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Study of the Properties of YBCO Superconductor Compound in Various Preparation Methods: A Short Review

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ABSTRACT

Superconductors have entered into many applications and advanced technological fields, due to their excellent properties identified by zero resistance and expelling the magnetic field applied to them. Superconductivity is a viable technology to prevent energy losses contributed by electrical resistivity. Also, the magnetic flux is repelled entirely out of the body of superconducting material which makes the Meissner Effect. High-Temperature Superconductors (HTS) have become the focus of researchers and scientists. This is because it uses liquid nitrogen "LN" in cooling, which gives it significant critical temperatures compared to traditional materials based on liquid helium "LHe" in cooling. From this point of view, began to employ these materials in most disciplines and modern technologies. In this article, the phenomenon of Superconductivity will define with explain its most prominent characteristics and focus on the preparation of the HTS (Yttrium-Barium-Copper-Oxide) compound (Abbreviated as YBCO) in different methods "The Sol-Gel and Citrate Pyrolysis Methods", to creating ultrafine superconducting (Y-123) powders. Generally known that by adopting any preparation technique, the superconducting transition temperature (Tc) value of ≈ 92 K could be achieved in the bulk samples. The Citrate Pyrolysis method is a unique route to prepare reactive precursor mixtures through an ignition process of a concentrated aqueous solution including metallic ions of stoichiometric composition. This procedure enables to synthesize of highly homogeneous and fine powders for functional materials, in comparison to the Sol-gel technique.

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1. Introduction

A new era in science and technology is ushering with the control of atoms and molecules at the nanometer scale (1 nm=10^{-9} m). The conventional sciences of chemistry, physics, biology, and engineering have all come together to produce the new field of nanotechnology. Because of the wide range of interests engaged in nanotechnology, there is frequently confusion among the general public regarding the area's nature, primarily due to nanobiotechnology, nanoelectronics, nanomaterials, and nanophotonics currently being studied. Nanotechnology may be defined as "materials and systems whose structures and components, due to their nanoscale size, display innovative and greatly enhanced physical, chemical, and biological characteristics, phenomena, and processes". Fabrication of functional nanostructures with engineered properties, nanoparticle synthesis and processing, supramolecular chemistry, self-assembly and replication techniques, sintering of nanostructured metallic alloys, quantum effects, chemical, and biological templates, and sensors, surface modification, and films are all examples of nanotechnology. The scientific community is divided on the borders of the new disciplines due to this convergence, such as microtechnology and nanotechnology. Still, no clear distinction can be formed in practice. Sensors and biochips developed at the nanoscale, for example, must be packaged using microtechnology for commercial use [1-4]. This article focuses on Superconducting materials, their characteristics, the fundamental theories on which they are based, and their application in nanotechnology. Besides, it explains the preparation methods for the high-temperature Y-Ba-Cu-oxide (YBCO) in two different techniques, "The Sol-gel method Citrate pyrolysis method" to the synthesis of ultrafine superconducting $YBa_2Cu_3O_{x-\delta}$ powder. Fine powder has assumed significant importance. From the voluminous research activities on YBCO, it is known that by adopting any preparation technique, the superconducting transition temperature (Tc) value of ≈ 92 K could be achieved in the bulk samples. These properties are mainly controlled by many parameters related, and the synthetic procedure plays an important role [5-8]. The discovery of Superconductivity was in 1911 by Dutch Scientist Heike Kamerlingh Onnes in mercury material at Leiden University's cryogenic laboratory. He noticed that the resistivity of mercury metal (Hg) abruptly vanished at about 4.2 K. For his efforts, he received the Nobel Prize [9, 10]. The historical measurement of Superconductivity in mercury is shown in Fig. 1 [11]. In physics, Superconductivity is a phenomenon that happens when certain materials are cooled to very low temperatures, near absolute zero, allowing electricity to flow through with virtually no resistance. The temperature at which it happens is called critical temperature (Tc) [12]. In 1933, German scientists Walther Meissner and Robert Ochsenfeld reported a new magnetic behaviour of tin in its superconducting state during increasing Superconductivity research. The Superconductor expels the magnetic field, as illustrated in Fig. 2-A [13], which is called "The Meissner Effect" [14]. This phenomenon significantly influences the Master's remark in a vacuum (Levitation effect). If we place small magnets on the surface of high-transmission dimensions Oberon magnet dimensions and the critical temperature, then reduce the temperature below the critical temperature (Tc). The interests will jump above the supercarrier, and the generated electric current will flow through the material's surface. This trend will, in turn, create a field magnet that will remove the initial magnetic field that is attempting to affect the ultra-carrier (see Fig. 2-B) [15-17].

