UNIVERSITI PUTRA MALAYSIA

STRUCTURAL, MAGNETIC AND ELECTRICAL PROPERTIES OF YBCO-123 SUPERCONDUCTOR REACTED WITH Y_2O_3 AND $BaZrO_3$ NANOPARTICLES

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By

NURHIDAYAH BINTI MOHD HAPIPI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

December 2017

DEDICATION

This work is dedicated to my beloved father and mother

MOHD HAPIPI BIN HANAFI

ASPALILA BINTI JUSOH

and to my sibling

NORHIWANI BINTI MOHD HAPIPI

MOHD IQRAM BIN MOHD HAPIPI

NURHIDAYATI BINTI MOHD HAPIPI

Thank you for everything

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Master of Science

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Chairman: Assoc. Prof. Chen Soo Kien, PhD
Faculty: Science

In this work, superconducting properties of $YBa_2Cu_3O_{7-\delta}$ (Y-123) reacted with 5.0 mol.% of Y_2O_3 and different molar percentages (mol.%) of $BaZrO_3$ (BZO) nanoparticles were studied. Series 1 samples are Y-123 reacted with *x* mol.% BZO nanoparticles and Series 2 samples are Y-123 reacted with 5.0 mol.% of Y_2O_3 and *x* mol.% BZO nanoparticles (*x* = 0.0 – 7.0 mol.%). The samples were prepared using co-precipitation (COP) method. The phase formation, microstructure, magnetic and electrical properties of the samples were investigated using thermogravimetric analysis (TGA), X-ray diffraction (XRD), scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDX), temperature dependence of resistance measurement, and alternating current susceptibility (ACS). XRD patterns indicated that all of the samples could be indexed to space group (*Pmmm*) with orthorhombic crystal structure. Y-123 is the major phase while Y-211 was detected as minor secondary phase in all the samples. Besides, BZO peaks started to appear when its addition level was increased from 1.0 mol.%. The SEM images showed that all the samples have irregular shaped grains and they are randomly distributed. The average grains size for both series increased in the range of 0.30 μm to 0.50 μm with increasing amount of BZO nanoparticles addition. Yet, the grain size for Series 2 samples is slightly higher than that in Series 1 indicating that Y_2O_3 may promote grain growth. The temperature dependence of resistance measurements showed a metallic behaviour at normal state and a superconducting transition to zero resistance for all the samples. The value of T_c for the pure sample is 91.6 K and it decreased to 81.5 K and 87.6 K for Series 1 and Series 2 samples, respectively for 7.0 mol.% BZO addition. The T_c values and the transition width, ΔT_c for the Series 2 are slightly higher than Series 1. The higher value of transition width, ΔT_c shows the degradation of homogeneity within the samples. The ACS measurement showed the decreasing of $T_{c\text{-onset}}$, T_{cj} and T_p with the increase of BZO nanoparticles addition for all the samples. The decrease of T_{cj} and T_p is

due to the weakening of the intergranular coupling and the decrease of pinning forces. The obtained I_o and J_{cm} for Series 2 are higher than that for Series 1 indicating that the grain coupling of the former is stronger. As a conclusion, the results shows that the co-addition of Y_2O_3 and BZO (Series 2) can maximize the J_{cm} value and improve a flux pinning if compared to the addition of BZO only (Series 1). However, the optimum value for co-addition of BZO is only up to 2.0 mol.% since further addition will degrade the superconductivity of the samples. The highest J_{cm} is 2.096 A/ cm^2 for co-addition of 2.0 mol.% BZO and Y_2O_3.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Sarjana Sains

SIFAT-SIFAT STRUKTURAL, MAGNETIK DAN ELEKTRIK DALAM SUPERKONDUKTOR YBCO-123 YANG BERTINDAK BALAS DENGAN Y_2O_3 DAN $BaZrO_3$ NANOPARTIKEL

Oleh

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Dalam kajian ini, sifat-sifat superkonduktor $YBa_2Cu_3O_{7-\delta}$ (Y-123) yang bertindak balas dengan 5.0 mol.% Y_2O_3 dan nanopartikel BZO pada peratusan molar yang berbeza (mol.%) telah dikaji. Sampel Siri 1 adalah Y-123 yang bertindak balas dengan *x* mol.% nanopartikel BZO dan sampel Siri 2 adalah Y-123 yang bertindak balas dengan 5.0 mol.% Y_2O_3 dan *x* mol.% nanopartikel BZO (x = 0.0 – 7.0 mol.%). Sampel Y-123 telah disediakan menggunakan kaedah se-pemendakan. Kesan penambahan nanopartikel pada pembentukan fasa, mikrostruktur, sifat-sifat magnetik dan elektrikal ke atas sampel telah dikaji menggunakan analisis termogravimetrik (TGA), pembelauan sinar-X (XRD), mikroskop elektron pengimbas (SEM), spektroskopi serakan tenaga sinar-X (EDX), pergantungan suhu pada pengukuran kerintangan, dan kerentanan arus ulang-alik (KAU). Corak XRD menunjukkan bahawa semua sampel boleh diindekskan kepada kumpulan ruang (*Pmmm*) dengan struktur hablur ortorombik. Y-123 adalah fasa utama manakala Y-211 dikesan sebagai fasa minor kedua di dalam semua sampel. Selain itu, puncak BZO mula kelihatan apabila aras penambahan meningkat daripada 1.0 mol.%. Imej SEM menunjukkan bahawa semua sampel mempunyai bentuk tak menentu dengan taburan rawak. Purata saiz bijirin bagi kedua-dua siri bertambah dalam kadar 0.30 μm hingga 0.50 μm dengan peningkatan jumlah penambahan nanopartikel BZO. Walau bagaimanapun, saiz bijirin bagi sampel Siri 2 adalah tinggi sedikit berbanding Siri 1 menunjukkan Y_2O_3 menggalakan pertumbuhan bijirin. Semua sampel dalam Siri 1 dan Siri 2 menunjukkan sifat logam pada keadaan normal dan peralihan mensuperkonduksi ke rintangan sifar seperti yang ditunjukkan oleh pergantungan suhu pada pengukuran rintangan. Nilai T_c bagi sampel tulen adalah 91.6 K dan nilai ini berkurang kepada 81.5 K dan 87.6 K bagi sampel Siri 1 dan Siri 2, masing-masing dengan penambahan 7.0 mol.% nanopartikel BZO. Nilai T_c dan lebar peralihan, ΔT_c bagi Siri 2 adalah tinggi sedikit berbanding Siri 1. Ketinggian nilai lebar peralihan, ΔT_c menunjukkan

