doped YBCO superconductor occurs at 900 °C, intermediately. Which means, it is grinded and sinter thoroughly. Sintering process occurs in furnace, and the furnace used is Tube Furnace and Box Furnace. When using Tube Furnace, there is a specific crucible for that particular furnace called boat crucible. Only 1 boat crucible is allowed during sintering to reduce the amount of burned impurities from other sample to react onto another sample. The burning process takes about 24 hours at 900 °C. For precaution, do not take out the sample immediately after 24 hours. It needs to be cooled for a while for the sample to cooled a little to avoid burn damage. The minimum cooling time is 3 hours. The first sintering (in powder) happen after the first grinding. Second sintering (in powder) after the second grinding and lastly sintering in the form of pellets.

3.4.3 PELLETIZING

The sintered powder is then proceed to pelletizing. The apparatus for this synthesis are Hydraulic Press and Pellet Press Mold. The size is 13 mm diameter and 2 mm thickness. Since normal hydraulic press cannot be use, the other pressing machine is use to make pellet. The pellet is press up to 25 Pa and hold it for at least 25 seconds. After 25 s of maintaining its pressure, it is then set to loose and eject the mold. Slowly press the pellet out with some force and a fine looking pellet is produced

3.5 MATERIAL CHARACTERIZATIONS

Figure 3.2 *Flowchart of standard operating procedure (SOP) for analyzing* Al_2O_3 *doped YBCO superconductor in this research*



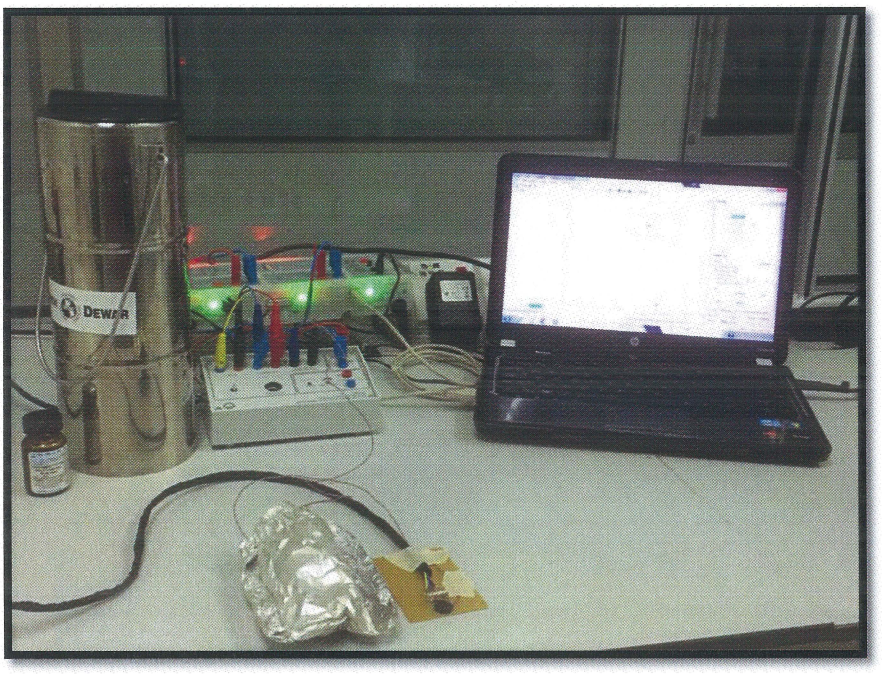
3.5.1 INTRODUCTION

Next step is to proceed with material characterization, this is only carry out when the sample of each composition are fabricated and ready for analysis. The main purpose for this analysis is to check whether it is superconducting at a higher rate or lower rate. It is useless if proceeding for the analysis without knowing the superconducting state of the samples. Thus, before proceed with other analysis, it is assure to make a Meissner Effect Test on the samples. When the samples passed the

Meissner Effect Test, then only it can proceed to other type of analysis. If the sample passed the Meissner Effect Test, it is confirmed that the samples are superconducting.

3.5.2 FOUR POINT PROBE TEST

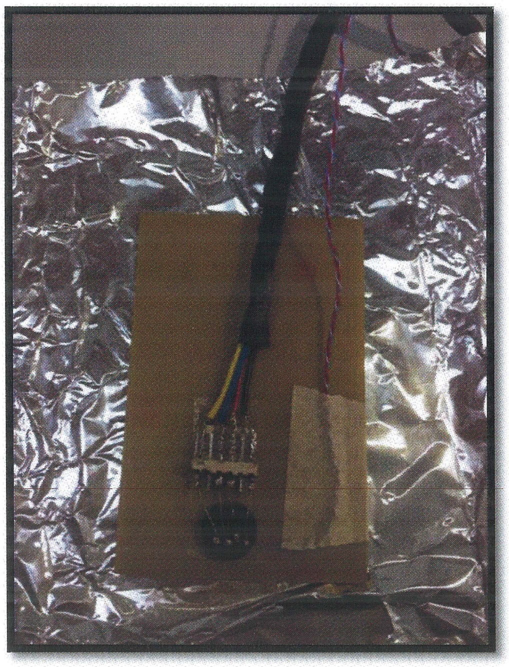
Figure 3.3 *Laboratory four point probe setup*



This four point probe test is set-up by ourself using the ordered materials and apparatus earlier. The main purpose of this testing is to calculate the resistivity of any semiconductor material. This testing is used for bulk and thin film specimen. Measurement of pellet resistivity is calculated when current passes through the outer probes and measured voltage through the inner probes. Liquid nitrogen is the main solvent used in this testing for measuring the change in critical temperature and the critical current density. By using the set-up, current is supplied at the outer probe which is the yellow and black coloured wire, while voltage is measured by the inner probe in blue and red wire that allow pellet (sample) resistivity to be measure. T type thermocouple is used in this research which is also known as tungsten/thenium alloy thermocouples. The reason why this type of thermocouple is used because of its suitability for measuring high temperatures. This type of thermocouple are usually used for hydrogen and inert atmosphere as well as vacuum furnaces. Thermocouple is placed beside the pellet (sample) so that it can detect the smallest changes that occur on the pellet surrounding.

Four equally spaced metallic tips is placed in this four point probe that consist of finite radius. High impedance current is provided via current supplies to the outer probe with a constant value of 0.14 A. While on the other hand, using Cassy Lab 2 software, voltage across the inner probe is calculated to determine the sample resistivity. Since the inner probe receive zero current due to high input impedance voltmeter in the circuit. Resulting in unwanted voltage drop that is caused by resistance contact between probes and the sample eliminated from potential measurement.

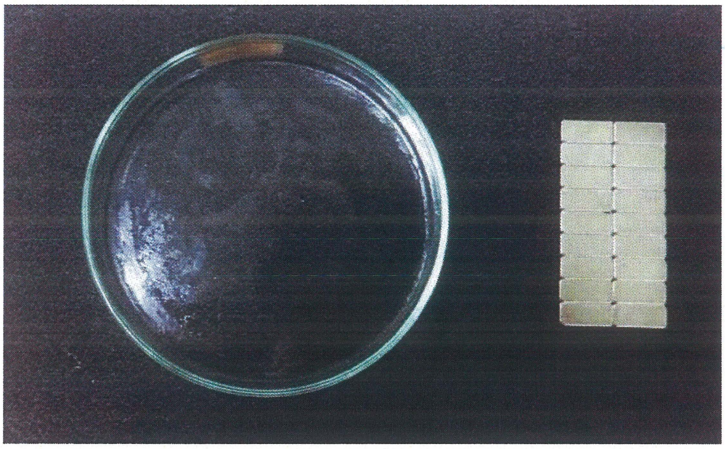
Figure 3.4 *Four point probe wire connecting and thermocouple*



After the set-up is complete, it is wrap around aluminium foil in wrapping-like box. This is done to prevent any drastic changes of temperature when immerse in liquid nitrogen. Also, to protect the connection between the wire and the pellet. When reading is done taking, the probe is taken out together with aluminium foil. This greatly can kept the low temperature of probe.

3.5.3 MEISSNER EFFECT

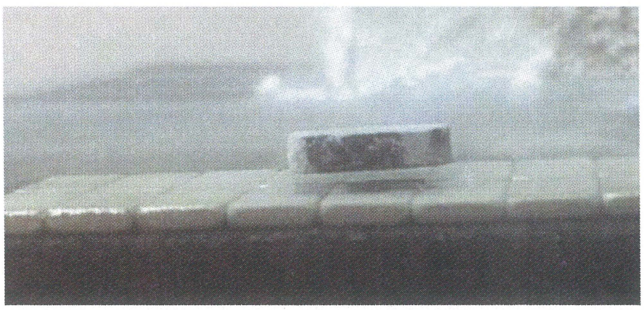
Figure 3.5 *Apparatus needed for meissner effect test*



Apparatus set-up for Meissner Effect Test. The needed apparatus are strong magnet (neodymium magnet) to form a plane or trail at least, petri dish and liquid nitrogen. The main purpose of doing this testing is to classify whether the sample having superconducting behavior or negative. This Meissner Effect occur when any type of superconductor obtained its transition temperature and completely repel the magnetic field.

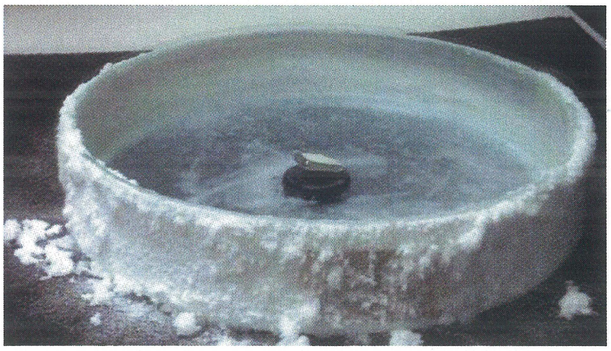
There are two ways of doing this testing. First is immersed the sample (pellet) into the petri dish that is filled with liquid nitrogen. Make sure the pellet is fully immersed for higher and better cooling condition. Time taken for the pellet immersion is by visual, which is when the bubbles around the liquid nitrogen stops to forming and disappear, the sample is taken out from the petri dish and placed on top the strong magnet plane. Sample will float if it has superconducting behavior.