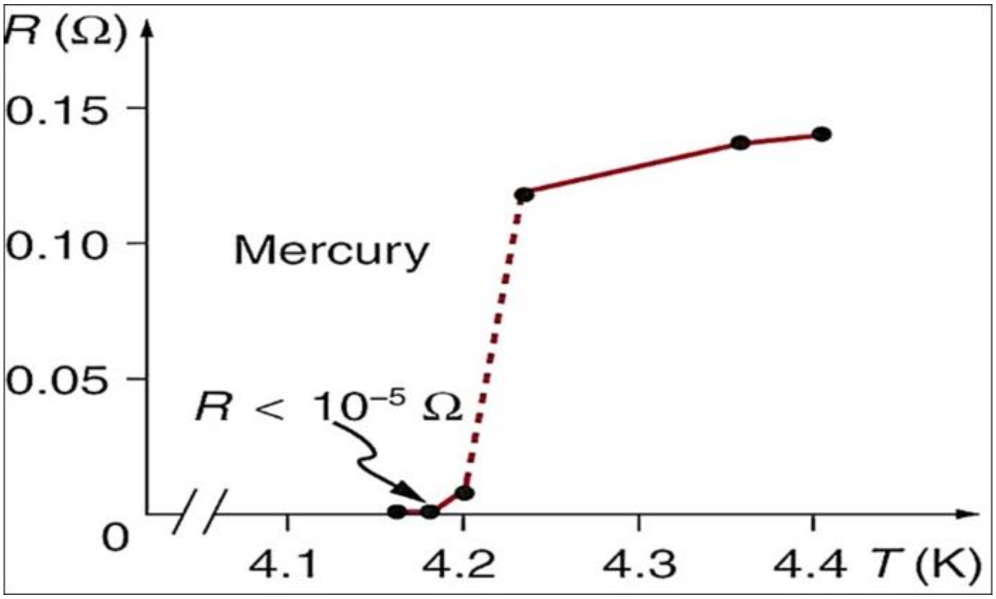

Figure 1: Mercury Superconductor transition [11].

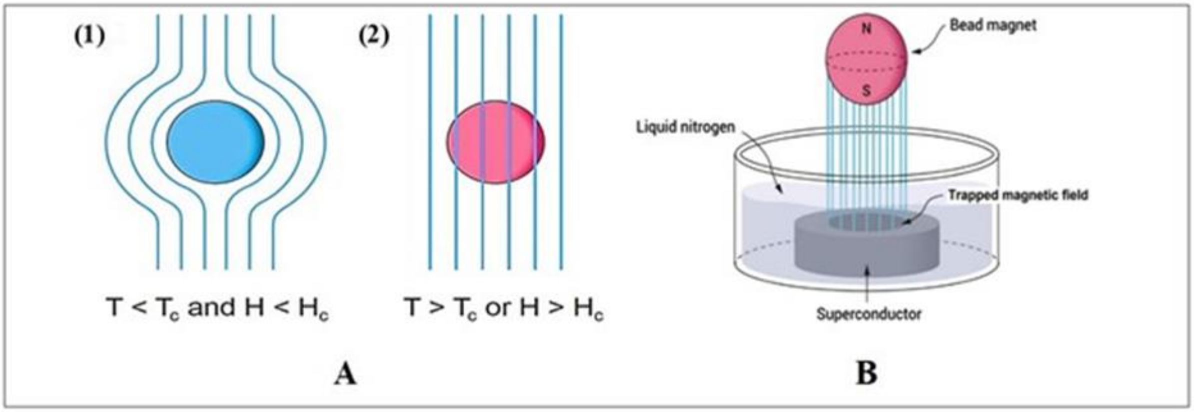

Figure 2: A-Magnetic fields in (1) Superconductor state (2) Conductor state, and B- the Meissner effect [13].

2. BCS Theory of Superconductors

Bardeen, Cooper, and Schrieffer (BCS) provided a fundamental macroscopic theory of Superconductivity in 1957, which included all initial ideas and explained recent developments [18]. The BCS theory states that electrons in a superconductor pair are due to phonons (lattice vibrations) that happen suddenly in the crystal lattice. Although electrons are ferromagnetic, when they pair, they create bosons, which are not bound by the Pauli Exclusion Principle and may condense into a single quantum state (same energy state), resulting in the Bose-Einstein Condensation. The coherence length is the distance between individual electrons in each pair, and it is a material-dependent characteristic of superconductors. BCS places restrictions on pairing, requiring that pairs of electrons have opposing spin and momentum, ensuring that momentum is constantly maintained when a pair scatters. These cooper pairs of electrons may then travel cooperatively through a crystal without losing forward momentum, resulting in Superconductivity (see Fig. 3) [19, 20].