ketakhomogenan di dalam sampel. Pengukuran bagi KAU menunjukkan penurunan bagi $T_{c\text{-onset}}$, T_{cj} dan T_p dengan peningkatan penambahan nanopartikel BZO untuk semua sampel. Penurunan T_{cj} dan T_p adalah disebabkan gandingan antara butiran yang melemah dan penurunan daya pengepinan. Keputusan arus Josephson, I_o dan ketumpatan arus genting antara butiran, J_{cm} bagi Siri 2 adalah lebih tinggi berbanding Siri 1 menunjukkan bahawa gandingan butiran bagi Siri 2 adalah lebih kuat. Sebagai konklusi, keputusan menunjukkan bahawa penambahan bersama Y_2O_3 dan BZO (Siri 2) boleh memaksimumkan nilai J_{cm} dan menambahbaik pengepinan fluks jika dibandingkan dengan penambahan BZO sahaja (Siri 1). Walaubagaimanapun, nilai optimum bagi penambahan bersama BZO adalah sehingga 2.0 mol.% memandangkan penambahan selanjutnya akan merosotkan kesuperkonduksian sampel. J_{cm} yang tertinggi adalah 2.096 A/ cm^2 bagi penambahan bersama 2.0 mol.% BZO dan Y_2O_3.

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I certify that a Thesis Examination Committee has met on 7 December 2017 to conduct the final examination of Nurhidayah binti Mohd Hapipi on her thesis entitled "Structural, Magnetic and Electrical Properties of YBCO-123 Superconductor Reacted with Y_2O_3 and $BaZrO_3$ Nanoparticles" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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LIST OF SYMBOLS AND ABBREVIATIONS

ACS	Alternating current susceptibility
θ	Angle of diffraction
Å	Angstrom (Unit of length equal to 10^{-10} m)
H_{ac}	Applied magnetic field
a.u.	Arbitrary unit
$BaZrO_3$ (BZO)	Barium Zirconate
$BaCO_3$	Barium Carbonate
BaO	Barium Oxide
BSCCO	Bismuth Strontium Calcium Copper Oxide
ξ	Coherence length
CuO	Copper (II) Oxide
CuO_2	Copper (II) Peroxide
COP	Co-precipitation
T_p	Coupling peak temperature
J_c	Critical current density
T_c	Critical temperature
DSC	Differential scanning calorimetry
EDX	Energy-dispersive X-ray spectroscopy
$Bi_2Sr_2Ca_2Cu_3O_{10}$ (Bi-2223)	Family member in BSCCO
$YBa_2Cu_3O_{7-\delta}$ (Y-123)	Family member in YBCO
Y_2BaCuO_5 (Y-211)	Family member in YBCO
FWHM	Full width at half maximum
κ	Ginzburg-Landau constant
HTS	High temperature superconductor
p	Hole concentration
d	Interatomic spacing
J_{cm}	Intergranular critical current density
ICSD	Inorganic Crystal Structure Database
χ’	In-phase (real) susceptibility
I_o	Josephson’s current
K	Kelvin (Standard unit of temperature)
a-, *b*-, *c*-axis	Lattice parameter
LTS	Low temperature superconductor
F_L	Lorentz force
Φ_0	Magnetic flux
T_c^{max}	Maximum critical temperature
mol.%	Molar percentage
Oe	Oersted (Unit of magnetic field)
rpm	Rotation per minute
$T_{c\text{-}onset}$	Onset critical temperature
χ”	Out-of-phase (imaginary) susceptibility
T_{cj}	Phase lock-in temperature
F_p	Pinning force
rpm	Revolutions per minute
SEM	Scanning electron microscope
SQUIDs	Superconducting Quantum Interference Devices
T	Tesla (Standard unit of magnetic flux density)

TGA	Thermogravimetry Analysis
ΔT_c	Transition temperature width
TEM	Transmission Electron Microscopy
J	Transport current
wt.%	Weight percentage
XRD	X-Ray Diffractometer
λ	X-ray wavelength
YBCO	Yttrium Barium Copper Oxide
Y_2O_3	Yttrium Oxide
$T_{c\text{-zero}}$	Zero critical temperature

CHAPTER 1

INTRODUCTION

1.1 Background

A superconductor is a material that has a zero resistance when cooled below its critical temperature, T_c. The critical temperature or the transition temperature is the temperature at which a superconductor loses its resistance. Resistance causes the energy flows through the material to lose. All metals and alloy materials have a resistance and the resistance decreases at lower temperature due to the decrease in thermal vibrations of the atoms resulting in less scattering of conduction electrons. However, superconducting materials would suddenly lose all trace of electrical resistance once they are cooled into the superconducting state below the T_c (Rose-Innes and Rhoderick, 1978).

They are two distinctive properties to consider a material as a superconductor. First, no resistance is observed in a superconductor below its T_c value and superconductivity will disappear if the current passed is higher than the critical current density, J_c. Secondly, no magnetic induction, $B = 0$ inside the superconductor in weak external magnetic field when cooled below its T_c value (Cyrot and Pavuna, 1992).

The phenomenon of superconductivity was observed for the first time in 1911 when Heike Kamerlingh Onnes cooled mercury to the temperature of liquid helium, 4 K and he found that the resistance of mercury disappeared (Eck, 1999). Over the years, it was believed that superconductivity could only occur when the materials were held at very low temperature (low temperature superconductor, LTS). Nevertheless, in 1986, the discovery of cuprates marked the beginning of superconductivity at higher temperatures (high temperature superconductor, HTS) hence provides a new prospective in the superconducting area (Khare, 2003).

