UNIVERSITI PUTRA MALAYSIA

SUPERCONDUCTING PROPERTIES OF MULTILAYERED THIN FILM STRUCTURE OF YBCO WITH NiO AND CoO FABRICATED BY PULSED LASER DEPOSITION

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

January 2015

Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

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January 2015

Chairman: Professor Dr. Abdul Halim Shaari, PhD
Faculty: Science

This thesis attempts to investigate theoretical aspect of transport properties and experimental preparation of Yttrium Barium Copper Oxide (YBCO) single layer and multilayer thin films. Theoretical discussion on possible electrical transport properties on the basis of important experimental facts to satisfy the requirements of practical YBCO devices applications have not been addressed. The Pulsed Laser Deposition (PLD) is one of the techniques that is used to develop fine quality epitaxial thin films. In this research the bulk YBCO and NiO doped YBCO are prepared by different methods namely solid state reaction method and co precipitation method. The simulation modeling of laser plasma dynamics has been done in Matlab 2012 and different parameters have been proposed under the light of theoretical modeling. The theoretical transport properties have also been modeled which may provide some important utilization in electronic devices.

The doping of NiO at Yttrium sites of the six samples with ratio from 0 - 0.1 exhibited tetragonal structure in pure while the orthorhombic structure in doped samples. The same orthorhombic structure has been found with decreased T_c values when the NiO has been added. AC susceptibility results indicate that the introduction of NiO during the final processing of YBCO bulk targets can decrease the T_c from 78-88K.
Then PLD experiments were carried out on two different setups with different ranges of substrate heating systems, the former has 0-500ºC while other has 0-800ºC under oxygen and nitrogen ambient.

The undertaken work involves two distinct studies, firstly, the YBCO epitaxial films and buffer layers have been probed numerically with the help of computer simulations. The simulations revealed the transport properties of the deposited YBCO thin films and analyzed the laser plasma dynamics and transport properties like resistive versus

magnetic field and temperature, susceptibility measurements, the activation energy versus current density and high temperature thermal factor.

The electrical transport properties of YBCO thin film have been investigated using different physical techniques. The physical transport properties were also estimated with temperature and magnetic fields limits using thermally-activated flux flow model with some modifications. The results of present simulation modelling have indicated that the magnitude of activation energy depends on temperature and magnetic field. The simulations revealed thickness dependent physical transport properties including electrical and magnetic properties of deposited YBCO thin films. The results have indicated that the temperature depends on the pinning energy and can be used to improve the superconducting properties (T_c) of the YBCO single layers thin films.
The YBCO thin film have been experimentally fabricated in PLD system with substrate heater (> 750ºC) annealed in-situ for the 30 minutes after the deposition under oxygen ambient. The heating and cooling rate for annealing the deposited sample was 3ºC/min, and 2ºC/min, respectively to improve the quality of film layer. The YBCO target used in those experiment were prepared by amorphous phase epitaxy method. The same procedure for the YBCO/NiO(CoO) double layer and YBCO/NiO(CoO)/YBCO triple layer have been adopted.

The results produce in the other PLD system with lower substrate heating system and ex-situ annealing via tubular furnace has not improved the quality of the layers either used by increasing heating rate and decreasing cooling rate. All the XRD diffraction peaks observed in bulk samples are also seen in the films.

The XRD patterns have indicated that the crystalline quality of the thin film samples prepared by Amorphous phase epitaxy was better than those with co-precipitation method. Furthermore, based on FESEM images, it has proven that thicker and high substrate heating can absorb more oxygen and improve the surface layer.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

SIFAT KESUPERKONDUKSIAN STRUKTUR FILEM NIPIS MULTILAPISAN YBCO DENGAN NiO DAN CoO DIFABRIKASI DENGAN PEMENDAPAN LASER DENYUT