Figure 3.6 *Example levitation of successful Meissner Effect test*



Second way of doing Meissner Effect Test is that, the sample is immered into the petri dish with liquid nitrogen. Instead of taking out the sample, small pieces of strong magnet is placed on the sample. The sample and the magnet will not touch each other since the sample is having superconducting behavior. This phenomenon occur due to transition temperature is obtained and repulsion of magnetic field occur completely. Magnet will float on top of the sample and can be seen visually.

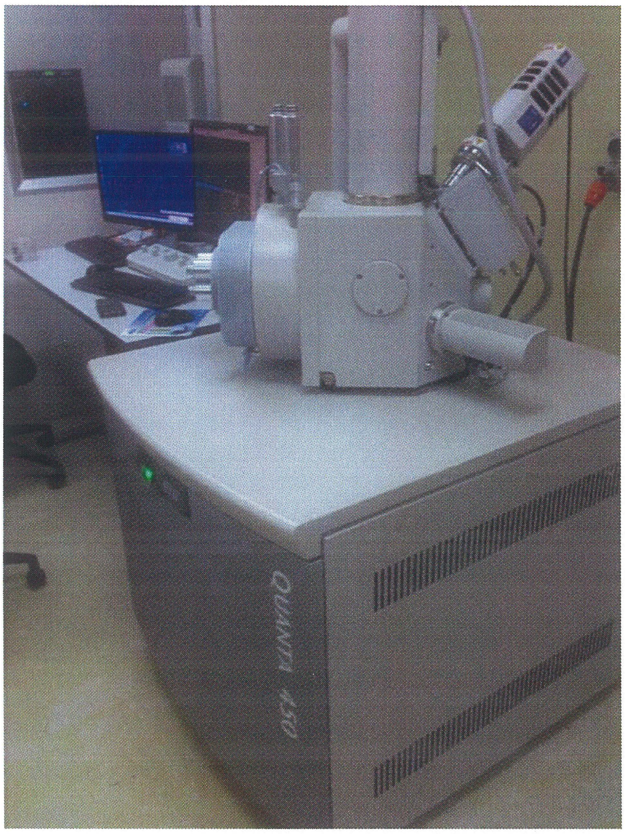
Figure 3.7 *Another example of Meissner Effect levitation*



Strong magnet used are Neodymium magnet which is really compactible when high magnetic field is needed in this testing. Grade for these magnets are N35 with magnetic field of 1.17 T. Dimension for each neodymium magnet is 15 mm x 6.5 mm x 2 mm, and the configuration of making the plane must be cuboid with large rectangular structure by using 4 pieces of magnet. This configuration is used due to its stable configuration which can produce stable repulsion magnetic field towards the sample.

3.5.4 SCANNING ELECTRON MICROSCOPY (SEM)

Figure 3.8 *Scanning Electron Microscopy (SEM) Quanta 450*



Scanning Electron Microscopy (SEM) Quanta 450 is used in this research for characterization. Magnification of this instrument is limited to 5,000 x magnification. For further magnification, it is advised to used Field Emission Scanning Electron Microscope (FESEM) due to its high degree of magnification. Nevertheless, by using SEM is enough to characterize the microstructure of Al_2O_3 doped YBCO superconductor. The magnification used on the sample is 100x, 500x and 1,000x magnification. The particular magnification is used to compared the microstructure of sample when added different amount of aluminium oxide to the superconductor. Working principle of this instrument is power supply with 10,000 kV and in high vacuum condition. This instrument is handled by Puan Nisa due to precaution steps taken by the UMP Central Laboratory. It is said the sample should produce porous like structure due to doping element.

3.5.5 X-RAY DIFFRACTOMETER (XRD)

Figure 3.9 *Instrument used for X-Ray Diffractometer (XRD) test*

For X-ray Diffractometer (XRD), the instrument used is Rigaku Miniflex X-ray Diffractometer (XRD) with Model Miniflex II. This instrument is used for sample in powder form with diffraction patterns from 3 to 145 degrees in 2-theta scanning range. In this research, the lattice parameter and phase formation can be determine by using this instrument. It is used to obtain the Al_2O_3 doped YBCO superconductor lattice paramenter and also the constant YBCO superconductor. Every solid material has its individual characteristic XRD pattern that can be used as a fingerprint or personal indentification including lattice constants and geometry, crystal orientation, defects, strain, phase identification, preferred orientation of polycrystals and crystallize size.

Working principle of XRD analysis consist of three basic elements which are X-ray tube, sample holder and X-ray detector. Cathode ray will generate X-rays via heating filament to produce electrons. Electrons will accelerate toward the specimen that is control by applying voltage, and bombarded to the target material. Sufficient energy of electrons will dislodge the inner shell electrons of the target amaterial, thus a characteristics spectrum is produced.

Elements that are to be check using XRD analysis are $YBa_2Cu_3O_7$, Y_2O_3, $BaCO_3$, CuO, and Al_2O_3. The scanning used for this research is :

2θ degree : 0°-90°

Scan rate : 1°/min

Step size : 0.02°

CHAPTER 4

RESULT AND DISCUSSION

4.1 CHARACTERIZATION OF YBCO SUPERCONDUCTOR WITH ADDITION OF ALUMINIUM OXIDE

For characterization, all the analysis and test are run to investigate the objective of this research. Frstly, is to study the effect of Al_2O_3 doping on the microstructure of YBCO superconductor. This study is done by laboratory instrument called Scanning Electron Microscopy (SEM), which can analyze the structure of the sample in micro-scale. Next, is to determine the effect of Al_2O_3 doping on electrical transport properties of YBCO superconductor which is done by Four Point Probe test. Using this instrument, the critical temperature, T_c of the sample can be calculated.

4.2 FOUR POINT PROBE TEST ANALYSIS

Figure 4.1 to 4.4 shows the curve of normalized resistance versus temperature for 0.01, 0.02, 0.03 and 0.04 wt% Al_2O_3-doped YBCO superconductor respectively. Zero resistance temperature (T_{czero}) is shown on each graph which conclude that the sample is superconductor due to resistance drops abruptly to zero when it is cooled below its critical temperature. Due to this resistance drops to zero, flow of electric current through the loop of superconducting wire can persist indefinitely with no power source. Based on Meissner Effect, sample with composition of 0.01% Al_2O_3 has the highest critical temperature, T_c. The T_c decreases as the composition of Aluminium increases in the YBCO superconductor.

Figure 4.1 *Normalized resistance versus temperature for 0.01 wt.% Al_2O_3 doped YBCO superconductor*

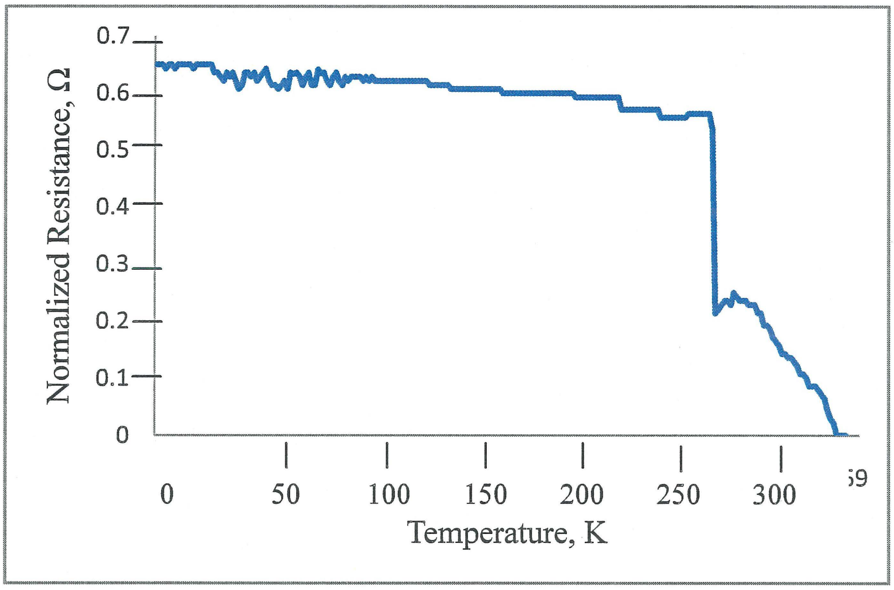


Figure 4.2 *Normalized resistance versus temperature for 0.02 wt.% Al_2O_3 doped YBCO superconductor*

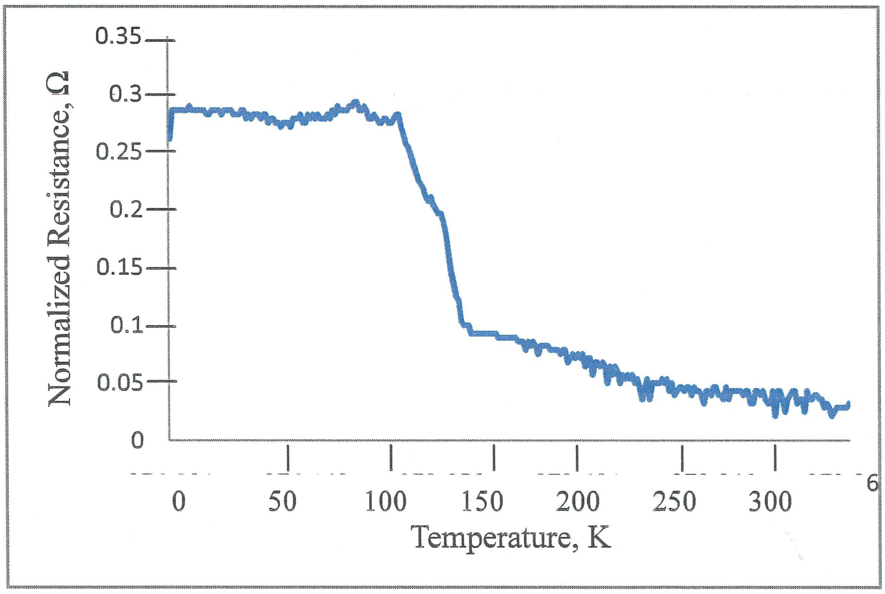


Figure 4.3 *Normalized resistance versus temperature for 0.03 wt.% Al_2O_3 doped YBCO superconductor*