1.2 History of High Temperature Superconductor (HTS)

High-temperature superconductors (HTS) are materials that superconduct at higher temperatures (above 30 K) and can be cooled to superconducting state using liquid nitrogen (77 K). The first HTS was discovered in late 1986, when Alex Müller and Georg Bednorz synthesized a brittle ceramic compound (La-Ba-Cu-O compounds) that was shown to be superconducting at the temperature above 30 K. However, the critical temperature of La-Ba-Cu-O compound was increased above 40 K when a pressure was applied (Chu et al., 1987). One interesting part was that scientists had never thought of ceramic could be HTS candidates because ceramic is normally insulating and cannot conduct electricity (Eck, 1999).

Since then, researchers began to study every combination of ceramics to get higher T_c. However, in January of 1987, a research team from University of Alabama-Huntsville achieved 92 K of T_c, when they substituted yttrium for lanthanum in yttrium barium copper oxide ($YBa_2Cu_3O_{7-x}$) which is the first superconductor with T_c above the boiling point of liquid nitrogen (Wu et al., 1987; Cyrot and Pavuna, 1992). Later, in 1988, Maeda and co-workers at the National Research Institute, Japan discovered Bi-cuprate oxides ($Bi_2Sr_2Ca_2Cu_3O_{10}$) with T_c value at 110 K (Maeda et al, 1988) and Tl-cuprate oxides ($Tl_2Sr_2Ca_2Cu_3O_{10}$) was discovered by Sheng and Hermann with T_c value at 125 K (Sheng and Hermann, 1988).

The search for new HTS materials with higher T_c reached the climax when the mercury based HTS compounds were discovered. The highest temperature superconductor was found in the three-layer system of $HgBa_2Ca_2Cu_3O_{8+\delta}$ (Hg-1223) with T_c value at 133.5 K. In January 2008, a research group led by Hideo Hosono in Japan discovered a new class of high-temperature superconductors (non-Cu-based superconductors) in layered iron arsenic compounds with T_c of 26 K. It was found that the parent compound, LaOFeAs became a superconducting upon replacing some of the oxygen with fluorine and this is known as “pnictides” (compounds of the nitrogen group) (Kamihara et al., 2008). In 2015, the highest T_c value at 203 K was found in hydrogen sulfide (H_2S) under extremely high pressure around 150 GPa (Drozdov et al., 2015).

1.3 Application of HTS

Superconductors have made a significant breakthrough in technological applications, especially in transportation, electronic, medical and superconducting energy storage system. A few of these applications are discussed as follow:

1.3.1 Maglev Train

In 1934, the train based on superconductivity was proposed and known as the Maglev train. Maglev stood for magnetic levitation. Maglev train is moved when the magnetic fields created by electrified coils within the track walls that propel the train. These strong superconducting magnets eliminate the friction between the trains and its tracks. Due to the frictionless properties, it allows the train to travel over long distances at speeds of hundreds of miles per hour (Galiano, 2011; Liu et al., 2015). The principle used for maglev trains to levitate is “Meissner effect” that will be explained later.

1.3.2 SQUID

Superconducting quantum interference device or SQUID magnetometer have been used to measure and recording small magnetic signals from the brain, heart, stomach and other organs. Besides, magnetic field sensors based on SQUIDs also has been widely used in geophysics for measuring the magnetic field oscillations of the earth and in some other fields (Wikswo, 1995).

1.4 Problem Statement and Research Objectives

Over the years, scientists had studied high temperature superconductor (HTS) extensively. HTS is very useful for industries because of their special properties which are zero resistance and perfect diamagnetism. However, there are some limitations of HTS application. For example, it only can behave as a superconductor below the room temperature which is above the T_c value. Therefore, a lot of studies had been done to improve the critical temperature, T_c and the critical current density, J_c (Klie et al., 2005; Horvath et al., 2008; Barnes et al., 2009). With this improvement, it can save lots of cost and energy since the current can be transported without any loss of energy. But, it is challenging to improve both the T_c and J_c value.

In this work, the addition of $BaZrO_3$ (BZO) nanoparticles and the co-addition of BZO nanoparticles and Y_2O_3 into Y-123 were studied. It is believed that both the addition and co-addition into Y-123 samples will improve the J_c without affecting much the T_c value. Previous study of bulk Y-123 composite with BZO by applying hot isostatic pressing (HIP) for sintering claimed that the nanoparticles size of BZO (30 - 50 nm) gave a good dispersion of pinning centres in the matrix and the introducing of BZO enhanced the J_c value up to 20000 A/ cm^2 (Awano et al., 2000). It was supported by Jin et al. (2015), when a smooth surface and a good texture have been observed in the YBCO + 5.0 mol.% BZO film, which exhibited the best J_c value (4.9 MA/ cm^2) for the YBCO + 5.0 mol.% BZO film at 77 K and 0 T. Although the J_c value was increased, it did not affect much the T_c values of these films that can be obtained around ~ 90 K. Ding et al. (2012), claimed that the co-addition of 7.0 mol.% BZO and 7.0 mol.% Y_2O_3 into Y-123 films showed a higher self-field J_c value of 6.5 mA/ cm^2 compared to the pure Y-123 film as 3.2 mA/cm^2. Besides, the T_c value of Y-123 film with co-addition of 7.0 mol.% BZO and 7.0 mol.% of Y_2O_3 was ~ 90 K, a value which is closed to that of the pure Y-123.

The method used was co-precipitation (COP) which is being used widely in the industry compared to solid-state method (Ochsenkuhn-Petropoulou et al., 2002; Cardwell and Ginley, 2003). The samples from COP method can be produced at large scale for various applications such as fly wheel motor, transmission power cable, wires, tapes and magnets. Until now a few conventional materials, like NbTi or Nb_3Sn have been commercialized (Wang, 2013). The wires made of HTS oxides such as YBCO and BSCCO are still under development. Since the previous studies had focused more on the thin films (Haugan et al., 2007; Ciontea et al., 2008), therefore this work focused more on bulk superconductor.

Hence, the objectives of this work are:

i. To prepare high purity of Y-123 precursor by using co-precipitation method.
ii. To study the influence of nanoparticles addition, BZO on structural, magnetic and electrical properties of Y-123 bulk superconductor.
iii. To investigate the effects of co-addition of BZO nanoparticles and Y_2O_3 on structural, magnetic and electrical properties of Y-123 bulk superconductor.