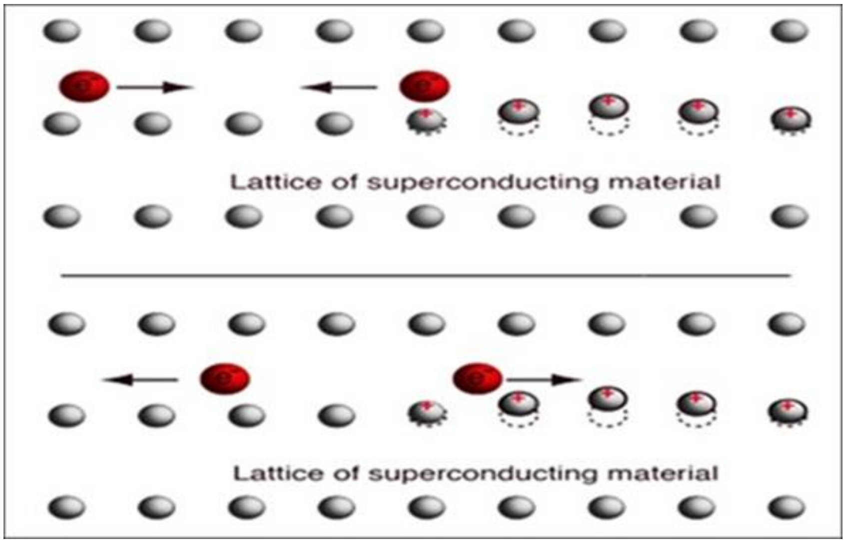

Figure 3: The generation of attractive force between electrons in a crystal. a) When an electron passes through the lattice, it attracts it and causes a little wave along its path. b) The displacement attracts another electron traveling in the opposite direction [19].

Superconductivity was initially described in quantum mechanics by BCS theory. It isn't elementary to use, yet it thoroughly explains Superconductivity from the perspective of individual particle interactions. Nonetheless, a cooper pair is a system with zero momentum and zero spins, similar to a boson, in the superconducting state and in the absence of current flow. Cooper pairs are unaffected by defects in the lattice or vibration. The pair's total momentum is zero; thus, it travels through the lattice without dispersion, resulting in zero resistance [21].

3. Discovery of High-Temperature Superconductivity (HTS)

George Bednorz and Karl Müller of IBM Zurich discovered Superconductivity in a perovskite-structured lanthanum-based cuprates oxide with a Tc of 35 °K in 1986, and the scientists were awarded the Physical Noble Prize in 1987 for their achievement. This was a significant discovery because it enabled chemical substitution in perovskite cuprates to raise the transition temperatures far beyond the temperature of liquid Nitrogen (77 K), which is a considerably less expensive and accessible medium than liquid helium [22]. After then, there was a significant jump. Superconductivity was discovered at temperatures over 90 °K. This was achieved by exchanging Y for La, resulting in YBCO with a Tc of 92 K, first shown by Wu and his team at the University of Alabama Huntsville in 1987. The materials exhibit the largest Tc when slightly faulty oxygen components, i.e., x = 0.15. Superconductivity vanishes at x ~ 0.6 when the structure of YBCO changes from orthorhombic to tetragonal [23, 24]. Other oxides, such as thallium and mercury-based oxide compounds, have shown even higher critical temperatures [25-27]. Fig. 4 depicts the remarkable change in the field over a short period as a graph of a transition temperature vs time [28]. High-temperature superconductors belong to the Type-II superconductors family, with a progressive shift in critical temperature as a function of the magnetic field. A lot of work has gone into establishing a theory for high-temperature Superconductivity, and as a result, a few mechanisms have been suggested, two of which are widely accepted. The first mechanism depends on the antiferromagnetic spin fluctuations in a doped system like cuprates. Spin fluctuation investigations indicate the symmetry of the pairing wave function, which should be of the kind d_{x2-y2} for cuprates. The second concept is the interlayer coupling theory, which says that Superconductivity may be increased by itself in a layered structure with BCS-type symmetry, i.e., s-wave symmetry. However, these concepts fall short of thoroughly explaining high-temperature Superconductivity, and no explicit agreement emerges [29] [30].

