Journal of Applied Sciences and Nanotechnology, Vol. 2, No. 3 (2022)

Journal of Applied Sciences and Nanotechnology

Journal homepage: https://jasn.uotechnology.edu.iq/

Characterization of Superconductor Materials Doped with Nanoparticles on Their Properties: Review Article

[1]Hanan H. Kadhim*, [1]Noor Hasan, [2]Adawiya J. Haider

[1]Branch of Physics, Department of Applied Sciences, University of Technology – Iraq

[2]Branch of Laser Science & Technology, Department of Applied Sciences, University of Technology – Iraq

Article information

Article history:
Received: November, 13, 2021
Accepted: February, 16, 2022
Available online: September, 10, 2022

Keywords:
Superconductivity,
BSCCO compound,
HTS,
PLD,
Optoelectronics device

Corresponding Author:
Hanan H. Kadhim
hananhafeath@gmail.com

Abstract

Revolutionary developments have been started in the field of superconductors since their discovery. High-temperature superconductors have been a focus of attention in advanced technology for many scientists because of their potential applications. Therefore, many changes are made in the products that use such materials. It remains one of the most exciting research fields and can revolutionize the physics and technology of the future. It is required to understand and learn the history and basic principles of Superconductivity for its better implications. Considering its recent discoveries, its current applications can be studied. The mechanism of 'HTS' is much easier to understand after the significant development made in the field of Superconductivity. The purpose of this work is to better understand and appreciate research in the field of Superconductors. Basically, HTS has been used in many areas, but much progress is needed. HTS can be used in optoelectronics technologies and countless other applications after the effects seen by such improvements. In particular, this review focuses on the high-temperature BSCCO compound and its manufacture by the Solid-State reaction method and the PLD technique, which could be useful to electronics technology, particularly optoelectronic devices applications. Superconducting electronics devices have a lot of promise for future high-efficiency optoelectronics.

DOI: 10.53293/jasn.2022.4435.1109, Department of Applied Sciences, University of Technology

1. Introduction

Nanotechnology is an advanced field that includes manufacturing, processing, and applying many structures, devices, and systems consisting of small units on the scale of atoms and molecules with a diameter of fewer than 100 nanometres, referred to as "Nanoparticles". These nanoparticles are distinguished from bulk materials by their distinct properties, including their small size, specific chemical composition, surface structure, chemical response, high electrical conductivity, strong magnetism, optical effects, and mechanical strength. These distinguishing characteristics have aided the development of modern systems and devices that may be employed in a wide range of applications [1-4].

This work gives a brief overview of Superconducting materials, their characteristics in terms of electrical behaviour (zero resistance) and magnetic behaviour (expulsion of external magnetic field), the fundamental theories on which they are based, and their approach to nanotechnology. Besides, the focus is on preparing the high-temperature BSCCO compound and its applications in optoelectronics. The research on Superconducting electronics is valuable and essential, especially concerning optoelectronics. Superconducting optoelectronics devices exhibit considerable potential for application in future, such as transistors, diodes, electrodes, solar cells, sensors, etc. Due to its distinct benefits, such as quicker processing, smaller size, less weight, and reduced power consumption [5,7].

From this point, the discovery of Superconductivity began on April 8, 1911, when physicist H. K. Onnes and his colleagues at Leiden University's cryogenic laboratory in the Netherlands discovered a strange property by studying the resistance of solid mercury at low temperatures using the recently discovered liquid helium “LHe” as a cooling system, which observed that the resistivity of a mercury element (Hg) is dropped to zero at 4.2 ºK or -268.8 °C. This phenomenon is known as Superconductivity, which means that when a material's temperature lowers, its electrical resistance disappears, allowing current to pass through it without friction or loss in value. In this case, the conductivity of these materials becomes infinite. This transition is both sudden and sharp (as shown in Fig. 1), and the temperature at which it occurs is referred to as critical temperature/transition temperature (Abbreviated as Tc) [8,10]. Electrical resistance has a significant impact on our everyday lives, whether immediately apparent or not. This resistance causes a big waste of electrical energy in all ordinary materials. This loss comes at a financial cost and limits all systems based on electricity by causing these devices to overheat and sometimes fail. As a result, the prevailing belief was the impossibility of the absence of electrical resistance in these materials at low temperatures, even at absolute zero, due to the inability to produce perfect materials without crystalline flaws. Still, after discovering the phenomenon of Superconductivity, this barrier was broken, and it became possible to create materials without resistance and energy loss [11,12].