1.5 Thesis Overview

Basically, this thesis is consist of six chapters. The first chapter is about introduction of superconductor and the history of high temperature superconductor. Then, the applications of superconductor, the problem statement and the objectives of this work are given here too. Chapter 2 reviews some previous studies of Y-123 superconductor especially the study involved the co-precipitation method, the addition of BZO nanoparticles and the co-addition of BZO and Y_2O_3. Chapter 3 explains the theory and fundamental of superconductivity. The phenomena of superconductivity, classification of superconductors, properties of superconductors, vortex state, and the Cooper pair's formation are discussed here. Then, chapter 4 discusses the materials and method used for this work. Discussion in this chapter also includes sample characterization such as TGA, XRD, SEM, temperature dependence of electrical resistance measurement and AC Susceptibility. In chapter 5, the results obtained from all the samples are analyzed and discussed. Lastly, chapter 6 concludes the results for this work and the recommendation for future research is given.

BIBLIOGRAPHY

Afalla, J. P. C., and Sarmago, R. V. (2010). Differentiating AC and DC Field Effects on the Magnetic Susceptibility of Bulk $YBa_2Cu_3O_{7-\delta}$. *Science Diliman*, *21*(2), 25–34.

Ahmed, H. M., Miś, M., El-Geassy, A. H. A., and Seetharaman, S. (2010). Reduction-carburization of the oxides of Ni and W towards the synthesis of Ni-W-C carbides. *Materials Science Forum*, *636–637*, 952–962.

Alaghbari, E. S., Zainal, Z., Hamadneh, I., Hussein, M. Z., and Wahid, M. H. (2012). Effect of doping of Zn and Ca into $ErBa_2Cu_3O_{7-\delta}$ superconductor prepared via co-precipitation method. *Journal of Superconductivity and Novel Magnetism*, *25*, 255–260.

Alami, J. (2005). *Plasma characterization & thin film growth and analysis in highly ionized magnetron sputtering plasma*. Linkoping University.

Ambegaokar, V., and Baratoff, A. (1963). Tunneling between superconductors. *Physical Review Letters*, *10*(11), 486–489.

Arlina, A., Halim, S. A., Kechik, M. M. A., and Chen, S. K. (2015). Superconductivity in Bi-Pb-Sr-Ca-Cu-O ceramics with YBCO as additive. *Journal of Alloys and Compounds*, *645*, 269–273

Aruldhas, G., and P. Rajagopal. (2006). *Modern physics* (Second Edi). New Delhi: Prentice-Hall of India Pvt. Ltd.

Awano, M., Fujishiro, Y., Moon, J., Takagi, H., Rybchenko, S., and Bredikhin, S. (2000). Microstructure control of an oxide superconductor on interaction of pinning centers and growing crystal surface. *Physica C*, *341–348*, 2017–2018.

Aytug, T., Paranthaman, M., Specht, E. D., Zhang, Y., Kim, K., Zuev, Y. L., Cantoni, C., Goyal, A., Christen, D. K., Maroni, V. A., Chen, Y., and Selvamanickam, V. (2010). Enhanced flux pinning in MOCVD-YBCO films through Zr additions: systematic feasibility studies. *Superconductor Science and Technology*, *23*, 014005 (7pp).

Bansal, S., Bansal, T. K., Mcgreevy, R. L., Smith, S. H., and Garton, G. (1988). Effects of heat-treatments on Y-Ba-Cu-O and Y-Gd-Ba-Cu-O superconductors. *Materials Research Bulletin*, *23*, 843–850.

Bardeen, J., Cooper, L. N., and Schrieffer, J. R. (1957). Theory of superconductivity. *Physical Review*, *108*(5), 1175–1204.

Barnes, P. N., Haugan, T. J., Baca, F. J., Varanasi, C. V., Wheeler, R., Meisenkothen, F., and Sathiraju, S. (2009). Inducing self-assembly of Y_2BaCuO_5 nanoparticles via Ca-doping for improved pinning in $YBa_2Cu_3O_{7-x}$. *Physica C*, *469*, 2029–2032.

Bean, C. P. (1962). Magnetization of hard superconductors. *Physical Review Letters*, *8*(6), 250–253.

Bednorz, J. G., and Muller, K. A. (1986). Possible high T_c superconductivity in the Ba-La-Cu-0 system. *Condensed Matter, 193,* 189–193.

Belevtsov, L. V., and Kostikov, A. A. (2005). High-field Josephson effect caused by the inside-grain vortices. *Physics Letters A*, *343*(6), 454–461.

Bhargava, A., Mackinnon, I. D. R., Yamashita, T., and Page, D. (1995). Bulk manufacture of YBCO powders by coprecipitation. *Physica C*, *241*, 53–62.

Bolzan, A. A., Millar, G. J., Bhargava, A., Mackinnon, I. D. R., and Fredericks, P. M. (1996). A spectroscopic comparison of YBCO superconductors synthesised by solid-state and co-precipitation methods. *Materials Letters*, *28*, 27–32.

Brecht, E., Schmahl, W. W., Miehe, G., Rodewald, M., Fuess, H., Andersen, N. H., Hanβmann, J., and Wolf, T. (1996). Thermal treatment of $YBa_2Cu_{3-x}Al_xO_{6+\delta}$ single crystals in different atmospheres and neutron-diffraction study of excess oxygen pinned by the Al substituents. *Physica C*, *265*, 53–66.

Callister, W. D., and David G. Rethwisch. (2011). *Materials science and engineering* (Eight Edi). New Jersey: John Wiley and Sons Inc.

Cardwell, D. A., and Ginley, D. S. (2003). *Handbook of Superconducting Materials, Volume 1*. United States: CRC Press.

Chu, C. W., Hor, P. H., Meng, R. L., Gao, L., Huang, Z. J., and Wang, Y. Q. (1987). Evidence for superconductivity above 40 K in the La-Ba-Cu-O compound system. *Physical Review Letters*, *58*(4), 405–407.