Oleh

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Tesis ini bertujuan untuk menyelidik sifat angkutan teori secara dan penyediaan eksperimen Yttrium Barrium Copper oksida (YBCO) lapisan tunggal dan filem nipis multilapisan. Perbincangan secara teori tentang sifat angkutan elektrik yang mungkin berdasarkan fakta eksperimen yang penting untuk memenuhi cirri penggunaan peranti ybco tidak dibincangkan. Pemendapan Laser Denyut (PLD) adalah diantara teknik yang digunakan untuk membangunkan filem nipis epitaksi yang berkualiti. Aspek aplikasi peranti daripada PLD pada superkonduktor suhu tinggi filem epitaksi mempunyai peranan penting dalam bidang fizik keadaan pepejal dan kesuperkonduksian. Dalam kajian ini, YBCO pukal dan YBCO didopkan NiO telah disediakan dengan kaedah berbeza iaitu; tindakbalas keadaan pepejal dan kaedah ko-pemendakan. Pemodelan simulasi laser dinamik plasma telah dilakukan dalam Matlab 2012 dan parameter yang berbeza telah dicadangkan di bawah kaedah pemodelan teori. Sifat pengangkutan teori juga dimodelkan untuk menyediakan beberapa penggunaan penting dalam peranti elektronik.

Pendopan NiO pada tapak Yttrium untuk enam sampel dengan nisbah 0-0.1 mempamirkan struktur tetragonal untuk sampel tulin manakala struktur ortorombik dipamirkan untuk sampel yang didop. T_c ini berkurangan apabila pendopan meningkat seperti yang ditunjukkan dalam keputusan susceptibiliti. Struktur ortorombik juga dicerap dengan penurunan nilai T_c apabila NiO telah ditambah. Keputusan menunjukkan bahawa pengisian jumlah NiO yang sesuai semasa pemprosesan akhir sasaran pukal YBCO dapat menurun Tc dari 78-88K.

Kemudian ujikaji PLD telah dijalankan ke atas dua pemasangan yang berbeza dengan julat sistem pemanasan substrat yang berbeza iaitu pemasangan pertama berjulat 0-500ºC manakala yang lain mempunyai 0-800ºC dengan persekitaran oksigen dan nitrogen.

Tugas yang dijalankan melibatkan dua kajian yang berbeza, pertama, filem epitaksi YBCO dan lapisan penampan telah disiasat secara berangka dengan bantuan simulasi komputer. Simulasi mendedahkan sifat pengangkutan YBCO didepositkan filem nipis dan menganalisis struktur laser dinamik plasma dan filem, seperti rintangan lawan medan magnet dan suhu dan, pengukuran susceptibility tenaga teraktifan lawan ketumpatan arus dan factor terma suhu tinggi.

Sifat pengangkutan elektrik YBCO filem nipis telah dikaji dengan menggunakan teknik fizikal yang berbeza. Sifat fizikal pengangkutan juga dianggarkan dalam had suhu dan medan magnet menggunakan model aliran haba diaktifkan dengan sedikit pengubahsuaian. Keputusan pemodelan simulasi yang dilaksanakan telah menyatakan bahawa magnitud tenaga pengaktifan bergantung kepada suhu dan medan magnet. Simulasi mendedahkan ketebalan sifat fizikal bergantung kepada sifat pengangkutan termasuk sifat elektrik dan magnet untuk filem YBCO yang dimendapkan. Keputusan telah menunjukkan bahawa suhu bergantung kepada tenaga terpin dan boleh digunakan untuk memperbaiki sifat superkonduktor (T_c) untuk lapisan tunggal filem nipis YBCO.

Filem nipis YBCO telah difabrikasi dalam sistem PLD dengan pemanas substrat (> 750ºC) disepuhlindap in-situ untuk 30 minit selepas pemendapan dalam oksigen ambien. Pemanasan dan kadar penyejukan bagi penyepuhlindapan sampel yang dimendap adalah 3ºC / min, dan 2ºC / min, masing-masing untuk meningkatkan kualiti lapisan filem. Sasaran YBCO yang digunakan dalam eksperimen yang telah disediakan oleh kaedah epitaksi faser amorfus. Prosedur yang sama untuk YBCO / NiO (CoO) dua lapis dan YBCO / NiO (CoO) / YBCO tiga lapisan telah digunapakai.

Keputusan mengemukakan dalam sistem PLD yang lain dengan sistem pemanasan substrat yang lebih rendah dan melalui penyepuhlindapan eks-situ dalam relau tiub tidak meningkatkan kualiti filem sama ada digunakan dengan meningkatkan kadar pemanasan dan mengurangkan kadar penyejukan. Semua puncak belauan sinar-x dikesan dalam sampel pukal juga dicerap pada filem.