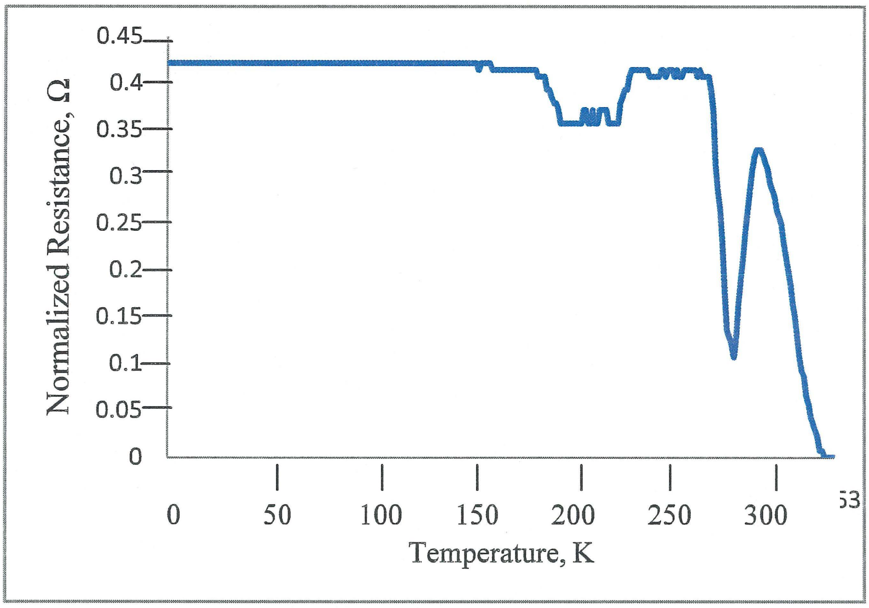


Figure 4.4 *Normalized resistance versus temperature for 0.04 wt.% Al_2O_3 doped YBCO superconductor*

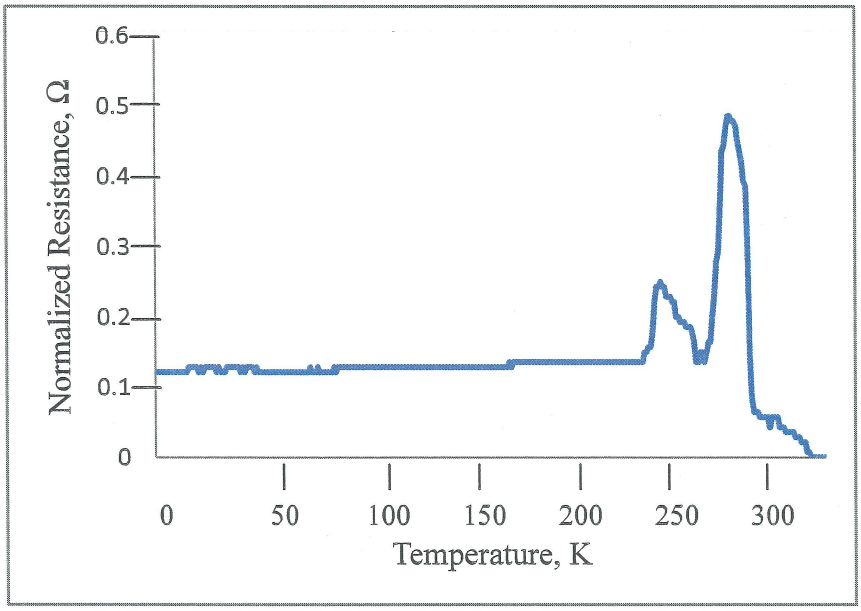


Figure 4.1 to 4.4 shows the normalized resistance against temperature graph.The graph obtained is not really accurate due to some errors that occur during the analysis. Such error causes problems to the reading of four point probe. Random and imbalance up and down of graph structure produced due to the problem when analysis takes place. Zero resistance of sample is obtained, but in a way the temperature of the condition is not the accurate value. This is due to problem with the thermocouple itself or also it is caused by the formation of ice around the probe during testing. By referring to the Meissner Effect results, it is shown that highest critical temperature of sample is obtained in the 0.01 Al_2O_3 wt.% sample.

4.3 MEISSNER EFFECT ANALYSIS

Table 4.1

Levitation time and average time for sample with different Al_2O_3 composition

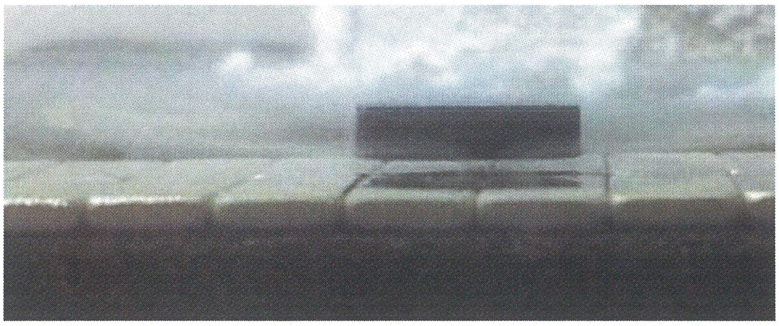
X	T_1 (s)	T_2 (s)	T_3 (s)	Mean (s)
0.01 %	12.90	9.06	10.93	10.96
0.02 %	8.70	7.58	13.41	9.90
0.03%	5.66	2.86	6.58	5.03
0.04 %	6.88	1.80	1.58	3.42

Table 4.1 shows that the time taken for each sample to start levitates and back to the surface again. For each sample, the reading is taken as much as three times. This is to ensure the average and precise reading of the result. From the above table, it is conclude that 0.01% of Al_2O_3 dope YBCO superconductor has higher levitation time compared to 0.04% of Al_2O_3 dope YBCO superconductor. It is conclude that higher percentage of Al_2O_3 dope YBCO superconductor, will have lower levitation time compared to plain YBCO superconductor without aluminium dopant.

Basically, theory of all superconductor sample, they have the same warming rate. It is said that the levitation time is directly propotional to the critical temperature, T_c of the material. It is assume that composition of 0.01% Al_2O_3 dope YBCO superconductor posses the highest T_c due to its longest time of levitation. While the T_c of the material decreases as the composition of Al_2O_3 dopant increases in the material. As for conclusion, T_c for 0.01% Al_2O_3 dope YBCO superconductor is greater than 77 K, which the T_c of superconductor because of its ability to levitate at an average of 10.96 s, whereas T_c for 0.04% Al_2O_3 dope YBCO superconductor is lower than 0.01% Al_2O_3 dope YBCO superconductor referring to its average levitating time is 3.42 s. This process occur due to with higher T_c, warming rate will be longer before reaching the T_c. Thus resulting in longer levitation time.

Figure 4.5

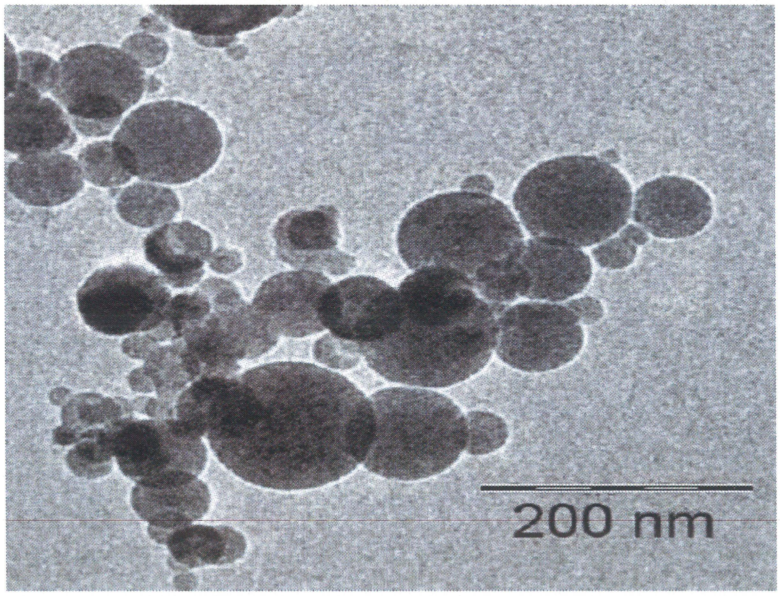
Meissner effect of Al_2O_3 doped YBCO superconductor when cooled below critical temperature, T_c of superconductor



4.4 SCANNING ELECTRON MICROSCOPY (SEM) ANALYSIS

SEM is used in this research to compare and contrast the microstructure of Al_2O_3 doped YBCO superconductor with the control YBCO superconductor. The difference of element inside can be seeing through the SEM technology that is by observing the porosity, the shape of material and also the size of the atom. Aluminium oxide is to be exepcting having a nanoparticle with the size of around 50 nm, and mostly are below than 50 nm. It is shown in figure 4.6 below.

Figure 4.6 *Images of aluminium oxide (Al_2O_3) nanoparticles observed under Transmission Electron Microscope (TEM)*



According to Abd-Ghani et al. (2012), he said that when increasing the nanoparticles in YBCO superconductor will result in increasing of porosity in microstructure and a variation in crystal structure. On the other hand, with addition of different composition % of aluminium oxide to the YBCO superconductor, it is said that the microstructure does not change drastically. The porosity of the original (constant) YBCO constant is almost the same as the Al_2O_3 doped sample.