Ciontea, L., Celentano, G., Augieri, A., Ristoiu, T., Suciu, R., Gabor, M. S., Rufoloni A., Vannozzi A., Galluzi V., and Petrisor, T. (2008). Chemically processed $BaZrO_3$ nanopowders as artificial pinning centres. *Journal of Physics: Conference Series*, *97*, 012289.

Clem, J. R. (1988). Granular and superconducting-glass properties of the high-temperature superconductors. *Physica C*, *153–155*, 50–55.

Cracolice, M. S., & Peters, E. I. (2012). *Introductory Chemistry: An Active Learning Approach*. United States: Brooks Cole.

Cyrot, M. (1973). Ginzburg-Landau theory for superconductors. *Reports on Progress in Physics*, *36*, 103–158.

Cyrot, M., and Pavuna, D. (1992). *Introduction to superconductivity and high-T_c materials*. Singapore: World Scientific Publishing Co. Pte. Ltd.

Deac, I. G., Burzo, E., Pop, A. V., Pop, V., Tetean, R., Kovacs, D., and Borodi, G. (1999). Intergranular properties of $(Y_{1-x-y}Zr_xCa_y)Ba_2Cu_3O_{7-\delta}$ compounds. *International Journal of Modern Physics B*, *13*(13), 1645–1654.

Dean, D. (n.d.). *Thermal gravimetric analysis*. University of Alabama, Birmingham.

Demydov, D. V. (2006). *Nanosized alkaline earth metal titanates: Effects of size on photocatalytic and dielectric properties*. Kansas State University.

Dihom, M. M., Shaari, A. H., Baqiah, H., Al-Hada, N. M., Talib, Z. A., Chen, S. K., Aziz, R. S., Awang Kechik, M. M., Lim, K. P., and Shukor, R. A. (2017). Structural and superconducting properties of $Y(Ba_{1-x}K_x)_2Cu_3O_{7-\delta}$ ceramics. *Ceramics International*, *43*(14), 11339–11344.

Ding, F., Gu, H., Zhang, T., Wang, H., Qu, F., Dai, S.,Peng X., and Cao, J. (2012). Enhanced flux pinning in MOD-YBCO films with co-doping of $BaZrO_3$ and Y_2O_3 nanoparticles. *Journal of Alloys and Compounds*, *513*, 277–281.

Drozdov, A. P., Eremets, M. I., Troyan, I. A., Ksenofontov, V., and Shylin, S. I. (2015). Conventional superconductivity at 203 kelvin at high pressures in the sulfur hydride system. *Nature, 525*, 73-76.

Durrant, A. (2000). *Quantum Physics of Matter*. United States: CRC Press.

Eck, J. (1999). Superconductors. Retrieved from http://www.superconductors.org/author.htm

Fa-Zhu, D., Hong-Wei, G., Teng, Z., Hong-Yan, W., Fei, Q., Qing-Quan, Q., Shao-Tao, D., and Xing-Yu, P. (2013). Strong flux pinning enhancement in $YBa_2Cu_3O_{7-x}$ films by embedded $BaZrO_3$ and $BaTiO_3$ nanoparticles. *Chinese Physics B*, *22*(7), 077401.

Feng, J., Zhou, L., Lu, Y., Zhang, P., Xu, X., Chen, S., Zhang C., Xiong X., and Liu, G. (2008). The effect of $BaZrO_3$ addition on melt-processed $YBa_2Cu_3O_{7-x}$ superconductors. *Journal of Alloys and Compounds*, *458*, 432–435.

Flewitt, P. E. J., and Wild, R. K. (1994). *Physical Methods for Materials Characterisation* (Second Edition). Briston: IOP Publishing

Forrest, A. M. (1983). Meissner and Ochsenfeld revisited. *European Journal of Physics*, *4*, 117–120.

Fujihara, S., Kozuka, H., Yoko, T., and Sakka, S. (1994). Mechanism of formation of $YBa_2Cu_40_8$ superconductor in the sol-gel synthesis. *Journal of Sol-Gel Science and Technology*, *1*, 133–140.

Galiano, D. (2011). *Electric and magnetic phenomena* (First edition). New York: The Rosen Publishing Group, Inc.

Ginzburg, V. L., and E. A. Andryushin. (2004). *Superconductivity* (Revised Edition). Singapore: World Scientific Publishing Co. Pte. Ltd.

Gupta, S., Yadav, R. S., Lalla, N. P., Verma, G. D., and Das, B. (2010). Microstructural and superconducting properties of $YBa_2Cu_{3-x}Co_xO_{7-\delta}$ system. *Integrated Ferroelectrics*, *116*, 68–81.

Hamadneh, I., Halim, S. A., and Lee, C. K. (2006). Characterization of $Bi_{1.6}Pb_{0.4}Sr_2Ca_2Cu_3O_y$ ceramic superconductor prepared via coprecipitation method at different sintering time. *Journal of Materials Science*, *41*, 5526–5530.

Hamadneh, I. (2002). *Synthesis and characterization of Samarium doped $Bi_{1.6}Pb_{0.4}Sr_2Ca_2Cu_3O_{10}$ superconductor prepared via coprecipitation method*. Universiti Putra Malaysia.

Hamadneh, I., Rosli, A. M., Abd-Shukor, R., Suib, N. R. M., and Yahya, S. Y. (2008). Superconductivity of $REBa_2Cu_3O_{7-\delta}$ (RE = Y, Dy, Er) ceramic synthesized via coprecipitation method. *Journal of Physics: Conference Series*, *97*,012063.

Hassanzadeh-Tabrizi, S. A., Mazaheri, M., Aminzare, M., and Sadrnezhaad, S. K. (2010). Reverse precipitation synthesis and characterization of CeO_2 nanopowder. *Journal of Alloys and Compounds*, *491*, 499–502.

Haugan, T. J., Barnes, P. N., Campbell, T. A., Pierce, N. A., Javier Baca, F., and Maartense, I. (2007). Flux pinning of Y-Ba-Cu-O films doped with $BaZrO_3$ nanoparticles by multilayer and single target methods. *IEEE Transactions on Applied Superconductivity*, *17*(2), 3724–3728.