Corak XRD menunjukkan bahawa kualiti kristal sampel filem nipis yang disediakan oleh fasa amorfus epitaksi adalah lebih baik daripada filem yang disediakan dengan kaedah ko-pemendakan. Tambahan pula, berdasarkan imej FESEM, ia telah membuktikan bahawa substrat yang lebih tebal dan pemanasan substrat yang tinggi boleh menyerap lebih banyak oksigen dan meningkatkan lapisan permukaan.

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

HTS	High Temperature Superconductor
YBCO	$YBa_2Cu_3O_{7-\delta}$
BSCCO	$Bi_2Sr_2Ca_2Cu_3O_{10-\delta}$
O-Ba-O	Barium Oxide
J_c	Critical current density
I_c	Critical current
H_{irr}	Irreversibility field
GBs	Grain boundaries
ϑ_c	Critical angle
BCS	Bardeen-Cooper-Schrieffer
λ_L	London penetration depth
H_c	Critical field
H_{c1}	Critical field 1
H_{c2}	Upper critical field 2
h	Plank's constant
e	Electron charge
GL	GInzburg-Landau

CHAPTER 1

INTRODUCTION

The discovery of superconductivity generated a completely new field of study in condensed matter physics. Great efforts were made to understand physical transport properties while exploring mechanisms that prompted the microscopic theory of superconductivity, first elaborated in 1957. Thirty years later, new high temperature superconductors (HTS) were discovered which prompted even more research as venders looked for better superconducting materials with higher T_c values, as well as innovative applications and optimized cost efficiency.

1.1 Generations of HTS Materials

High current density HTS flexible conducting wires have been the main focus of research since their discovery in the late 1980's (Foltyn *et al.*, 1993). Researchers seek to produce affordable high density HTS wires to improve various technologies and applications, particularly in magnetic motors and transformers for high speed levitation trains, high speed water boats, electronics for SQUIDs construction, transistors, sensor microchips, detectors, filters, resonators and filters, etc (Foltyn *et al.*, 1999). The first generation HTS wire, BSCCO, has been synthesized and used in many applications but has very limited critical current density at ~77.2 ºK (-346°F / -320.44 °F; temperature of liquid nitrogen) in magnetic fields of higher value (Wu *et al.*, 1995, Kang *et al.*, 2002). YBCO wire-second generation HTS-overcomes such drawbacks due to high J_c potential in higher magnetic fields at 77K. Extensive research on YBCO based materials is directed towards the development of reliable products amenable to practical applications in electric power.

1.1.1 YBCO cuprates and other Systems

Copper oxide based complexes such as BSCCO, Hg compounds, YBCO (Grove *et al.*, 2001) and TI compounds have the advantage of a higher critical temperature (T_c > 77 K) which makes them ideal for many industrial and commercial applications. But there remains a need to understand their complicated structure and physics to enhance potential applications. Among these, YBCO cuprates are considered best due to their irreversibility field, higher T_c, and superior pinning force.

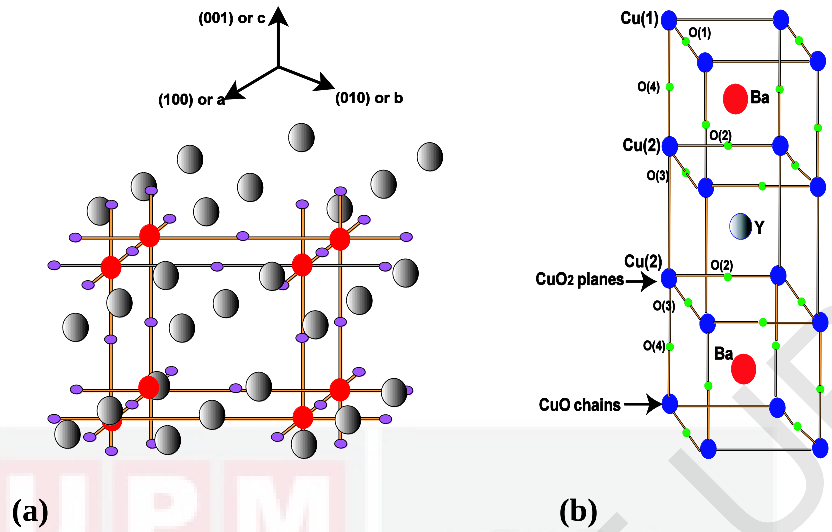


Figure 1.1: YBCO Unit Cell consisting of (a) CuO chain in the 'b' direction; (b) a pair of CuO_2 planes with a single CuO chain along ab planes.