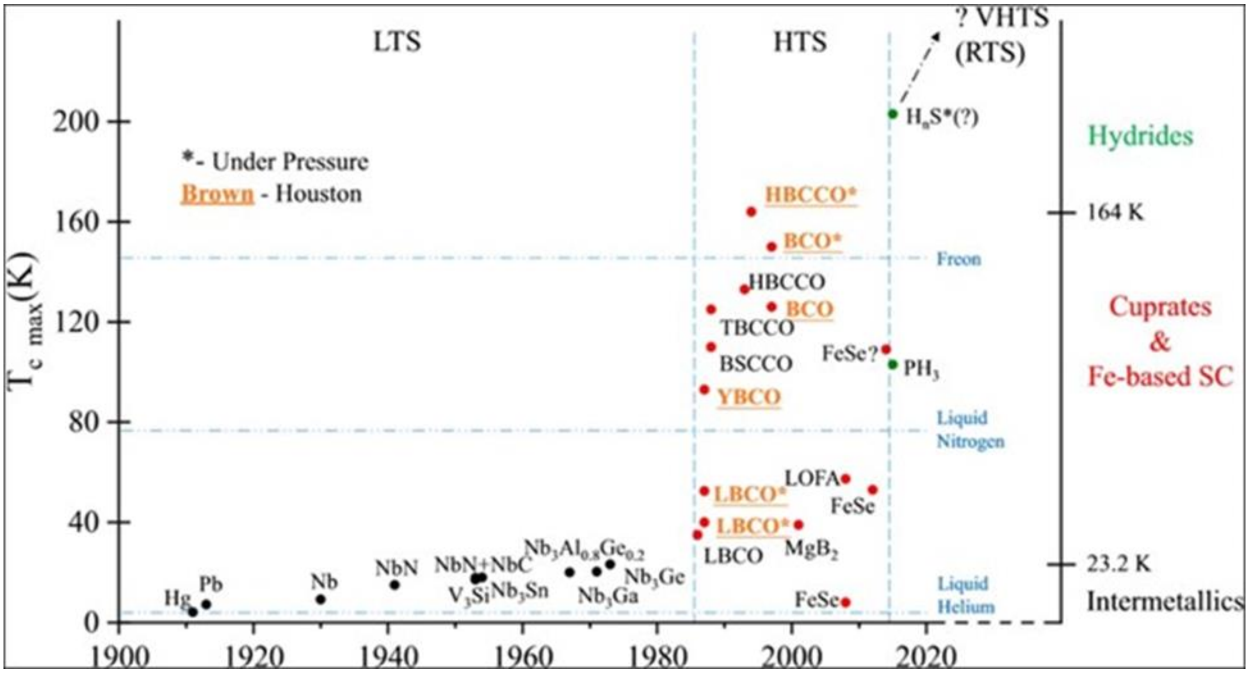

Figure 4: A graph of critical temperature vs. time [28].

4. Classifications of Superconductors

4.1 Based on Critical Temperature (Tc)

Low-Temperature Superconductor (LTS): Refer to materials with critical temperatures below the boiling point of Liquid Nitrogen (LN) at 77 K.

High-Temperature Superconductor (HTS): Become a Superconductor above the boiling point of Liquid Nitrogen (LN) at 77 K. This condition is used to see whether we can freeze the sample using liquid Nitrogen (which has a boiling point of 77 K), which is a lot easier than liquid helium (which is the only way to get the temperatures needed for low-temperature Superconductors) [31] [32].

4.2 Theoretical Basis

According to the BCS theory (J. Bardeen, L. Cooper, and J. Schrieffer), they are categorized as:
Conventional: They are low Tc superconductors since they are modelled by BCS theory and have a low Tc. Unconventional: They disagree with the BCS theory. They are known as high Tc superconductors because their Tc is more remarkable than regular superconductors. This concept is significant because the BCS theory has been used to describe the characteristics of conventional superconductors since 1957; no unified theory has been created to explain the properties of completely unconventional superconductors. Most Type-I superconductors are traditional, although a few exceptions, such as niobium, are both conventional and Type -II.

4.3 Based on Magnetic Response (Hc)

Type -I: It has a single critical magnetic field (Hc) and the same features as Type-I superconductors, such as zero resistivity below the critical temperature, zero internal magnetic fields (Meissner effect), and a critical magnetic field Hc beyond which Superconductivity disappears. The transition from Superconductor to normal state is abrupt in this situation. These superconductors follow the BCS theory of electron pairing due to lattice vibration. Because the Hc and Tc are so low, they can only be employed in certain circumstances.

Type -II: Two critical magnetic fields (H_{c1}, H_{c2}), that the material exhibits perfect diamagnetism and no flux penetration for a field less than H_{c1}. Flux penetrates the material after Hc1 and increases before H_{c2}. At H_{c2}, the material loses its magnetism and becomes a natural conductor [13] [33].

4.4 Materials Based

- Pure elements, for example (mercury (Hg) and lead (Pb)). However, not all pure elements are superconductors, and some cannot acquire this state.
- Alloys, such as (Niobium-Titanium (NbTi) and Germanium-Niobium (Nb3Ge)).
- Ceramics, Like (YBCO, BSCCO).
- Organic superconductors, likes (fullerenes (C60) and carbon nanotubes (C)).

5. Y-Ba-Cu-O Compound

YBCO is a group of crystalline chemical compounds known for their Superconductivity at high temperatures. It considers the first compound to become superconducting above the boiling point of liquid Nitrogen (77 °K), at about 92 °K [34-37]. YBCO is a second-generation (2G) high-temperature Superconductor, and it is characterized as a ceramic oxide and relates to the cuprates group [38, 39] [40, 41]. YBCO compounds have the standard formula $YBa_2Cu_3O_{7-x}$ (also referred to as Y-123), but materials with other Y: Ba: Cu ratios exist, such as $YBa_2Cu_4O_y$ (Y-124) or $Y_2Ba_4Cu_7O_y$ (Y-247). There are currently no standard primary principles for high-temperature Superconductivity. YBCO crystallized in a flawed perovskite structure consisting of layers. The boundaries of each layer are determined by planes of square planar CuO_4 units having four corners. The planes are sometimes slightly puckered. Perpendicular to these CuO_4 planes is CuO_2 bands having two corners. The yttrium atoms are observed between the CuO_4 planes, while the barium atoms are observed between the CuO_2 strands and the CuO_4 planes [42, 43]. Fig. 5 presents this structural characteristic. The oxygen concentration of the YBCO compound varies greatly, which has a significant effect on the superconducting properties [44]. Materials having fewer than seven oxygen atoms per formula unit are non-stoichiometric compounds, even though $YBa_2Cu_3O_{7-x}$ is a well-defined chemical compound with a particular structure and stoichiometry. The x in the chemical formula $YBa_2Cu_3O_{7-x}$ denotes the non-stoichiometry when x = 1, the $Cu_{(1)}$ layer's $O_{(1)}$ sites are empty and the tetragonal structure YBCO in its tetragonal form is non-superconducting and insulating. When the oxygen concentration is increased significantly, more $O_{(1)}$ sites get inhabited. Cu-O chains arise along the crystal's b axis for x = 0.65. The structure becomes orthorhombic when the b axis is lengthened, with lattice parameters of a = 3.82, b = 3.89, and c = 11.68. Whenever x ~ 0.07, nearly all of the $O_{(1)}$ sites are occupied with minimal holes, and excellent superconducting characteristics exist [45-48].