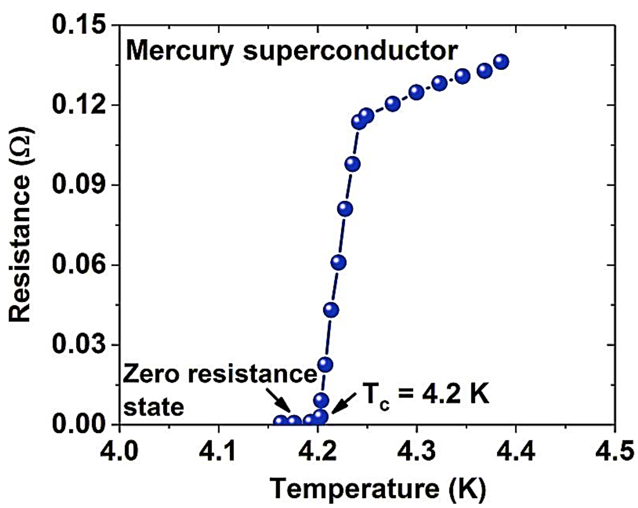

Figure 1: Illustration of Kamerlingh Onnes’ discovery of superconductivity and disappearance of the electrical resistivity of Hg element (in 1911).

The subsequent significant discovery was in 1933 by German researchers W. Meissner & R. Ochsenfeld; they found that the superconducting material does not allow magnetic flux to pass through it (B_{inside} =0). This phenomenon is termed the Meissner effect, which supports perfect diamagnetism. Fig. 2 displays a piece of magnet levitating above a superconductive material due to the Meissner effect. As a result, the magnetic flux that passes through the material is entirely ejected [13,14].

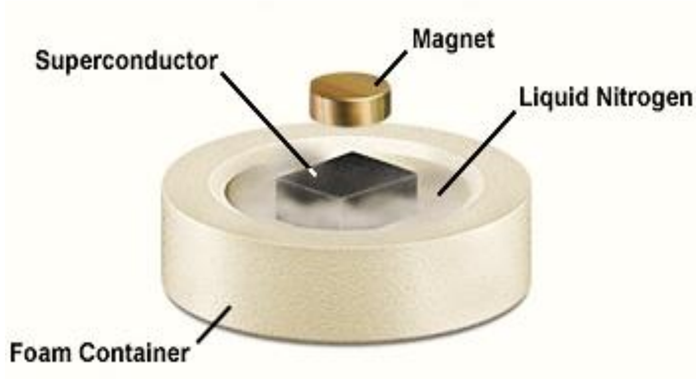

Figure 2: Meissner Effect in Superconducting state.

2. Types of Superconductors

Superconducting materials are classified into two types based on their behaviour in a magnetic field [15]:

Type-I Superconductors (Soft) have one critical magnetic field (Abbreviated as Hc). It shows zero resistance and perfect diamagnetism when cooled below its critical temperature. This implies that the magnetic flux cannot penetrate until the material reaches a maximum magnetic field (Hc), after which it loses its Superconductivity (see fig. 3 (a)).
In general, Type-I superconductors are not technologically significant because the Hc is extremely low (0.01 to 0.1 Tesla). In contrast, the field of an ordinary magnet used in an actual medical application in magnetic resonance imaging (MRI) is approximately 1.5 Tesla. In such a high field, none of the Type-I superconductors remains superconducting. This type usually comprises most pure metal superconductors.