Larger anisotropies were observed in cuprate superconductors which led to changes in physical properties such as bidimensionality. A complex layered perovskite crystalline structure leads to larger anisotropy (see Figure 1.1.) which is considered necessary for higher T_c . CuO_2 planes result in layers and planes of various oxides while rare earths separate different planes into charge reservoirs (insulating planes). It is now well established that superconductivity and charge transport are mostly restrained to CuO_2 planes, both theoretically and experimentally. Figure 1.1 depicts CuO_2 superconductive planes and multiple layers of a charge-reservoir (O-Ba-O and O-Cu) stacked around YBCO, which is a layered perovskite structure centered on the Y-layer. Furthermore, mechanically hard, extremely brittle, and very poor ductile properties are also exhibited by cuprate superconductors.

Cuprate superconductors show bidimensionality in physical properties caused by large anisotropies. Its complex crystalline structure comprises CuO_2 planes that are isolated from each other by rare earths and sundry oxides that probably accounts for their greater anisotropy. Charge transport and superconductivity are theoretically and experimentally established properties of CuO_2 planes along with a relatively low anisotropy for YBCO (electron mass anisotropy $\gamma = (m_c/m_{ab})^{0.5} \sim 5\text{-}7$) compared to HTS materials. Hence, HTS materials are used for commercial applications due to their metallically charged reservoirs. BSCCO has a very large 'γ' value of at least 30. Sufficiently textured YBCO thin films have shown a high J_c (> a few MA/cm^2 for self-field at ~77K), and relatively high in-field performance (irreversibility field at 77K ~ 6-7 T). It is also known that by establishing many kinds of pinning-force centers, the J_c and irreversibility field can be increased. Moreover, greatly improved in-field performance in the temperatures ranging from 30 to 65 K has been exhibited by YBCO where a closed cycle cooling system based on mechanical cryocoolers may be utilized. The lattice structure becomes tetragonal and non-superconducting possessing lattice parameters where a = 3.820 Å, b = 3.890 Å, and c = 11.680 Å when *x* value ($YBa_2Cu_3O_{7-x}$) is ~ 0 or very small.

1.1.2 YBCO Multilayer

Oxides have an electron single-particle transport property with very high mobility and complex oxide material can be utilized as insulating metal or semiconductors that exhibit interesting properties in solid-state systems with rich phenomenology compared to comparable classes of material.

The behavior of oxides strongly correlates with the Mott-Hubbard transition. A third type of oxide shows collective states such as magnetism that can be coupled to form ferromagnetic and anti-ferromagetic phases at high temperatures. The layer-by-layer growth design, with one metal sandwiched between two similar YBCO layers with analogous crystalline structures but very different physical properties, obtains benefits of the naturally layered YBCO structure. With two layers, one YBCO and the other metallic deposited one after the other, comprise multilayers that can be grown by supplying materials sequentially from different atomic constituents. The layer-by-layer approach achieves characteristics of thermodynamically stable compounds as shown in Figure 1.2. The main difficulty in layer-by-layer deposition is to accurately control the quantity of deposited material within an error rate of 1%. Additionally, a suitable temperature-oxygen pressure window permits the required lateral surface mobility that supports excellent crystallinity. Essentially, it is a quest to discover optimal conditions for kinetically controlled deposition (Kes and Tsuei, 1983, Civale *et al.*, 2004).

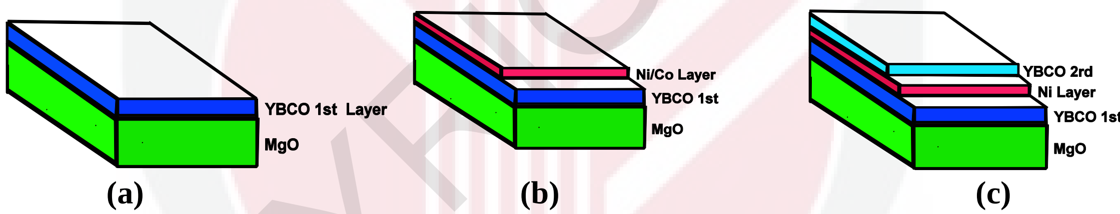


Figure 1.2: Pulse Laser Deopsition of (a) Single layer YBCO; (b) Double layer YBCO multilayer; (c) Triple layer YBCO multilayer.