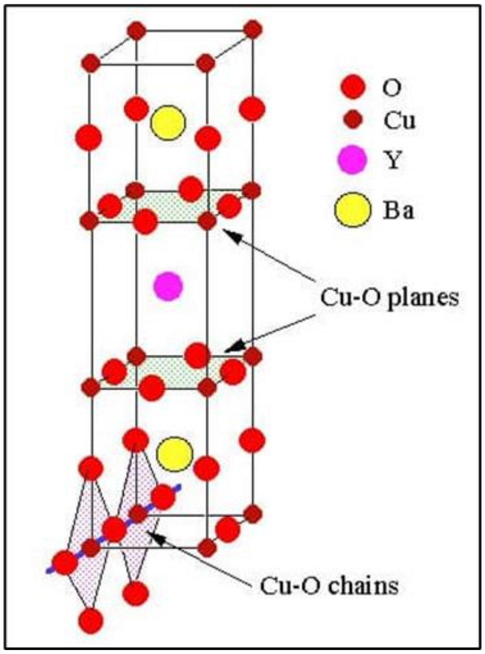

Figure 5: Part of the lattice structure of Y-Ba-Cu-O [44].

6. Appropriate Method for Prepare Y-Ba-Cu-O Oxide

YBCO was produced initially by heating a combination of metal carbonates between 1000 and 1300 K. Advanced syntheses of YBCO were using the related oxides and nitrates. The characteristics of YBCO are affected by the crystallization techniques utilized and sensitivity to the stoichiometric ratio of oxygen. Care should be taken to sinter YBCO. Because YBCO is a crystalline material, the best superconductive characteristics are achieved by carefully aligning crystal grain boundaries by controlling annealing and quenching temperature rates. Since the discovery of YBCO, many additional techniques for producing YBCO have emerged, including Chemical Vapor deposition (CVD), Sol-Gel, Citrate Pyrolysis, and Aerosol Processes. These alternative techniques still need careful sintering to create a high-quality result [39, 49-52]. This study will use Sol-gel and Citrate pyrolysis methods to produce a high-temperature YBCO compound.

6.1 Sol-gel Method

The sol-gel technique is a flexible chemical solution for making solid materials from small molecules. The method is used for the fabrication of ceramic and glass materials. The procedure entails changing monomers into a colloidal solution (called a sol) that serves as a precursor for forming an integrated network (or gel) of microparticles or network polymers [6] [53]. The principle of the Sol-gel technique was, shown in Fig. 6, generally characterized by five main steps: hydrolysis, polycondensation/condensation, aging/growth of particles, gel formation, and drying and heat decomposition. These processes are influenced by several experimental parameters such as pH, temperature, the concentration of the reactants, and the presence of additives. Traditional precursors for the sol-gel process are made to find less toxic and more environmentally friendly precursors [54].

In this process, small-sized initial sol particles were formed through a series of hydration and poly-condensation reactions (dissolved in an organic solvent to form a homogeneous solution with the addition of chelating agents). During age, the sol will continue to react chemically, and sol particles agglomerate to become significant. Followed by drying, thermal decomposition, and calcining treatment. The chemical solution deposition technique, sometimes called the sol-gel method, has been used in many fields of materials science to prepare metal oxides in the form of nanoparticles. One advantage of the sol-gel technique is that it is an easy and very cheap process to prepare metal oxides and allows control over the doping process or addition of transition metals, compared to other preparation techniques. Another advantage of the sol-gel process is that it can be controlled to obtain the required oxide with a high degree of homogeneity and Purity. In addition, small quantities of dopants can be introduced into the chemical solution and incorporated into the final product. This method is also distinguished because the desired metal oxide can be synthesized at lower temperatures, making it a suitable method. It is able also to obtain uniform and small-sized powders. Consequently, it has become a widespread technique widely accepted in scientific research [54-56].