Hong-yan, W., Fa-zhu, D., Hong-wei, G., and Teng, Z. (2015). Strongly enhanced flux pinning in the $YBa_2Cu_3O_{7-X}$ films with the co-doping of $BaTiO_3$ nanorod and Y_2O_3 nanoparticles at 65 K. *Chinese Physics B*, *24*(9), 097401.

Horvath, D., Harnois, C., and Noudem, J. G. (2008). Li and Ce doping of melt-textured YBCO: Improved J_c at medium fields. *Materials Science & Engineering B*, *151*, 36–39.

Howe, B. A. (2014). *Crystal structure and superconductivity of $YBa_2Cu_3O_{7-x}$*. Minnesota State University, Mankato.

Hutchings, M. T., Withers, P. J., Holden, T. M., and Lorentzen, T. (2005). *Introduction to the Characterization of Residual Stress by Neutron Diffraction*. United States: CRD Press.

Jha, A. K., and Khare, N. (2010). Investigation of flux pinning properties of YBCO:$BaZrO_3$ composite superconductor from temperature dependent magnetization studies. *Journal of Magnetism and Magnetic Materials*, *322*, 2653–2657.

Jiang, X. P., Zhang, J. S., Huang, J. G., Jiang, M., Qiao, G. W., Hu, Z. Q., and Shi, C. X. (1988). Study on solid state reaction process of the $YBa_2Cu_3O_{7-x}$ compound. *Materials Letters*, *7*(7, 8), 250–255.

Jin, L. H., Zhang, S. N., Yu, Z. M., Li, C. S., Feng, J. Q., Sulpice, Wang, Y., and Zhang, P. X. (2015). Influences of $BaZrO_3$ particles on the microstructure and flux pinning of YBCO film prepared by using modified TFA-MOD approach. *Materials Chemistry and Physics*, *149–150*, 188–192.

Kameli, P., Salamati, H., and Abdolhosseini, I. (2008). AC susceptibility study of $Bi_{1.66}Pb_{0.34}Sr_2Ca_{2-x}Mg_xCu_3O_y$ (x = 0, 0.2 and 0.4) superconductor systems. *Journal of Alloys and Compounds*, *458*, 61–65.

Kameli, P., Salamati, H., and Eslami, M. (2006). The effect of sintering temperature on the intergranular properties of Bi2223 superconductors. *Solid State Communications*, *137*, 30–35.

Kamihara, Y., Watanabe, T., Hirano, M., and Hosono, H. (2008). Iron-based layered superconductor $La[O_{1-x}F_x]FeAs$ (x = 0.05 - 0.12) with T_c = 26 K. *Journal of the American Chemical Society*, *130*, 3296.

Karaca, I., Celebi, S., Varilci, A., and Malik, A. I. (2003). Effect of Ag_2O addition on the intergranular properties of the superconducting Bi-(Pb)-Sr-Ca-Cu-O system. *Superconductor Science and Technology*, *16*, 100–104.

Khachan, J., and Bosi, S. (2003). *Superconductivity*. Brookhaven National Laboratory, University of California, Santa Barbara.

Khan, N. A., and Mumtaz, M. (2008). How grain-boundaries influence the intergranular critical current density of $Cu_{1-x}Tl_xBa_2Ca_3Cu_4O_{12-\delta}$ superconductor thin films? *Journal of Low Temperature Physics*, *151*(5–6), 1221–1229.

Khare, N. (2003). High-temperature superconductor microwave devices. In *Handbook of High-Temperature Superconductor Electronics* (pp. 317–351). New York: Taylor & Francis Inc.

Kim, C., Kim, K., Kuk, I., Hong, G., Lee, Y., and Park, H. (1997). Microstructure change during oxygen annealing and the effect on the levitation force of melt-textured Y–Ba–Cu–O superconductors. *Superconductor Science and Technology*, *10*, 947–954.

Klie, R. F., Buban, J. P., Varela, M., Franceschetti, A., Jooss, C., Zhu, Y., Browning, N. D., Pantelides, S. T., and Pennycook, S. J. (2005). Enhanced current transport at grain boundaries in high-T_c superconductors. *Nature*, *435*, 475–478.

Koblischka-Veneva, A., Koblischka, M. R., Hari Babu, N., Cardwell, D. A., and Mücklich, F. (2006). Embedded $Y_2Ba_4CuNbO_x$ nanoparticles in melt-textured YBCO studied by means of EBSD. *Physica C*, *445–448*, 379–381.

Kumar, P., Pillai, V., Bates, S. R., and Shah, D. O. (1993). Preparation of $YBa_2Cu_3O_{7-x}$ superconductor by coprecipitation of nanosize oxalate precursor powder in microemulsions. *Materials Letters*, *16*, 68-74.

Langford, J. I., and Wilson, A. J. C. (1978). Scherrer after sixty years: A survey and some new results in the determination of crystallite size. *Journal of Applied Crystallography*, *11*, 102–113.

Lei, L., Zhao, G., Xu, H., Wu, N., and Chen, Y. (2011). Influences of Y_2O_3 nanoparticle additions on the microstructure and superconductivity of YBCO films derived from low-fluorine solution. *Materials Chemistry and Physics*, *127*, 91–94.

Liu, Z., Long, Z., and Li, X. (2015). *Maglev Trains: Key Underlying Technologies*. New York: Springer.

London, F., and London, H. (1935). The electromagnetic equations of the supraconductor. *Proceeding of the Royal Society of London*, *149*(866), 71–88.

Luo, Y. Y., Wu, Y. C., Xiong, X. M., Li, Q. Y., Gawalek, W., & He, Z. H. (2000). Effects of precursors with fine $BaZrO_3$ inclusions on the growth and microstructure of textured YBCO. *Journal of Superconductivity: Incorporating Novel Magnetism*, *13*(4), 575–581.

MacManus-Driscoll, J. L., Foltyn, S. R., Jia, Q. X., Wang, H., Serquis, A., Civale, L., Maiorov, B., Hawley, M. E., Maley, M. P., and Peterson, D. E. (2004). Strongly enhanced current densities in superconducting coated conductors of $YBa_2Cu_3O_{7-x}$ + $BaZrO_3$. *Nature Materials*, *3*, 439–443.