1.1.3 Performance Requirements of HTS Deposited Material

Practically, layer-by-layer deposition is characterized by three important parameters: critical current density (J_c); critical current per unit width (I_c); and irreversibility field H_{irr} (or H). Another important parameter for practically coated conductors is high J_c (4-7 MA/cm^2) which is routinely achieved by many deposition techniques for thin YBCO films (a few hundred nanometers thick). However, high J_c for thin films yields I_c of only ~ 200–300 A/cm-width. Hence, a major challenge is to achieve adequately thick films with high J_c of over 500–1000 A/cm-width at 77K.
The practical limitation of a magnetic field applied to superconductors is defined by (H_{irr}) where critical current and flux pinning is no longer effective (i.e., no effective J_c).

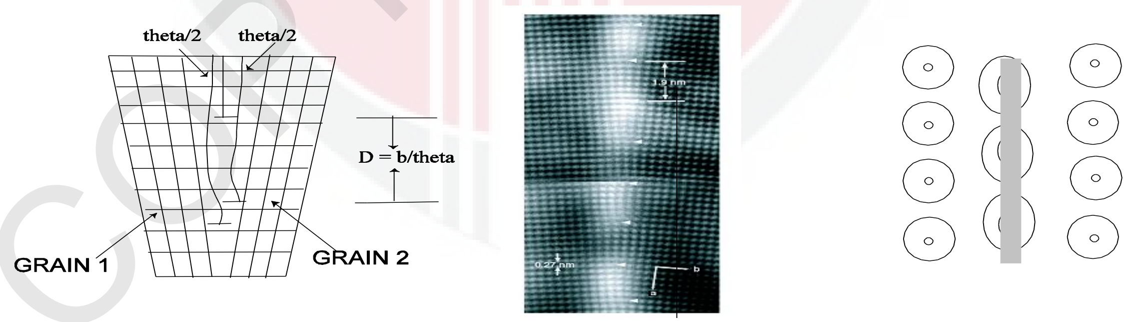
However, for high field applications, the higher value of H_{irr} is essential. In-field J_c should attain 10^4-10^6 A/cm^2 in fields of 1-10 T at temperatures ranging from 20-77K (Foltyn *et al.*, 1999) for applications. Moreover, longer length (typically km) is also required.

1.1.4 Scientific Challenges of HTS Sandwiches

Much effort is concentrated on the manufacture of YBCO sandwiches. However, important scientific issues are not yet fully satisfied or even stated. This section highlights critical scientific challenges to YBCO multilayer research, including weak coupling across grain boundaries, flux pinning, and J_c reduction with increased film thickness.

1.1.5 Weak Superconducting Coupling Across Grain Boundaries

Grain Boundaries (GBs) in YBCO have an heterogeneous structure on a scale of 1-5 nm which is comparable to the coherence length ξ of HTS YBCO. Coherence length (ξ) is a measure of distance within planes in which electron concentration cannot drastically change in a spatially-varying applied magnetic field; simply interpreted as the pairing length of a superconducting electron pair. Low angle GBs consist of a grain boundary, dislocation cores, and conductive grain-like channels (Ohnishi *et al.*, 2004), as shown in Figure 1.3(a). Atomic disruptions at the dislocation cores as well as in strain fields surrounding the cores depress the superconducting order parameter and disrupt the supercurrent within a region of 1–2 nm near grain boundary cores. Wider depleted regions have been observed for longer misorientations which result in weaker coupling across GBs (Wong-Ng *et al.*, 2004, Wong-Ng *et al.*, 2005).