Figure 4.7 *SEM images of YBCO superconductor under 500x magnification*

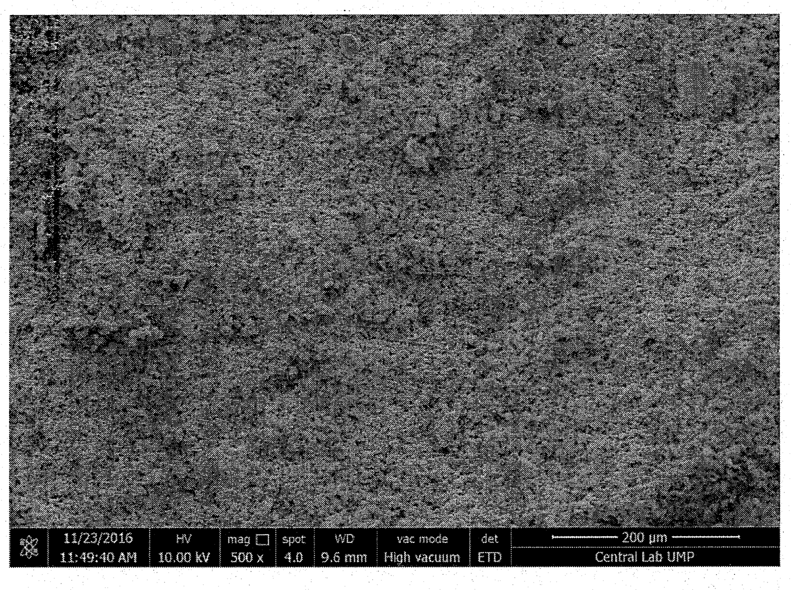
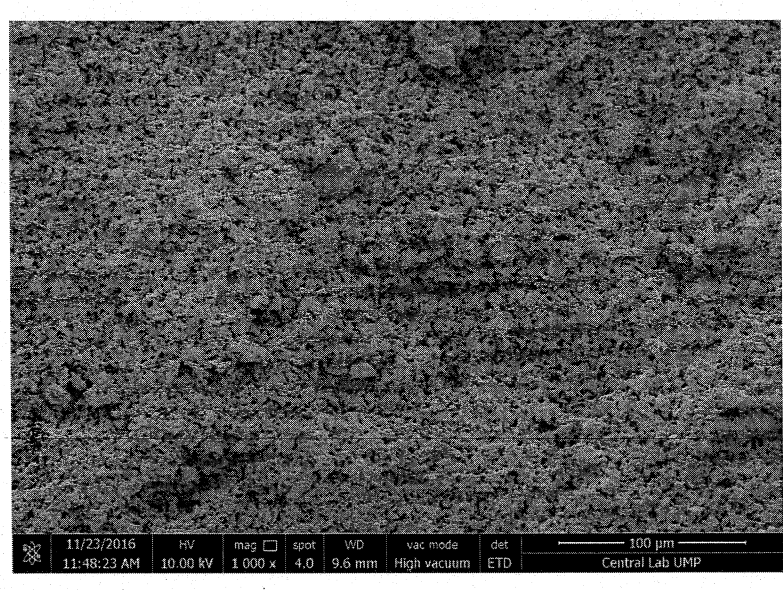


Figure 4.8 *SEM images of YBCO superconductor under 1000x magnification*



Based on above images, it is observed that YBCO superconductor having uneven surface and pores. Image is produced using Quantu 450 SEM instrument, with 10 kV as high voltage (HV). Presence of pores influence the effectiveness of sample current transportation. Therefore, increasing the connectivity and homogenizing the surface level of the sample are expected to increase current density, J_c distribution. In fact, according to Li Chun Liang et al. (2008), pores can greatly increase the effective surface area of the film that could lead to faster film degradation due to unavoidable exposure to air and humidity. While, the familiar on function of pores as thermal relieving. According to K. Develos-Bagarinao et al. (2008), result obtained is related to abundance of yttrium in YBCO films that results in porous morphologies, whereas the deficiency in barium and copper deposited from the stoichiometric YBCO was considered due to scattering effect of oxygen during deposition process.

From the analysis of SEM images, the morphology of the sample can be clearly seen and compare. An increasing of Al_2O_3 dopant into the YBCO superconductor will produce more crystal like structure of image. As compared for pure YBCO superconductor above, composition of 0.01% aluminium generate higher crystals-liked surface which can be assume as aluminium oxide structure. Thus, the higher the composition of Al_2O_3 dopant in YBCO superconductor, the higher the formation of crystal-liked structure of samples.

According to Abd-Ghani et al. (2012) that conclude the addition of more nanoparticles will increase the porosity of the sample is not obtained due to low magnification level. Higher level of magnification need to be used, example an instrument that posses high magnification level is FESEM. Higher chances of seeing the porosity when using FESEM, it is proven from previous research.

Figure 4.9 *SEM images of 0.01% Al_2O_3doped YBCO superconductor under 500x magnification*

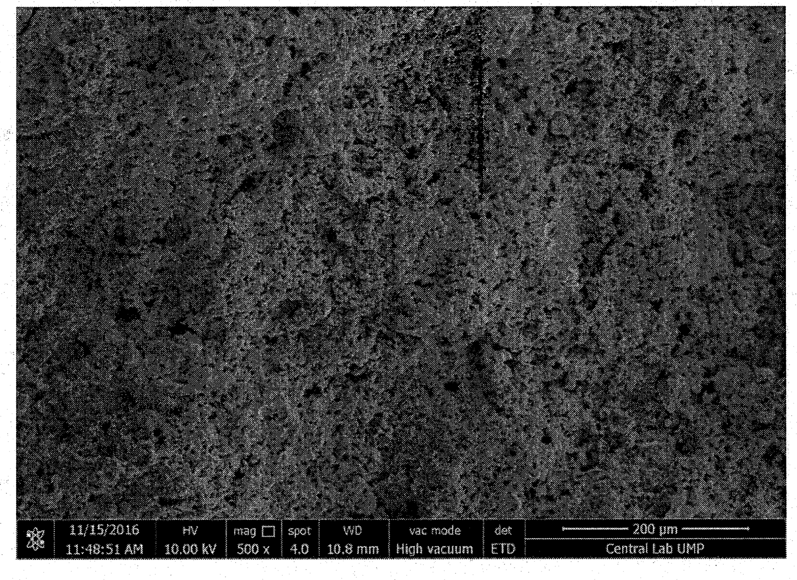


Figure 4.10 *SEM images of 0.01% Al_2O_3 doped YBCO superconductor under 1000x magnification*

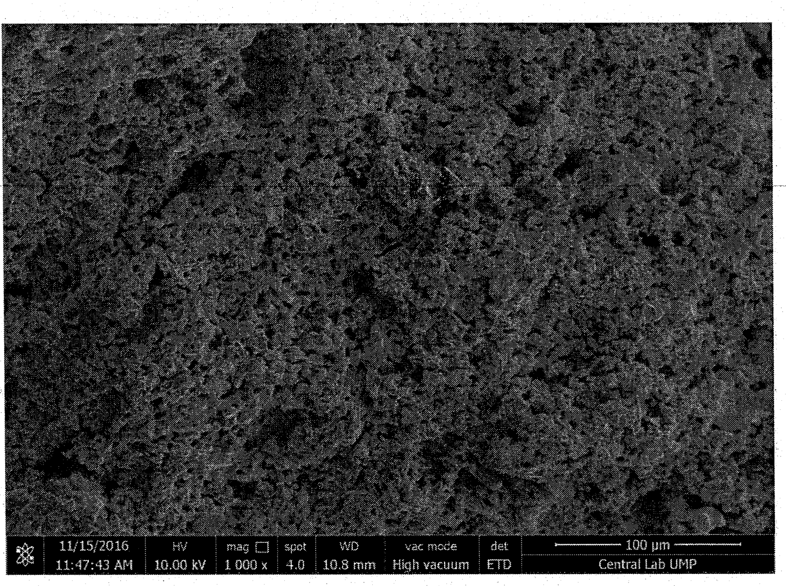


Figure 4.11 *SEM images of 0.02% Al_2O_3 doped YBCO superconductor under 500x magnification*

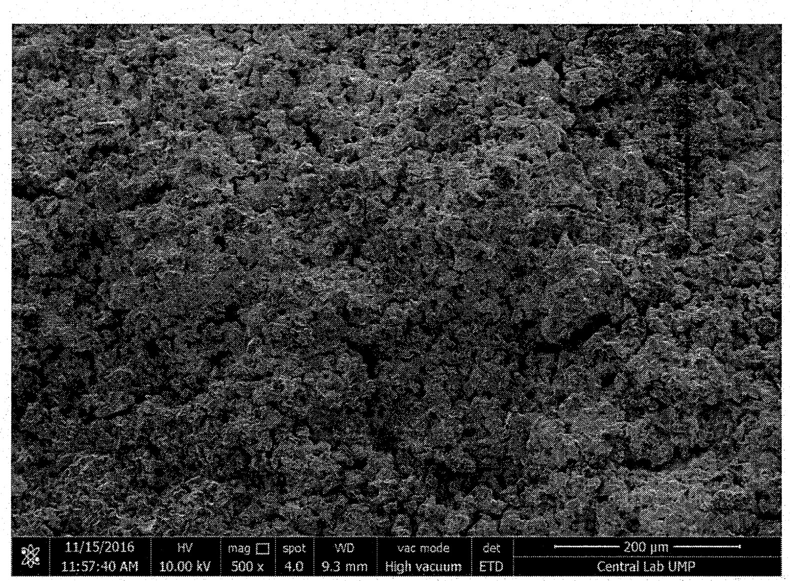


Figure 4.12 *SEM images of 0.02% Al_2O_3 doped YBCO superconductor under 1000x magnification*

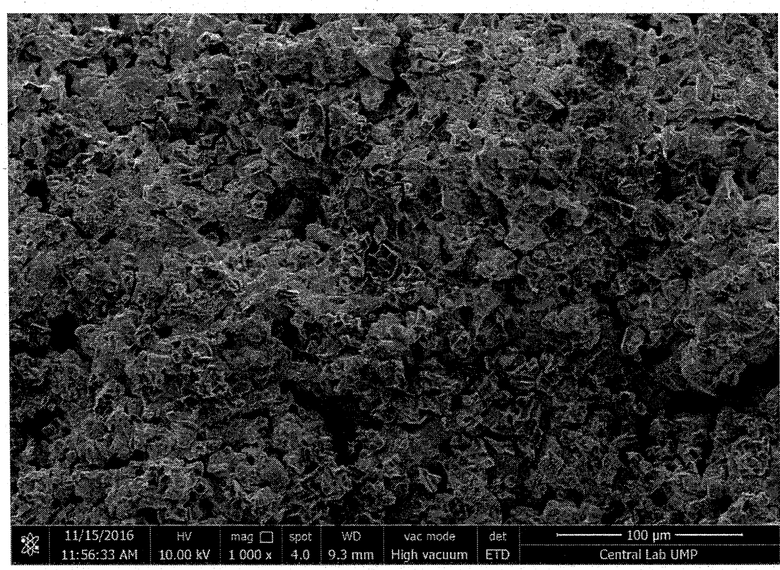


Figure 4.13 *SEM images of 0.03% Al_2O_3 doped YBCO superconductor under 500x magnification*