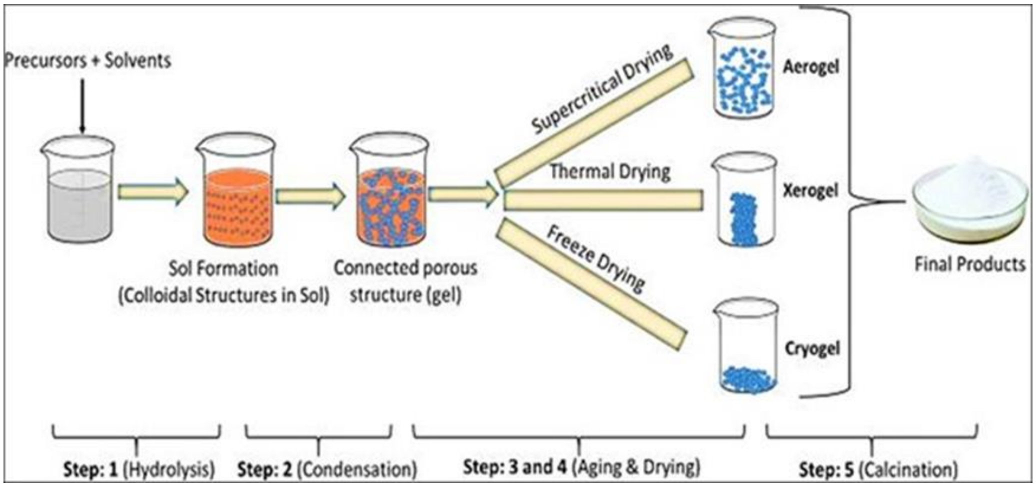

Figure 6: The steps in the synthesis of YBCO using the sol-gel method [54].

The sol-gel technique is widely used in nanotechnology applications for the following reasons [57]:

- This process consumes less energy and is also an eco-friendly process.
- The Sol-Gel process uses fewer precursors for preparing the solution.
- High Purity and controlled synthesis process.
- The Sol-Gel method of thin-film deposition is cheap.
- Allow control over the doping process.
- Allow maintaining the pH during the reaction.

6.2 Citrate Pyrolysis Method

The citrate pyrolysis technique was discovered in 1987 and proved more stable than the traditional solid-state reaction. Pyrolysis is thermal decomposition occurring in the absence of oxygen gas. It is always the first step in combustion and gasification processes, followed by total or partial oxidation of the primary products. The principle of the citrate pyrolysis technique is shown in Fig. 7 [58]. A citrate pyrolysis technique is a unique route to prepare reactive precursor mixtures through an ignition process of a concentrated aqueous solution including metallic ions of stoichiometric composition. This procedure enables it to synthesize highly [59].

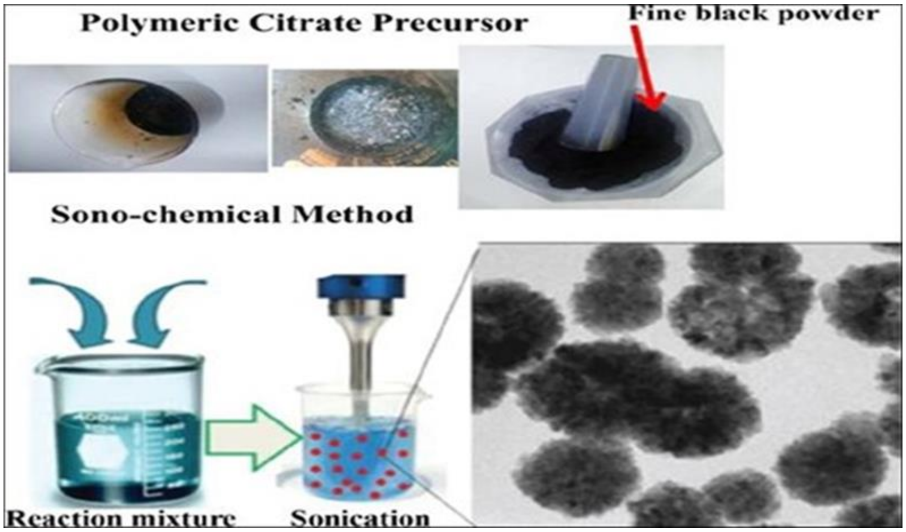

Figure 7: Illustration of Citrate Pyrolysis Technique [58].

7. Literature Survey of Bi-Pb-Sr-Ca-Cu-O System

This part will show some recent studies on the YBCO compound that have received much attention in the latest years. Specifically, the literature survey focuses on preparing the High-Temperature Superconducting Y-Ba-Cu-O compound using the Sol-Gel and Citrate Pyrolysis methods" and comparing them. These recent studies are summarized in Table 1 following.

Table 1: Presents some recent studies on the BSCCO compound and its preparation as powder and thin film.