(a) (b) (c)

Figure 1.3: (a) Grain Boundary with low angle showing insulation because dislocation cores are highly distorted and strained. (b) HRTEM image of 8º (001) tilted grain boundary in HTS (Foltyn *et al.*, 1999) (c) Grain boundary carrying vortices structure. A schematic illustration of Abrikosov vortices, designated within the grain boundaries, but with cores extended at GB (Abrikosov-Josephson vortices), containing compact J_c of the Grain Boundary.

GBs reduce critical current density (J_c). An initial experiment by Dimos et al. (Feldmann *et al.,* 2003) established that J_c across GBs was highly dependent on the misorientation angle. This has since been well established so that J_c at GBs decrease exponentially with a rising misorientation angle beyond a given critical angle (θ_c), as derived by tilted bicrystal experiments as well as micro-bridge experiments on coated conductors [100] (Holesinger *et al.,* 2005, Foltyn *et al.,* 2005). The critical angle (θ_c) (Wang *et al.,* 2002) occurs at about 3–4° at self-field and 77K when J_c at GBs is below that of the grain. Figure 1.4 shows an exponential J_c dependence on the GB misorientation angle at 4.2K. It is, therefore, very important to reduce GB misorientation angles in conductor development and thus, maximize current carrying capability for J_c and I_c.

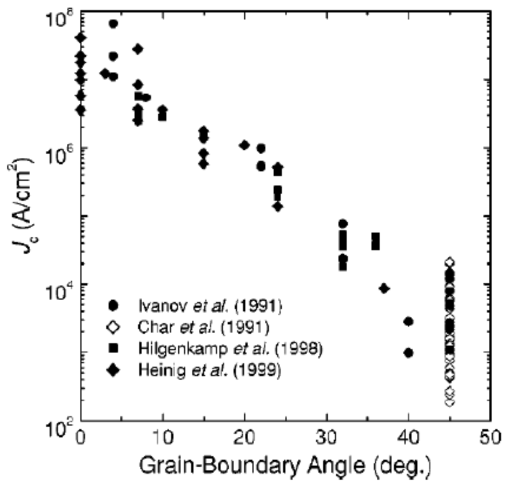


Figure 1.4: J_c transport of [001], tilted grain boundaries as a function of tilted angle in YBCO at 4.1 K (Eom *et al.,* 1992).

1.2 Magnetization Models of HTS

The critical current density, J_C, strongly depends on the value of the magnetic field in consideration of the following factors:

1) The characteristic response to an applied field value.

2) The historical background of the applied field.

3) The initial and final states, and boundary conditions of the system.

Theoretical models for magnetization are given below.

1.2.1 Bean Model

Bean proposed a critical-state model in 1964 which stated that the hysteresis loop is plugged in a macroscopic critical current density parameter, J_C (Bean, 1964).

According to the Bean model, critical current density, J_C, is considered a constant given by

$J_{C0}(H_i,T)= J_{C0}(T)$
(1.1)

H_i and T represents local magnetic field and the temperature, respectively. It was found that the J_{C0} was directly determined by the microstructure of the superconductors.

The relationship of J_{C0} vs. temperature can be expressed as $J_{C0}(T)= J_{C00}(T_C -T)/(T_C – T_0)$(Berger *et al*., 2007).

where T_C represents the critical temperature, J_{C0} the critical current density with reference temperature (T_0) respectively.

1.2.2 Kim Model

In 1964 Anderson and Kim modified Bean's proposed a model (Anderson & Kim, 1964; Kim, *et al*., 1962) and claim that J_{C0} varied with local magnetic field as

$$J_{C0}(H_i,T)=\frac{J_{C0}(T)}{1+H_i/H_0}$$

(1.2)

The macroscopic material parameter, H_0 is within the field's dimension. For conventional solid cylinder shaped superconductor, the model was then fit to experimental values.

J_{C0} depends on the term H_i/H_0, as different materials may vary. Watson observed that in some material the condition $H_i >> H_0$ was satisfied. Later, Hindley and Watson (1969) verified field dependence (J_{C0}) as $J_{C0}(H_i)= A – CH_i$ (Hindley & Watson, 1969).