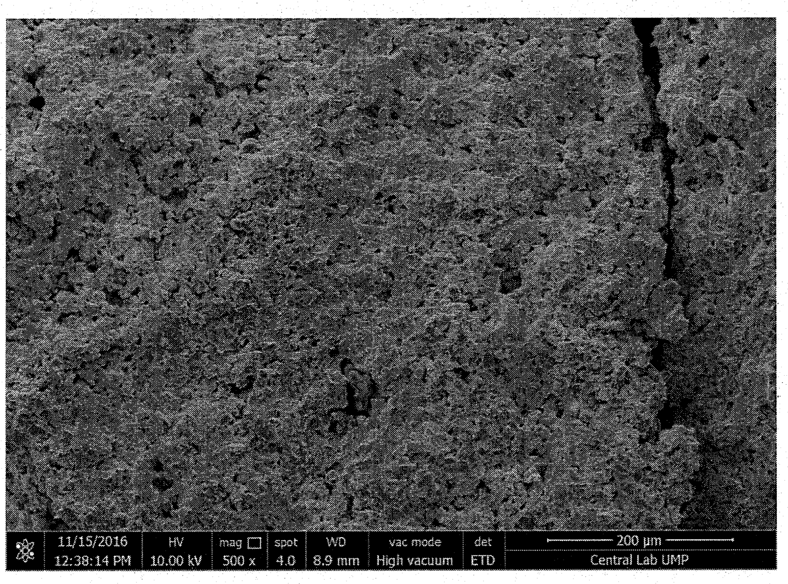


Figure 4.14 *SEM images of 0.03% Al_2O_3 doped YBCO superconductor under 1000x magnification*

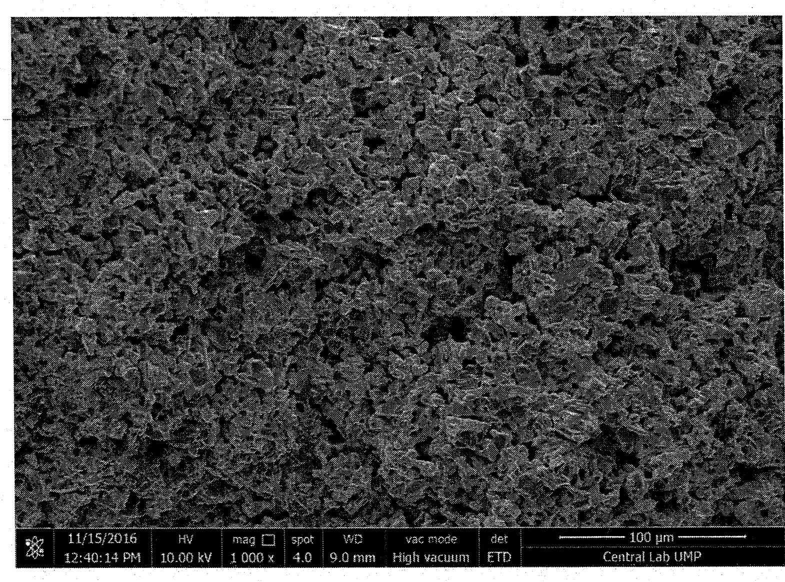


Figure 4.15 *SEM images of 0.04% Al_2O_3 doped YBCO superconductor under 500x magnification*

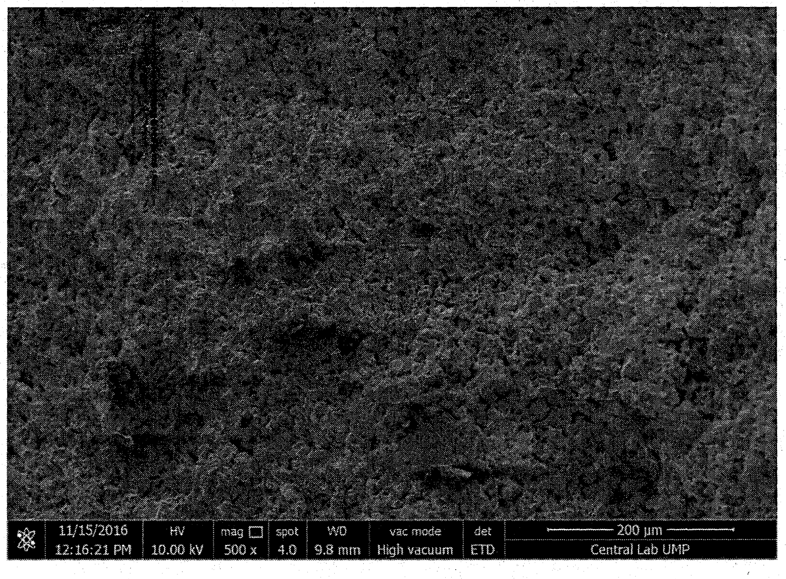
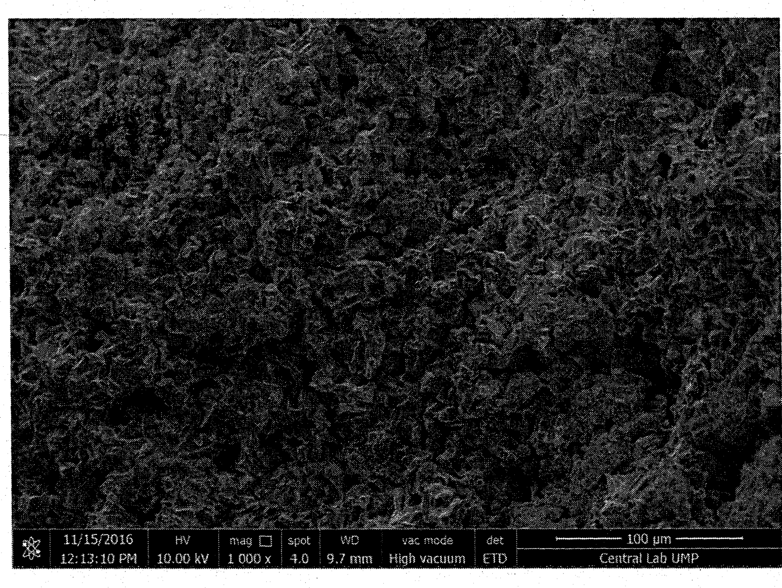


Figure 4.16 *SEM images of 0.04% Al_2O_3 doped YBCO superconductor under 1000x magnification*



4.5 X-RAY DIFFRACTOMETER (XRD) ANALYSIS

X-ray powder diffraction (XRD) analysis were carried out to Al_2O_3 doped YBCO superconductor samples which were sintered at 900 °C. Figure 4. Shows the powder diffraction patterns of pure YBCO specimens with 0.00 % of addition composition. Previous study shows that the effect of substitution by Al_2O_3 with respect to Cu atoms, will produce a compound of orthorhombic structure. It is noticeable with the volume of unit cell increase with the value x and will contribute to the effect of Aluminium-substitution on variation of the lattice parameter (a,b.c). As citated by Saxena et al. (2010), orthorhombic structure is achieve when $a \neq b \neq c$ and make a superconducting behaviour to YBCO.

Figure 4.17 *XRD analysis of pure YBCO superconductor with corresponding Miller indices of each peaks where Y=YBCO*