Submitted Year	Method	Component Results	Application References
Preparation of YBCO Compound by Sol-Gel method			
2002	Influence of PH parameter during sol-gel synthesis on the phase purity, elemental composition, and electrical properties of YBCO compound	According to the data, the best YBCO samples were made by keeping the pH of the sol solution between 5.5 and 6.0. All specimens had different impurity phases if no complexing agent was utilized in the system during the sol-gel process. The findings of the synthesized samples' elemental analysis and electrical characteristics correlate well with the metal speciation analysis and powder XRD analysis data.	[60]
2013	Influence of initial pH on the microstructure of YBCO superconducting material	According to the findings, the best YBCO samples were obtained by maintaining a pH of 6.5 in the sol solution; the precursor solution had the lowest resistance at this pH, signifying excellent ionization of the beginning metal components.	[61]
2019	Investigate the characteristics of a YBCO superconducting ceramic prepared using a one-pot synthesis method in only two stages and a few hours	There was no requirement for pH or temperature control in this synthesis. No chelating agents or polymerization components were utilized, which added a lot of contaminants like the Pechini Method. In the one-pot method provided here, we have a production rate of 2.0 instead of 0.15 when comparing the weight of the ceramic powders and the quantity of polymer employed.	[62]
2021	Synthesis and characterization of the bulk YBCO-target of superconducting material	According to the findings, a calcination temperature of 850 °C and a sintering temperature of about 950 °C for 5 hours were employed to produce bulk superconductor materials. The critical transition temperature (Tc) of roughly 93 °K might characterize YBCO. YBCO samples exhibit an orthorhombic crystal structure, according to the structural characterizations.	[63]
Preparation of YBCO Compound by Citrate Pyrolysis Method			
2008	The study on various sintering temperatures on YBCO superconducting oxides powder preparation	YBCO samples are synthesized for 4 hours at four specific calcination temperatures of 880, 900, 920, and 950 °C. For this procedure, the best calcination temperatures are 900 and 920 degrees Celsius, respectively.	[64]
2013	Synthesis of YBCO-high temperature superconductor using citrate pyrolysis method	According to heat treatment processing of YBCO samples, the optimal calcination and sintering temperatures were 900 °C for a specified period of 24 hours. The only purpose of this heat treatment is to raise the compound's oxygen concentration.	[65]
2016	Synthesis of YBCO superconductor powder using citrate pyrolysis method	The resultant black powder was sintered at 510 °C using Spark Plasma Sintering (SPS) after calcination at 900 °C and vacuum at a uniaxial pressure of 12 MPa.	[66]

8. Technological Application of HTS Materials

Superconductivity has received great expectations for modern applications since its discovery in 1911. However, scientists had to overcome many challenges to convert these materials into usable conductors. Superconducting technologies have been an established industry for more than a century, providing over 7 BCHF each year to the medical and high-energy physics sectors. Still, there is a potential for many times that amount in the clean energy area power applications [67-71]. As a result of the above, many novel applications in the following areas are being developed:

8.1 Magnetic Levitation Trains (Maglev)

Maglev trains utilize magnetism to float above the tracks on which they move. They are more beneficial to the environment, quicker, and more efficient than traditional wheeled trains. They also do not depend on traction or friction, have faster acceleration and deceleration than conventional trains, and are not influenced by the weather. The energy required for levitation does not account for a significant portion of the total energy used; as with any high-speed mode of transportation, most of the energy consumed is utilized to overcome air resistance (drag). These trains may travel at higher speeds for more extended periods than regular trains, carrying more passengers [72] (see Fig. 8 [73]). Magnetic levitation has significantly advanced and efficient technology. It may be used for industrial, office, and household purposes, such as constructing fans, transportation, weapons (guns, rockets), nuclear reactors, civil engineering elevators, toys, and pens. As a result, it has a wide range of applications in use throughout the globe. It provides pure energy, and its whole application eliminates touch, resulting in zero friction. The system's efficiency and longevity are improved via magnetic levitation. It cuts down on the system's maintenance expenses. As a result, we may conclude that flying trains and automobiles are the way of the future. Rail travel is the quickest mode of transit [74].

Figure 8: Magnetic Levitation Trains (Maglev) [73].

8.2 Superconducting Quantum Interference Device (SQUID)

SQUID is the most sensitive sensor for detecting magnetic flux. They were used in many application areas, such as susceptometry, nuclear magnetic resonance, non-destructive evaluation, biomagnetism, scanning SQUID microscopy, etc. Other potential uses include the lossless storage of electrical energy, the construction of superconducting computers, non-invasive fruit quality monitoring, and so on. Although low-temperature (Low-Tc) SQUIDs are utilized in the applications above, the development of high-temperature superconductors (materials with a critical temperature in the range of 100 °K) has made the manufacturing and usage of these devices more practical. From developing YBCO thin films through device characteristics, quality optimization, and applications [75-81] (see Fig. 9 [82]).

8.3 Magnetic Resonance Imaging (MRI)

MRI is a non-invasive medical imaging method that produces detailed and high-resolution pictures and other relevant functional data for clinical diagnosis (see Fig. 10). The central field of the MR magnet has increased significantly over the past several decades, from a low of 0.35 T to 3 T and more significant, making it the most commercially viable use of Superconductivity [83-87].