1.2.3 Power Law Model

In 1967 Irie and Yamafuji worked on some specific pinning mechanisms and suggested a power-law for the field dependence of J_{C0} (Irie & Yamafuji, 1967).

$$J_{C0}(H_i,T)=\frac{K(T)}{H_i^n} \qquad (1.3)$$

Where n is the pinning strength and K represents the material parameter. Fietz and co-worker developed a formula based on the experimental data given as (Fietz *et al*., 1964)

$$J_{C0}(H_i,T)=J_{C0}(T)\exp(-H_i/H_0)$$

(1.4)

The critical state model for the critical current density has been obtained from all the equations from Eq. (2.1 - 2.4), as

$$J_{C0}(H_i,T)=\frac{J_{C0}(T)}{[1+H_i/H_0]^{\beta}} \tag{1.5}$$

By using Eq. (2.1 and 2.2), Eq. (2.5) may be converted to Bean and Kim models when the dimensionless constant, β, equals 0 and 1. When $-H_i$ / H_0 >> 1 is satisfied for Eq. (2.5), Eq. (2.3) is formed where K and n are set to $J_{C0}(T)=H_0^{\beta}$ and β. When $-H_i$/ H_0 << 1 and β >>1 with $-H_0/\beta_0 << H_i$, H_i is finite within the field dimension; and when taking the limit of $J_C(H_i)$ while letting $-H_i/H_0$ = x, then

$$\lim J_{C0}(H_i,T)=\frac{J_{C0}(T)}{\lim\limits_{x\to0}[1+x]^{\beta}}=\frac{J_{C0}(T)}{\lim\limits_{x\to0}[1+x]^{(1/x)(H_0/H_0)}}=J_{C0}(T)\exp(-H_i/H_0)$$

(1.6)

The physical meaning of the Eq. (2.4 are Eq. 2.6) are identical.

1.2.4 Yin Model

In 1994, the Yin develop the following equation (Yin *et al.*, 1994)

$$E(j)=2\upsilon_0 H\exp\left[-\left(\frac{U_0+W_V}{kT}\right)\right]\sinh\left[\frac{W_L}{kT}\right] \tag{1.7}$$

where factors υ_0, U_0, $W_v = \eta\upsilon P = E(j)HP/\rho_f$, $W_L=JHP$ and P have dimensions of velocity, pinning potential, viscosity coefficient, respectively, where the viscous dissipative flux motion $\eta = HH_{C2}/\rho_n = H^2/\rho_f$, as a product of the 'volume of a moving flux bundle' and the 'range of force' was said to be energy due to the Lorentz driving force. The term (υ) within W_L corresponds to $\upsilon_0 exp[-U(j)/kT]$. Yin's model added the terms 'pinning barrier' and 'viscous dissipation' in addition to a direction dependent, while (U) is the activation barrier. The entire framework provided a unified description that included all regimes for flux such as thermally activated flux flow, critical state, flux creep, and flux flow for the model, and also for Anderson-Kim, Bardeen-Steven and critical state ($F_P = J_C \times H$) models.

1.2.5 Dew-Hughes Model of Mechanism in Flux Pinning YBCO

The vortex line in HTS normally has a core diameter of 2ξ with a coherence length of ξ. The calculated coherence length of pure YBCO is 2 nm at 0K. Hence, nano precipitates smaller than 2ξ are the most important pinning centers in YBCO films (Yamasaki *et al.*, 2008). Dew-Hughes developed a model to more accurately study flux pinning in HTS. Elementary pinning forces according to this model are effected by magnetic field influences or core interactions. Higher κ values in HTS permit core pinning to dominate from two sources:

1) Normal particles encircle the superconducting matrix leading toward the scattering of the mean free path (δ*l* pinning).

2) Spatial variations in the Ginzburg parameter coupled with fluctuations in critical temperature T_c (δT_c or Δ κ pinning) (Pu *et al.,* 2003).

Hence, the total pinning force becomes

$$F_{pp} = \sum f_{pp} \tag{1.8}$$

where f_{pin}, is the force's pinned flux line per unit length. Hence, the normalized pinning force density which Dew-Hughes proposed is expressed as follows:

$$F_{pp}(b) = F_{pp} / F_{pp}^{\max} \propto b^{pp}(1-b)^{qq} \tag{1.9}$$

In HTS, *pp* and *qq* depend on specific characteristics of the pinning flux while *b* is a reduced magnetic field (B / B_{c2} or *B / Birr*). These *pp* and *qq* values explain different types of pinning centers while different pinning functions describing core pinning are defined by an equation derived from the Dew- Hughes model. Here, k = λ/ξ (Hughes 1974).