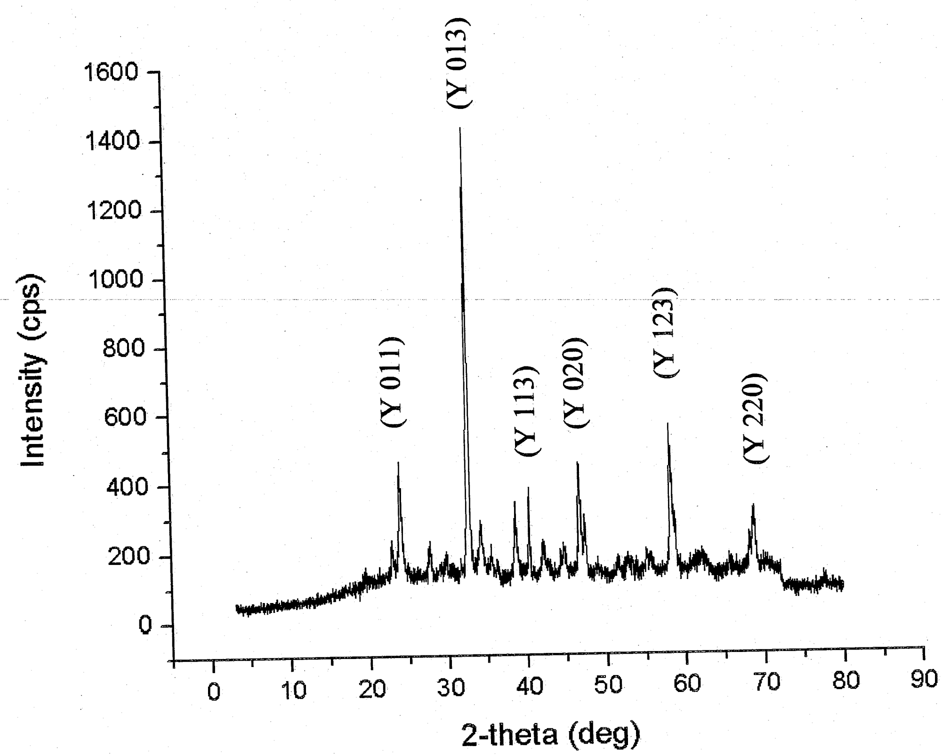
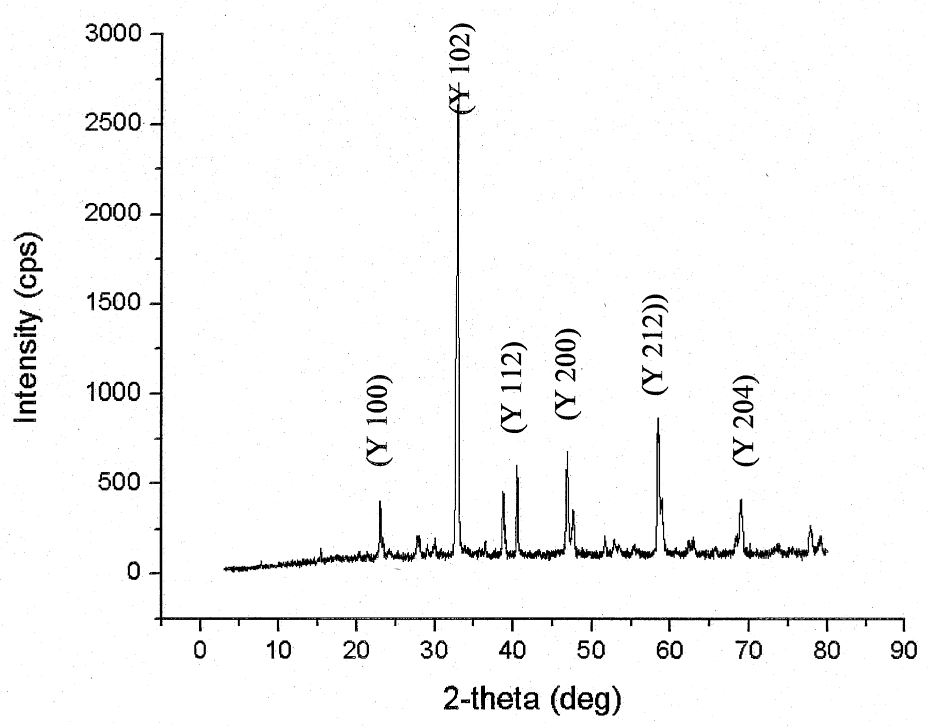
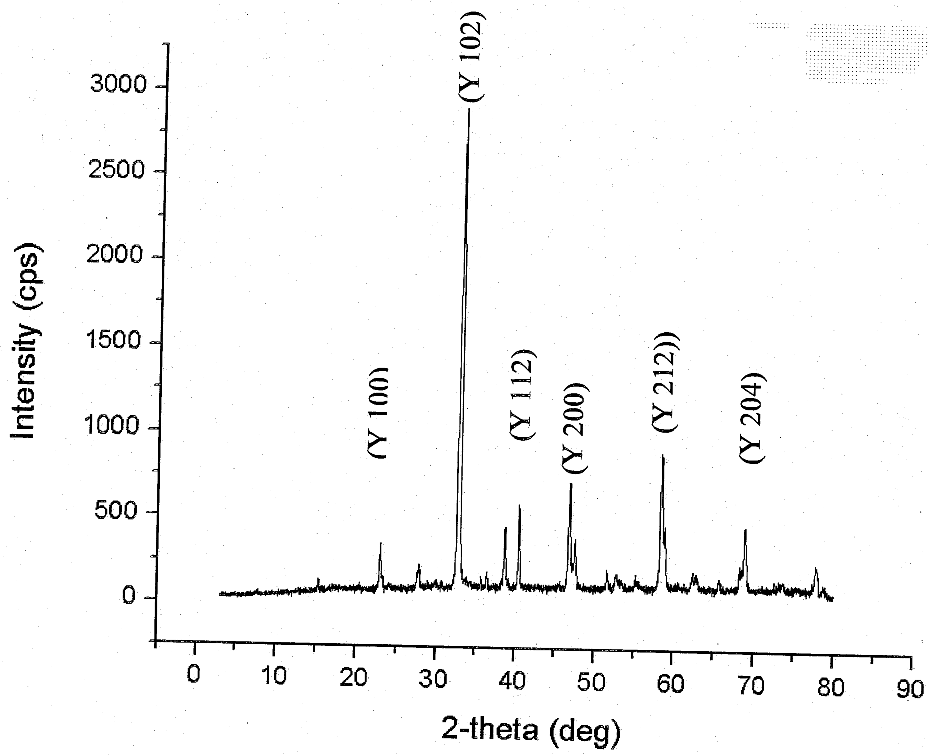


Figure 4.18 *XRD analysis of 0.01 wt.% of Al_2O_3 doped in YBCO superconductor with corresponding Miller Indices of each peaks where Y=YBCO*



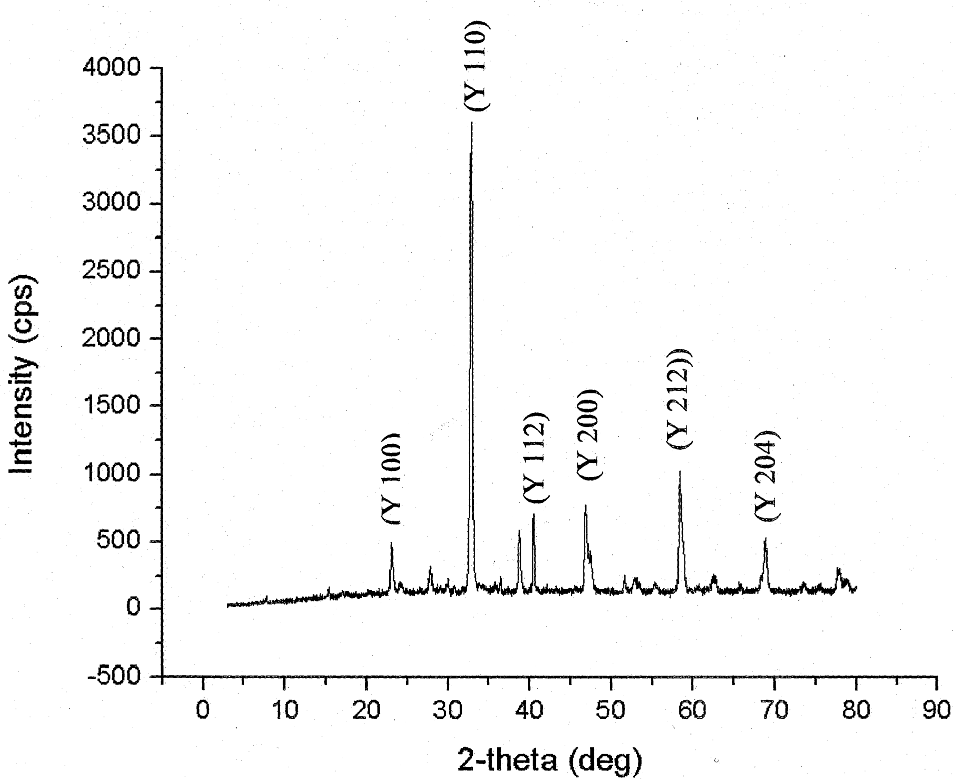
The above figure shows XRD patterns of 0.01 wt.% of Al_2O_3 doped YBCO superconductor with correspond to Miller Indices of each peaks. Highest peak obtained from the analysis is at 32.98° with the intensity of 2727.36 while the lowest peak is situated at 3.32° with an intensity of 23.58. Adding Al_2O_3 dopant to pure YBCO superconductor does no lead to variation in crystal structure due to small addition process only occurred during doping and mostly does not enter the YBCO crystal structure. No Al_2O_3 peaks are found due to the presence is very small. It is concluded that percentage of Al_2O_3 doped YBCO superconductor increases the value of intensity peak compared to pure YBCO which has much smaller value for highest peak intensity.

Figure 4.19 *XRD analysis of 0.02 wt.% of Al_2O_3 doped in YBCO superconductor with corresponding Miller Indices of each peaks where Y=YBCO*



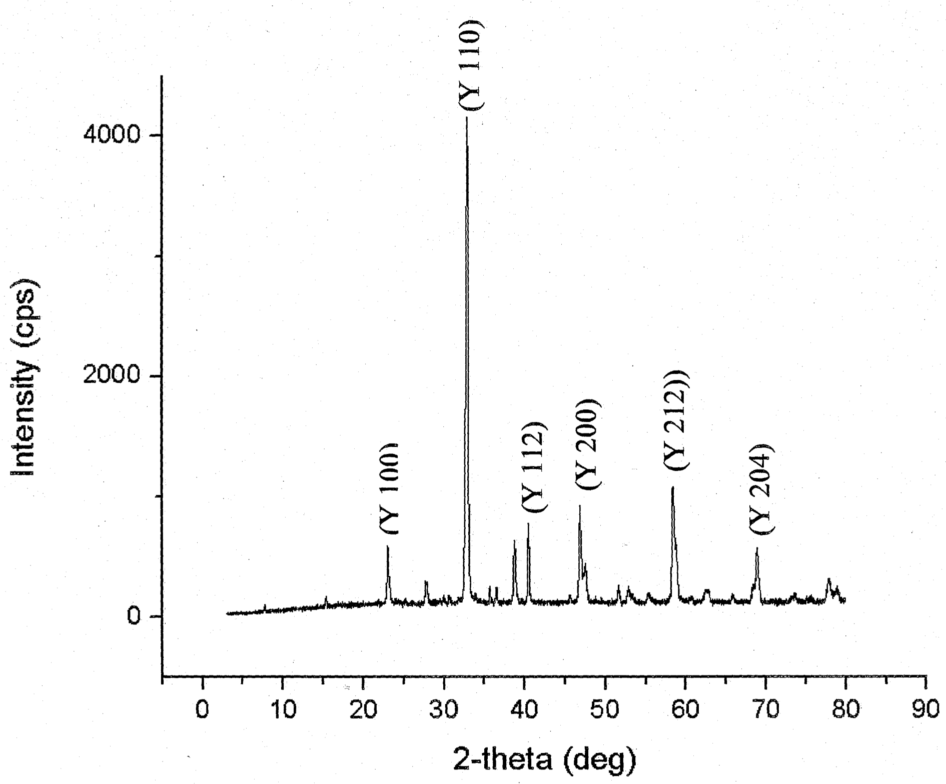
The above figure shows XRD patterns of 0.02 wt.% of Al_2O_3 doped YBCO superconductor with correspond to Miller Indices of each peaks. Highest peak obtained from the analysis is at 32.93° with the intensity of 2905.59 while the lowest peak is situated at 3.10° with an intensity of 29.39. Adding Al_2O_3 dopant to pure YBCO superconductor does no lead to variation in crystal structure due to small addition process only occurred during doping and mostly does not enter the YBCO crystal structure. No Al_2O_3 peaks are found due to the presence is very small. It is concluded that percentage of Al_2O_3 doped YBCO superconductor increases the value of intensity peak compared to pure YBCO which has much smaller value for highest peak intensity.