Maeda, H., Tanaka, Y., Fukutomi, M., and Asano, T. (1988). A new high-T_c oxide superconductor without a rare earth element. *Japanese Journal of Applied Physics*, *27*(2), L209–L210.

Malmivirta, M., Yao, L. D., Huhtinen, H., Palonen, H., Dijken, S. Van, and Paturi, P. (2014). Three ranges of the angular dependence of critical current of $BaZrO_3$ doped $YBa_2Cu_3O_{7-\delta}$ thin films grown at different temperatures. *Thin Solid Films*, *562*, 554–560.

Martien, D. (n.d.). Introduction to AC susceptibility. California: Quantum Design.

Matic, V. M., and Lazarov, N. D. (2007). The origin of the 60 K plateau in $YBa_2Cu_3O_{6+x}$. *Journal of Physics: Condensed Matter*, *19*, 346230 (9pp).

Matsushita, T. (2007). *Flux pinning in superconductors*. New York: Springer.

Mellekh, A., Zouaoui, M., Ben Azzouz, F., Annabi, M., and Ben Salem, M. (2006). Nano-Al_2O_3 particle addition effects on $YBa_2Cu_3O_y$ superconducting properties. *Solid State Communications*, *140*, 318–323.

Mote, V. D., Purushotham, Y., and Dole, B. N. (2012). Williamson-Hall analysis in estimation of lattice strain in nanometer-sized ZnO particles. *Journal of Theoretical and Applied Physics*, *6*, 1–9.

Mourachkine, A. (2002). *High-temperature superconductivity in cuprates*. New York: Kluwer Academic Publishers.

Narlikar, A. V. (1995). *Field Penetration and Magnetization of High Temperature Superconductors*. New York: Nova Science Publisher, Inc.

Nedkov, I., and Veneva, A. (1997). Grain boundaries contribution to the complex susceptibility of KCu-doped YBCO high-temperature superconductors. *Journal of Low Temperature Physics*, *107*, 497–502.

Nikolo, M. (1995). Superconductivity: A guide to alternating current susceptibility measurements and alternating current susceptometer design. *American Journal Physics*, *63*(1), 57–65.

Ochsenkuhn-Petropoulou, M., Argyropoulou, R., Tarantilis, P., Kokkinos, E., Ochsenkuhn, K. M., and Parissakis, G. (2002). Comparison of the oxalate co-precipitation and the solid state reaction methods for the production of high temperature superconducting powders and coating. *Journal of Materials Processing Technology*, *127*, 122–128.

Ochsenkuhn-Petropulu, M., Tarantilis, P., Argyropulu, R., and Parissakis, G. (1998). Optimization of the sintering process by DSC for the preparation of high-temperature superconductors. *Journal of Thermal Analysis*, *52*, 903–914.

Owens, F. J., and Charles P. Poole, J. (2002). *The new superconductors*. New York: Kluwer Academic Publishers.

Ozdas, E., and Firat, T. (1992a). Influence of the hole concentration on T_c in 110 K BiPbSrCaCuO superconductor: The intergrain and intragrain effects. In *Physics and Materials Science of High Temperature Superconductors, II* (Vol. 209, pp. 381–393). New York: Kluwer Academic Publishers.

Patnaik, P. (2004). *Dean's analytical chemistry handbook* (Second edition). New York: McGraw Hill Professional.

Paulose, K. V, Koshy, J., and Damodaran, A. D. (1991). Superconductivity in $YBa_2Cu_3O_{7-\delta}$ - ZrO_2 systems. *Superconductor Science and Technology*, *4*, 96–101.

Paz-Pujalt, G. R., Mehrotra, A. K., Ferranti, S. A., and Agostinelli, J. A. (1989). Solid state reactions in the formation of $YBa_2Cu_3O_{7-\delta}$ high T_c superconductor powders. *Solid State Ionics*, *32/33*, 1179–1182.

Pomar, A., Vlad, V. R., Llordes, A., Palau, A., Gutiérrez, J., Ricart, S., Puig, T., Obradors, X., Usoskin, A. (2009). Enhanced vortex pinning in YBCO coated conductors with BZO nanoparticles from chemical solution deposition. *IEEE Transactions on Applied Superconductivity*, *19*(3), 3258–3261.

Poole, C. P., Farach, H. A., Creswick, R. J., and Prozorov, R. (2014). *Superconductivity* (Third edition). Amsterdam: Elsevier.

Presland, M. R., Tallon, J. L., Buckley, R. G., Liu, R. S., and Flower, N. E. (1991). General trends in oxygen stoichiometry effects on T_c in Bi and Tl superconductors. *Physica C*, *176*, 95–105.

Ramli, A., Halim, S. A., Chen, S. K., and Kechik, M. M. A. (2016). The effect of Gd2O3 nanoparticles addition on microstructural and electrical properties of YBCO superconductor. *ARPN Journal of Engineering and Applied Sciences*, *11*(23), 13708–13715.

Ramli, A., Shaari, A. H., Baqiah, H., Kean, C. S., Mustafa, M., Kechik, A., and Talib, Z. A. (2016). Role of Nd_2O_3 nanoparticles addition on microstructural and superconducting properties of $YBa_2Cu_3O_{7-\delta}$ ceramics. *Journal of Rare Earths*, *34*(9), 895–900.

Rani, P., Jha, R., and Awana, V. P. S. (2013). AC susceptibility study of superconducting $YBa_2Cu_3O_7$: Ag_x bulk composites (x = 0.0 – 0.20): The role of intra and intergranular coupling. *Journal of Superconductivity and Novel Magnetism*, *26*, 2347–2352.

Rose-Innes, A. C., and E.H. Rhoderick. (1978). *Introduction to superconductivity* (Second Edition). New York: Pergamon Press.

Salamati, H., and Kameli, P. (2003). Effect of deoxygenation on the weak-link behavior of $YBa_2Cu_3O_{7-\delta}$ superconductors. *Solid State Communications, 125*, 407–411.

Sbarciog, C., Redac, R. T., Deac, I. G., and Pop, I. (2006). Intergranular properties of Zr-substituted Y123 compounds. *Modern Physics Letters B*, *20*(19), 1191–1198.