1) pp = 0, qq = 2: normal pinning of core, volume pins;

2) pp = 1, qq = 1: Δ κ-pinning of core, volume pins;

3) pp = 1/2, qq = 2: normal pinning of core, surface pins;

4) pp = 3/2, qq = 1: Δ κ-pinning of core, surface pins;

5) pp = 1, qq = 2: normal pinning of core, point pins;

6) pp = 2, qq = 1: Δ κ-pinning of core, point pins;

This model is helpful for YBCO single and multilayer studied in this research when analyzing the pinning mechanism. The pinning force is calculated by the cross product of B, the applied magnetic field and J_c, the critical current density.

$$F_{pp}(b) = J_c \times B \tag{1.10}$$

In order to obtain specific fitting parameters p and q used to describe the pinning type for the above F_{pp}(b) curves were fitted by equation.

1.3 Problem Statement

Researchers race towards achieving higher and higher T_c with a focus on practical applications. On the basis of the nearly unlimited potential offered by superconductors, proactive thinkers and researchers seek to optimize the potential applicability of these materials and many groups characterize their available properties with a view on new and untested properties while seeking to understand the underlying mechanism of HTS. Although various theories signify the abilities of superconductors, there remains no clear consensus on the underlying mechanism(s) of superconductivity, although many physical transport properties are well known as are the effective metrics that measure the properties of HTS materials. The important question that attracts much research is the 'symmetry of order' parameter that characterizes metallic behavior, since it places serious constraints that pose various challenges to unclear aspects of reigning theories. The matter of material quality and the experimental accuracy of the apparatus has also generated a new series of the experiments concerning accuracy. This thesis concerns the fabrication of YBCO from single to multilayer and intends to explore all possible electrical transport properties based on theoretical ideas and significant experimental data to satisfy requirements for practical HTS YBCO device applications.

1.4 Research Objectives

1) To study the nucleation and growth of multilayer YBCO theoretically as well as experimentally and predict all related parameters.

2) To study the YBCO single and multilayer samples fabricated by using PLD.

3) To determine optimal experimental conditions for the fabrication of Multilayer samples.

4) To analyze and interpret the results obtained from theoretical and experimental metrics.

1.5 Scope of Research

The homogeneous growth of mobile particles in a YBCO multilayer involves the precise optimization of the synthesis process to attain optimal superconducting properties during that phase. As YBCO is a multi-cation oxide with a rather complex crystalline structure, the specific requirement for the formation of a YBCO multilayer with very little or no impurity includes strict control of the composition during the entire process. Similarly, for precise cation composition, the formation of the YBCO magnetic layer requires the optimization of both temperature and partial pressure for a chosen oxidizing species, and represents significantly important quality considerations for phase stability of the compounds.

Certainly, most interest is in homogeneous YBCO films which require equilibrium of the specific crystallographic orientation between the film and crystalline substrate. During layer-by-layer synthesis of different compounds, control of film surface morphology is the most important factor. Ambient gases or the mixture of two gases play a dynamic role on microstructure during the deposition process and thus, affect the quality of the multilayer end product.

Current work discusses the preparation of single and multilayers of YBCO under different experimental conditions and different electrical transport modeling for multilayers using Matlab on the basis of important experimental facts to satisfy requirements for practical high-T_c device applications.

The following set of parameters has been identified: preparation times for YBCO pure targets via the Solid State Reaction Method and Co-precipitation Method Deposition; different substrate heating times; and annealing, both in-situ and ex-situ. Characterization measurements are performed using the Atomic Force Microscope (AFM), X-Ray Diffraction (XRD), and Scanning Electron Microscopy (SEM).

1.6 Thesis Organization

This thesis comprises five chapters. The first chapter contains research background and specific aims, a problem statement, research objectives, scope, and thesis organization. Chapter Two discusses previous studies in the field focused on the theory of growth mechanisms, nucleation and fabrication techniques. Chapter Three covers experimental protocols, the preparation of YBCO targets, systems set ups, metrics and characterization. Chapter Four presents simulation and experimental results with a detailed discussion. Chapter Five concludes the study with a summary and recommendations for future work.

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LIST OF PUBLICATIONS

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