Figure 4.20 *XRD analysis of 0.03 wt.% of Al_2O_3 doped in YBCO superconductor with corresponding Miller Indices of each peaks where Y=YBCO*



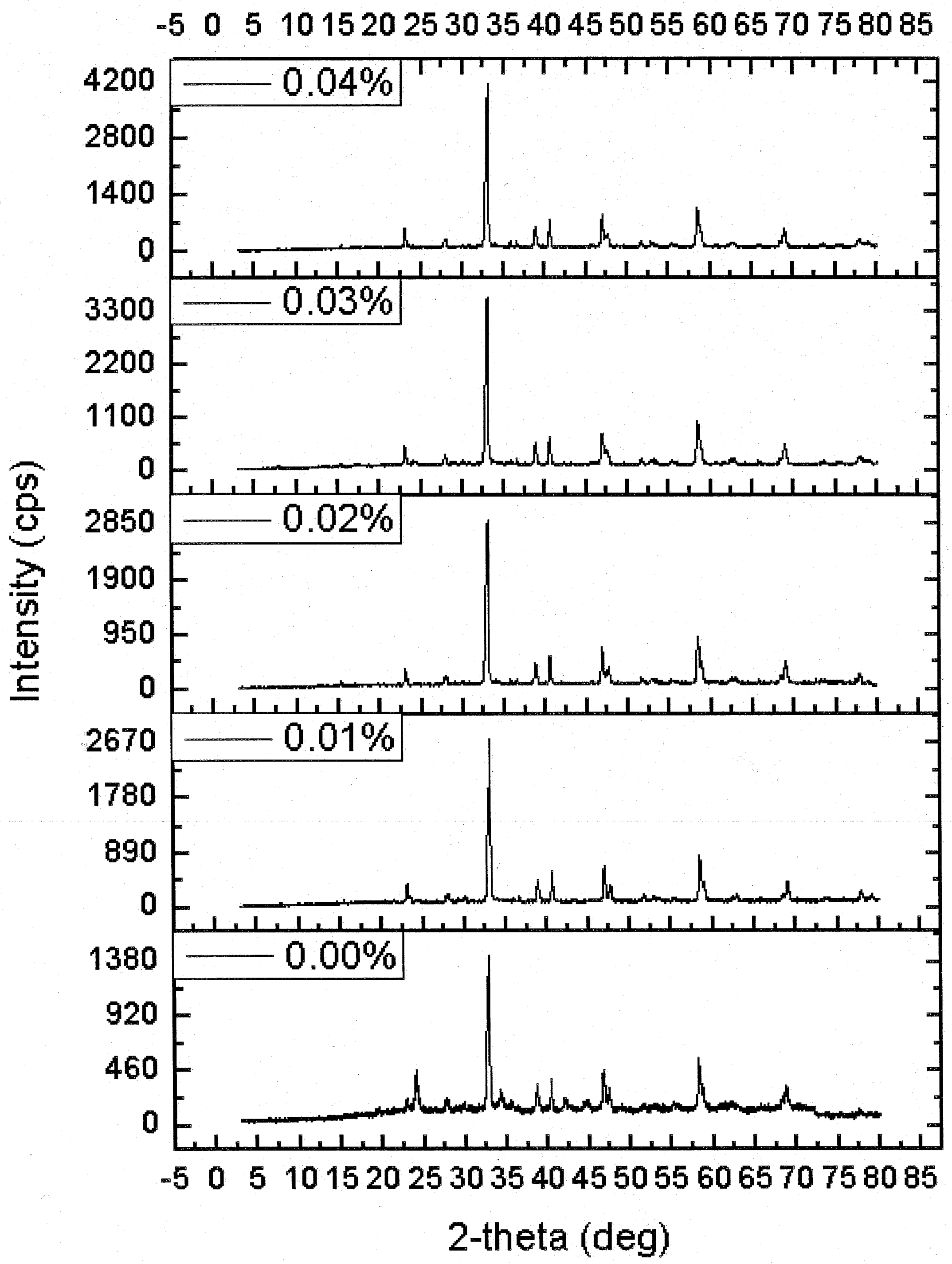
The above figure shows XRD patterns of 0.03 wt.% of Al_2O_3 doped YBCO superconductor with correspond to Miller Indices of each peaks. Highest peak obtained from the analysis is at 32.94^o with the intensity of 3692.90 while the lowest peak is situated at 3.02^o with an intensity of 23.80 Adding Al_2O_3 dopant to pure YBCO superconductor does no lead to variation in crystal structure due to small addition process only occurred during doping and mostly does not enter the YBCO crystal structure. No Al_2O_3 peaks are found due to the presence is very small. It is concluded that percentage of Al_2O_3 doped YBCO superconductor increases the value of intensity peak compared to pure YBCO which has much smaller value for highest peak intensity.

Figure 4.21 *XRD analysis of 0.04 wt.% of Al_2O_3 doped in YBCO superconductor with corresponding Miller Indices of each peaks where Y=YBCO*



The above figure shows XRD patterns of 0.04 wt.% of Al_2O_3 doped YBCO superconductor with correspond to Miller Indices of each peaks. Highest peak obtained from the analysis is at 32.93° with the intensity of 3992.16 while the lowest peak is situated at 3.17° with an intensity of 31.64 Adding Al_2O_3 dopant to pure YBCO superconductor does no lead to variation in crystal structure due to small addition process only occurred during doping and mostly does not enter the YBCO crystal structure. No Al_2O_3 peaks are found due to the presence is very small. It is concluded that percentage of Al_2O_3 doped YBCO superconductor increases the value of intensity peak compared to pure YBCO which has much smaller value for highest peak intensity.

Figure 4.22 *Stacked XRD analysis of pure YBCO superconductor and aluminium doped YBCO superconductor based on composition difference.*



It is shown that composition of aluminium oxide dopant affected the value of intensity of YBCO superconductor. Based on Figure 4.22 above, addition of Al_2O_3 as dopant into the YBCO superconductor had causes the intensity of highest peak increases. Increase in intensity shows by sharp peak is an indication that the sample has more order, crystallization and arrangement. When a substance is having a low peak with low intensity, it shows that the substance is having a less degree of crystallinity and may be a decrease in the crystallite size (peak boarding effect).

Based on the graph, the lattice parameter of the sample is calculated using :

$$\frac{1}{d^2} = \frac{h^2}{a^2} + \frac{k^2}{b^2} + \frac{l^2}{c^2} \qquad (1)$$

Table 4.2

Calculated lattice parameters of pure YBCO and Al_2O_3-doped YBCO super conductor with different percentage.

Wt. % of Al_2O_3	a (Å)	b (Å)	c (Å)
0.00 %	3.82	3.89	11.68
0.01 %	3.86	3.92	7.62
0.02 %	3.86	2.92	7.66
0.03 %	3.86	3.82	7.75
0.04 %	3.86	3.85	7.60

The obtained lattice parameters does not equal to pure YBCO superconductor due to during addition of Al_2O_3 may be there are impurities that were mixed together. The causes may be due to aluminium foil during keeping the sample, crucible leftover after furnace and also the mortar and pestle used is not properly cleaned by prior user leaving impurities around it.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

For the conclusion of this research, it is shown that addition of of aluminium oxide into pure YBCO superconductor will decrease the critical temperature of the sample. Higher amount of aluminium oxide during fabricating, will result in decreasing of critical temperature. Thus, when critical temperature is low, levitation time of Meissner Effect test will decrease due to its easily reached the ideal temperature. Meissner effect test is done to check whether the sample is superconducting or not superconducting. For four point probe test, the results shows the drop abruptly of resistance to zero when it is supercooled to critical temperature. During this state, the sample is superconducting with zero resistance and electric current flow through the loop indefinitely with no power source. For scanning electron microscopy, the microstructure observed under 500x and 1000x magnification shows the no difference in miscrostructure when adding aluminium oxide with different composition. Except, when adding more aluminium oxide, the structure tend to form a more crystal-liked structure. The microstructure that YBCO posses are porous foam structure. Porosity of the sample does not differ much with different Al_2O_3 compostion percentage. During XRD test, the result obtained are higher percentage of aluminium oxide added, the higher the intensity of the each peak. But for the lattice parameter, the sample could not obtain the exact lattice parameter as YBCO superconductor. This may be due to some errors or impurities during XRD test. Thus it does not shows an orthorhombic structure. The best sample is said to be 0.01 wt.% Al_2O_3 doped YBCO superconductor because of the characteristics of the sample to obtain the highest critical temperature among other sample tested.

5.2 RECOMMENDATIONS

There are some recommendations that could be suggested for the improvement of this research. Firstly, make sure that the amount of compound weigh is the exact amount of the compound that are going to used. This is recommended because not every compound is cheap and easy to get. It is the best to use the exact amount that is calculated for research purpose. Do not waste any compound. For an example in a research, that is using Yttrium Oxide compound which is a kind of metal powder that is very high cost.

Secondly, make sure the apparatus is well prepared. For instance, the four point probe is soldered firm and neatly, also to make sure no short circuit during the apparatus preparation. This is to minimize experimental error due to insturement failure. It is known that this error could be avoided, so then take early precaution when taking care of this appratus set up.

Moreover, Personal Protective Equipment (PPE) should be worn all the time. Whether handling or not with the equipment or mixture, once in laboratory, make sure to fulfilled all the PPE requirement. Such as gloves, lab coat, mask and also goggle. This is to ensure a safe environment is kept throughout the research process. For example, silver paint is a harmful liquid. During my research, when handling with silver paint, it is a compulsory to wear gloves, mask and lab coat. This is due to the harmful gas that is released when silver paint is used is quite hazardous and can cause infertility. Gloves are the most important PPE to avoid direct contact of any external environment that might contact with our skin during handling.