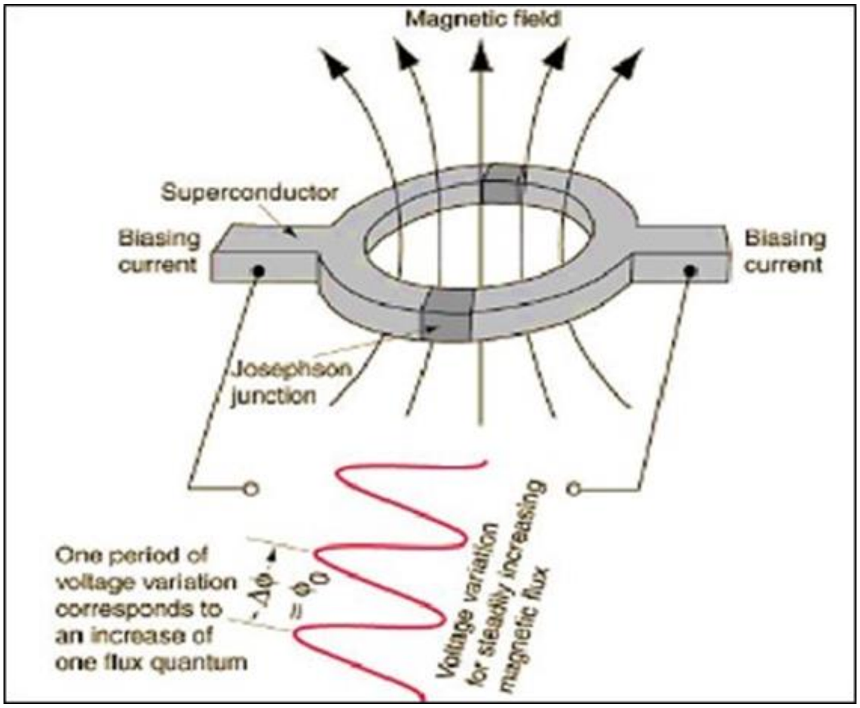

Figure 9: the schematic architecture of a SQUID sensor's core element [82].

Figure 10: MRI device for medical applications.

8.4 Superconducting Power Transmission Cables

The use of superconducting power transmission cables has progressed to the industrial level. Cable operation with a liquid nitrogen cooling system is possible because of high-temperature superconductor tapes. The need for such components in an electrical network is apparent, particularly for mitigating the effects of fault occurrences. Integrating a high-voltage cable into a network is always a unique situation, and various designs for superconducting cables are currently available to meet the technical and environmental criteria [31, 71, 88, 89] (see Fig. 11 [90]).

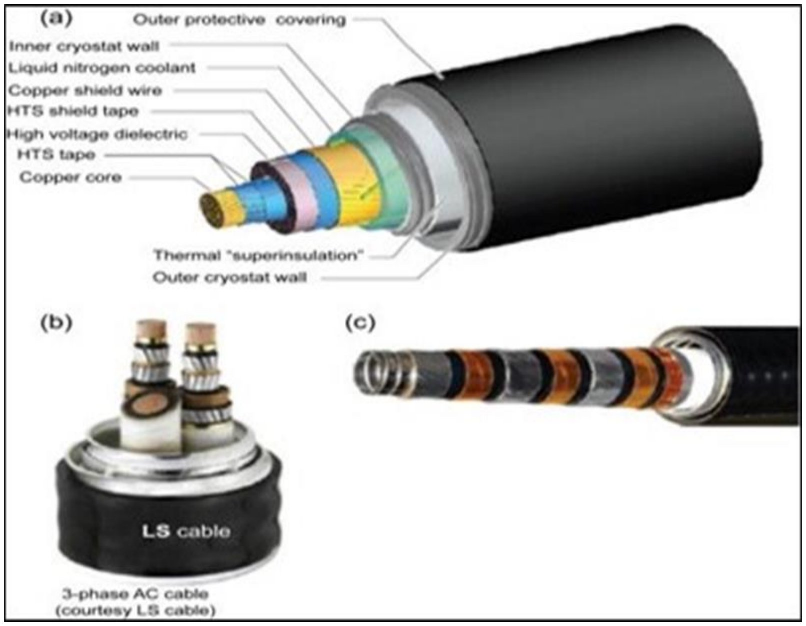

Figure 11: Typical HTS superconducting power transmission Cable Structure [90].

5. Conclusions

In this review, we provide a brief description of the phenomenon of Superconductivity over the last century, from its discovery to high temperature and their types and their life applications. It shows zero resistance and repulsion of the magnetic fields when cooling to critical temperature (Tc). The article has discussed the inadequacy of explanation of the BCS theory of Superconductivity regarding unconventional Superconductors. The theoretical basis of high-temperature Superconductivity is still uncertain. However, the critical temperature of superconducting materials has been gradually increasing and is still not approaching room temperature. The renaissance of superconductivity could apply in the future with radical breakthroughs differently and beautifully in various possible fields, like nanotechnology, computer, communication, IT, entertainment, clean energy, transportation, and many more. This shows the history of Superconductivity has been full of surprises and is a stimulating and continuing problem of Physics. In addition to focusing on preparing the YBCO compound using Sol-Gel and Citrate Pyrolysis Methods. Because of its significant advantages, it has been widely used in many modern techniques based on high-temperature Superconductors; in particular, it has been employed in the optoelectronics industries. This promising technology heralds a massive leap in all branches of science and engineering, and we predict that it will cast a shadow over all areas of life in the future. It will allow us to produce high-efficiency equipment and technologies that herald advanced and new uses to improve human life and activities.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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