Schildermans, I., Bael, M. Van, Knaepen, E., Yperman, J., Mullens, J., and Poucke, L. C. Van. (1997). Synthesis of the high temperature superconductor $YBa_2Cu_3O_{7-\delta}$ by the hydroxide co-precipitation method. *Physica C, 278*, 55–61.

Schildermans, I., Knaepen, E., Nouwen, R., Bael, M. K. Van, Vanhoyland, G., Mullens, J., Yperman, J., Franco, D., and Poucke, L. C. Van. (1999). Thermal treatment of a Y-123 precursor prepared using the hydroxide co-precipitation method. *International Journal of Inorganic Materials*, *1*, 351–355.

Schmidt, V. V., Muller, P., and Ustinov, A. V. (1997). *The Physics of Superconductors: Introduction to Fundamentals and Applications*. New York: Springer Science & Business Media.

Shams, G., Mahmoodinezhad, A., and Ranjbar, M. (2017). Magnetic levitation and some mechanism of $YBa_2Cu_3O_{7-\delta}$ superconductor doped with nano-sized Al_2O_3. *Iranian Journal of Science and Technology, Transactions A: Science*, *2*, 1–7.

Sheng, Z. Z., and Hermann, A. M. (1988). Bulk superconductivity at 120 K in the Tl-Ca/ Ba-Cu-O system. *Nature, 332*, 138–139.

Skoog, D. A., Holler, F. J., and Crouch, S. R. (2007). *Principles of instrumental analysis* (6th Intern). United States: Thomson Brooks/Cole.

Strickland, N. M., Long, N. J., Talantsev, E. F., Hoefakker, P., Xia, J., Rupich, M. W., Kodenkandath, T., Zhang, W., Li, X., and Huang, Y. (2008). Enhanced flux pinning by $BaZrO_3$ nanoparticles in metal-organic deposited YBCO second-generation HTS wire. *Physica C, 468*, 183–189.

Suan, M. S. M., Hasim, N. A., Manaf, M. E. A., and Johan, M. R. (2017). Effects of Ag_2O nanoparticles addition on electrical conductivity and microhardness properties of polycrystalline $YBa_2Cu_3O_{7-\delta}$. *Chinese Journal of Physics*, *55*, 1857–1864.

Suryanarayana, C., and Norton, M. G. (2013). *X-ray diffraction: A practical approach*. New York: Springer Science & Business Media.

Tallon, J. L., Bernhard, C., Shaked, H., Hitterman, R. L., and Jorgensen, J. D. (1995). Generic superconducting phase behavior in high-T_c cuprates: T_c variation with hole concentration in $YBa_2Cu_3O_{7-\delta}$. *Physical Review B, 51*(18), 911–914.

Tranquada, J. M., Heald, S. M., Moodenbaugh, A. R., and Xu, Y. (1988). Mixed valency, hole concentration, and T_c in $YBa_2Cu_3O_{6+x}$. *Physical Review B, 38*(13), 8893–8899.

Verma, N. K. (2017). *Physics for Engineers* (Second Edi). New Delhi: PHI Learning Pvt. Ltd.

Wahid, M. H., Zainal, Z., Hamadneh, I., Tan, K. B., Halim, S. A., Rosli, A. M., Alaghbari, E. S., Nazarudin, M. F., and Kadri, E. F. (2012). Phase formation of $REBa_2Cu_3O_{7-\delta}$ (RE: $Y_{0.5}Gd_{0.5}$, $Y_{0.5}Nd_{0.5}$, $Nd_{0.5}Gd_{0.5}$) superconductors from nanopowders synthesised via co-precipitation. *Ceramics International*, *38*, 1187–1193.

Wang, Y. (2013). *Fundamental Elements of Applied Superconductivity in Electrical Engineering*. New York: John Wiley & Sons.

Warren, N. (2003). *Excel HSC Physics (New Edition)*. New South Wales: Pascal Press.

Wikswo, J. P. (1995). SQUID magnetometers for biomagnetism and nondestructive testing: Important questions and initial answers. *IEEE Transactions on Applied Superconductivity*, *5*(2), 74–120.

Wu, M. K., Ashburn, J. R., Torng, C. J., Hor, P. H., Meng, R. L., Gao, L., Huang, Z. J., Wang, Y. Q., and Chu, C. W. (1987). Superconductivity at 93 K in a new mixed-phase Y-Ba-Cu-O compound system at ambient pressure. *Physical Review Letters*, *58*(9), 908–910.

Zelati, A., Amirabadizadeh, A., Kompany, A., Salamati, H., and Sonier, J. (2014). Effects of Dy_2O_3 nanoparticle addition on structural and superconducting properties of BSCCO. *Indian Journal of Science and Technology*, *7*(2), 123–134.

Zhang, C. J., and Oyanagi, H. (2008). The synthesis condition and its influence on T_c in Mn doped $La_{1.85}Sr_{0.15}CuO_4$. *Physica C: Superconductivity*, *468*, 1155–1158.

Zhou, Y., Yuan, W., Huang, Q., Huang, W., Cheng, H., and Liu, H. (2015). Effect of Y_2O_3 addition on the phase composition and crystal growth behavior of YSZ nanocrystals prepared via coprecipitation process. *Ceramics International*, *41*, 10702–10709.

LIST OF PUBLICATIONS

Publication in Index Journal

Mohd Hapipi, N., Shaari, A. H., Awang Kechik, M. M., Tan, K. B., Abd-Shukor, R., Mohd Suib, N. R., and Chen, S. K. (2017). Effect of heat treatment condition on the phase formation of $YBa_2Cu_3O_{7-\delta}$ superconductor. *Solid State Phenomena*, *268*, 305–310.

Journal and Abstracts in conference proceedings

Nurhidayah Mohd Hapipi, Nursyafiqah Ismail, Cheong Choon Min, Abdul Halim Shaari, Mohd Mustafa Awang Kechik, Lim Kean Pah and Chen Soo Kien."Comparative study of phase formation of $YBa_2Cu_4O_8$ prepared via solid state and co-precipitation method", Programme and Abstract Book for 5th International Conference on Solid State Science and Technology 2015, 13-15 December 2015.

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