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APPENDICES

Appendix A

Calculation of YBCO weight

$$2\ Y_2O_3 + 8\ BaCO_3 + 12\ CuO + O_2 \rightarrow 8\ CO_2 + 4\ YBa_2Cu_3O_7$$

$$\tfrac{1}{2}\ Y_2O_3 + 2\ BaCO_3 + 3\ CuO + \tfrac{1}{4}\ O_2 \rightarrow 2\ CO_2 + YBa_2Cu_3O_7$$

(Where; Y= 88.90585 g/mol, Ba= 137.327 g/mol, C= 12.0107 g/mol, O= 15.9994 g/mol, Cu= 63.546 g/mol)

Molar mass of $\frac{1}{2}Y_2O_3$

$[(2\times88.90585\ g/mol) + (3\times15.9994\ g/mol)] \div 1/2$

$= 112.9050\ g/mol$

Molar mass of $2BaCO_3$

$2\ [137.327\ g/mol + 12.0107\ g/mol + (3\times15.9994\ g/mol)]$

$= 394.6718\ g/mol$

Molar mass of 3CuO

$3\ [63.546\ g/mol + 15.9994\ g/mol]$

$= 238.6362\ g/mol$

Total molar mass

$112.9050\ g/mol + 394.6718\ g/mol + 238.6362\ g/mol$

$=746.2130\ g/mol$

Mass of 1 mol YBCO

i. ½ Y_2O_3

(112.9050 g/mol ÷ 746.2130 g/mol) × 40 g

= 6.05 g

ii. 2 $BaCO_3$

(394.6718 g/mol ÷ 746.2130 g/mol) × 40 g

= 21.16 g

iii. 3CuO

(238.6362 g/mol ÷ 746.2130 g/mol) ×40 g

= 12.79 g

Appendix B

Calculation for lattice parameters of 0.01%, 0.02%, 0.03%, and 0.04% wt. % Al_2O_3 doped YBCO superconductor.

i) 0.01 % Al_2O_3-doped YBCO superconductor

Plane (1,0,0)

$$\frac{1}{d^2} = \frac{h^2}{a^2} + \frac{k^2}{b^2} + \frac{l^2}{c^2}$$

$$\frac{1}{3.856^2} = \frac{1^2}{a^2} + \frac{0^2}{b^2} + \frac{0^2}{c^2}$$

$$\frac{1}{3.856^2} = \frac{1}{a^2}$$

$$a = 3.856$$

Plane (1,0,2)

$$\frac{1}{d^2} = \frac{h^2}{a^2} + \frac{k^2}{b^2} + \frac{l^2}{c^2}$$

$$\frac{1}{2.710^2} = \frac{1^2}{3.856^2} + \frac{0^2}{b^2} + \frac{2^2}{c^2}$$

$$\frac{1}{2.710^2} = \frac{1}{3.856^2} + \frac{4}{c^2}$$

$$\frac{1}{7.3441} = \frac{1}{14.8687} + \frac{4}{c^2}$$

$$0.06891 = \frac{4}{c^2}$$

$$c^2 = \frac{4}{0.06891}$$

$$c = \sqrt{\frac{4}{0.06891}}$$

$$c = 7.6189$$

Plane (1,1,2)

$$\frac{1}{d^2} = \frac{h^2}{a^2} + \frac{k^2}{b^2} + \frac{l^2}{c^2}$$

$$\frac{1}{2.229^2} = \frac{1^2}{3.856^2} + \frac{1^2}{b^2} + \frac{2^2}{7.6189^2}$$

$$\frac{1}{4.9684} = \frac{1}{14.8687} + \frac{1}{b^2} + \frac{4}{58.0476}$$

$$0.0651 = \frac{1}{b^2}$$

$$b^2 = \frac{1}{0.0651}$$

$$b = \sqrt{\frac{1}{0.0651}}$$

$$b = 3.9191$$

Therefore, for 0.01 % Al_2O_3-doped YBCO superconductor, the lattice parameters are a=3.856, b=3.9191, c=7.6189

ii) 0.02 % Al_2O_3-doped YBCO superconductor

Plane (1,0,0)

$$\frac{1}{d^2} = \frac{h^2}{a^2} + \frac{k^2}{b^2} + \frac{l^2}{c^2}$$

$$\frac{1}{3.857^2} = \frac{1^2}{a^2} + \frac{0^2}{b^2} + \frac{0^2}{c^2}$$

$$\frac{1}{3.857^2} = \frac{1}{a^2}$$

$$a = 3.857$$

Plane (1,0,2)

$$\frac{1}{d^2} = \frac{h^2}{a^2} + \frac{k^2}{b^2} + \frac{l^2}{c^2}$$

$$\frac{1}{2.7184^2} = \frac{1^2}{3.857^2} + \frac{0^2}{b^2} + \frac{2^2}{c^2}$$

$$\frac{1}{2.7184^2} = \frac{1}{3.857^2} + \frac{4}{c^2}$$

$$\frac{1}{7.3897} = \frac{1}{14.8764} + \frac{4}{c^2}$$

$$0.0681 = \frac{4}{c^2}$$

$$c^2 = \frac{4}{0.0681}$$

$$c = \sqrt{\frac{4}{0.0681}}$$

$$c = 7.6638$$

Plane (1,1,2)

$$\frac{1}{d^2} = \frac{h^2}{a^2} + \frac{k^2}{b^2} + \frac{l^2}{c^2}$$

$$\frac{1}{2.227^2} = \frac{1^2}{3.857^2} + \frac{1^2}{b^2} + \frac{2^2}{7.6638^2}$$

$$\frac{1}{4.9613} = \frac{1}{14.8764} + \frac{1}{b^2} + \frac{4}{58.7338}$$

$$0.1173 = \frac{1}{b^2}$$

$$b^2 = \frac{1}{0.1173}$$

$$b = \sqrt{\frac{1}{0.1173}}$$

$$b = 2.9196$$

Therefore, for 0.02 % Al_2O_3-doped YBCO superconductor, the lattice parameters are a=3.857, b=2.9196, c=7.6638

iii) 0.03 % Al_2O_3-doped YBCO superconductor

Plane (1,0,0)

$$\frac{1}{d^2}=\frac{h^2}{a^2}+\frac{k^2}{b^2}+\frac{l^2}{c^2}$$

$$\frac{1}{3.864^2}=\frac{1^2}{a^2}+\frac{0^2}{b^2}+\frac{0^2}{c^2}$$

$$\frac{1}{3.864^2}=\frac{1}{a^2}$$

$$a=3.864$$

Plane (1,1,0)

$$\frac{1}{d^2}=\frac{h^2}{a^2}+\frac{k^2}{b^2}+\frac{l^2}{c^2}$$

$$\frac{1}{2.7186^2}=\frac{1^2}{3.864^2}+\frac{1^2}{b^2}+\frac{0^2}{c^2}$$

$$\frac{1}{2.7186^2}=\frac{1}{3.864^2}+\frac{1}{b^2}$$

$$\frac{1}{7.3908}=\frac{1}{14.9305}+\frac{1}{b^2}$$

$$0.06833=\frac{1}{b^2}$$

$$b^2=\frac{1}{0.068331}$$

$$b=\sqrt{\frac{1}{0.06833}}$$

$$b=3.8257$$

Plane (1,1,2)

$$\frac{1}{d^2}=\frac{h^2}{a^2}+\frac{k^2}{b^2}+\frac{l^2}{c^2}$$

$$\frac{1}{2.2254^2}=\frac{1^2}{3.864^2}+\frac{1^2}{3.8257^2}+\frac{2^2}{c^2}$$

$$\frac{1}{4.9524}=\frac{1}{14.9305}+\frac{1}{14.6360^2}+\frac{4}{c^2}$$

$$0.06662=\frac{4}{c^2}$$

$$c^2=\frac{4}{0.06662}$$

$$c=\sqrt{\frac{4}{0.06662}}$$

$$c=7.7486$$

Therefore, for 0.03 % Al_2O_3-doped YBCO superconductor, the lattice parameters are a=3.864, b=3.8257, c=7.7486

iv) 0.04 % Al_2O_3-doped YBCO superconductor

Plane (1,0,0)

$$\frac{1}{d^2} = \frac{h^2}{a^2} + \frac{k^2}{b^2} + \frac{l^2}{c^2}$$

$$\frac{1}{3.8539^2} = \frac{1^2}{a^2} + \frac{0^2}{b^2} + \frac{0^2}{c^2}$$

$$\frac{1}{3.8539^2} = \frac{1}{a^2}$$

$$a = 3.8639$$

Plane (1,1,0)

$$\frac{1}{d^2} = \frac{h^2}{a^2} + \frac{k^2}{b^2} + \frac{l^2}{c^2}$$

$$\frac{1}{2.7253^2} = \frac{1^2}{3.8639^2} + \frac{1^2}{b^2} + \frac{0^2}{c^2}$$

$$\frac{1}{2.7186^2} = \frac{1}{3.8539^2} + \frac{1}{b^2}$$

$$\frac{1}{7.4273} = \frac{1}{14.8525} + \frac{1}{b^2}$$

$$0.06731 = \frac{1}{b^2}$$

$$b^2 = \frac{1}{0.06731}$$

$$b = \sqrt{\frac{1}{0.06731}}$$

$$b = 3.8544$$

Plane (1,1,2)

$$\frac{1}{d^2} = \frac{h^2}{a^2} + \frac{k^2}{b^2} + \frac{l^2}{c^2}$$

$$\frac{1}{2.2250^2} = \frac{1^2}{3.8639^2} + \frac{1^2}{3.8544^2} + \frac{2^2}{c^2}$$

$$\frac{1}{4.9506} = \frac{1}{14.8525} + \frac{1}{14.8564^2} + \frac{4}{c^2}$$

$$0.06919 = \frac{4}{c^2}$$

$$c^2 = \frac{4}{0.06919}$$

$$c = \sqrt{\frac{4}{0.06919}}$$

$$c = 7.6034$$

Therefore, for 0.04 % Al_2O_3-doped YBCO superconductor, the lattice parameters are a=3.8639, b=3.8544, c=7.6034