Type-II Superconductors (Hard) have two critical magnetic fields (abbreviated as Hc_1 & Hc_2). At low magnetic fields below Hc_1, they behave similarly to Type-I Superconductors. The Superconductor is returned into its conductor state at magnetic fields greater than Hc_2. Between the lower critical magnetic field Hc_1 and the upper critical magnetic field Hc_2, the flux density ($B_{inside} = 0$) and the Meissner effect are stated to be incomplete (see fig. 3 (b)). The amount of Hc_2 maybe 100 times more than the critical magnetic field Hc determined from the transition's thermodynamics. The Superconductor is considered in the **vortex state** [16] in the magnetic field between Hc_1 and Hc_2, where flux lines thread the Superconductor.
Almost all technologically significant superconductors, including the new High-Temperature materials, are type-II.

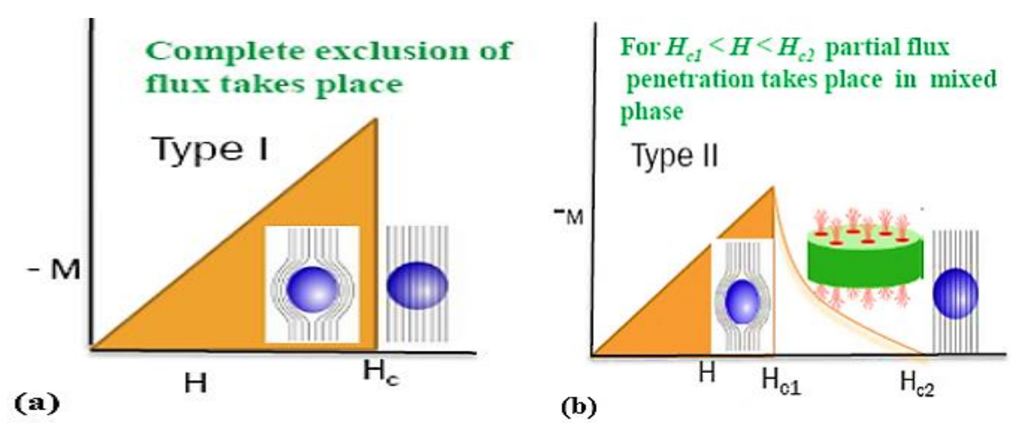

Figure 3: Variation in a critical magnetic field with temperature for **a)** Type-I superconductors and **b)** Type-II superconductors.

3. Superconductor theory

F. London & H. London presented a theoretical description in 1935. They hypothesized that supercurrent and magnetic field potential were proportional. The London equations described perfect conductance and flux expulsion [17]. Ginzburg-Landau developed the Ginzburg-Landau theory (GL) in 1950 to describe microscopic superconductor phenomena [18]. It was suggested as a solution to manage second-order phase transitions in principle. The concept extends the free energy near the transition as a polynomial with an order parameter. The density of electron pairs is the order parameter in superconductors. This Theory allows the study of various superconducting phenomena, including superconducting oscillations. The GL theory managed to win general acceptance only after Gorkov showed that it could be derived from the BCS theory. In many cases, the GL theory has replaced the more complex BCS theory [19]. The reality is that the ideal critical temperature (Tc) is now larger than (77 °K or -196 °C), the boiling point of Liquid Nitrogen "LN_2" that makes cooling the material much more accessible. Previously, LHe had to be utilized, ten times more expensive and more challenging to manage. A theoretical explanation of Superconductivity was not discovered until 1957, when three significant scientists, J. Barden, L. Cooper, and J. R. Schrieffer, developed the only successful Microscopic Theory of Superconductivity based on electron pairing, known as the BCS theory. The BCS theory and its expansions were effective in describing ordinary Superconductors. Still, there are signs that they will fail to explain new high-temperature superconductors, where the electron pairing process is yet unknown [20].

The BCS theory's ideas may be divided into three sections, each of which explains Superconductivity:

- **i.** In the presence of an attractive force, electrons form pairs. Stable pairs of electrons with mutually opposite spins and opposing wave vectors will arise if there is an attractive contact between electrons at the Fermi surface, no matter how faint. Cooper predicted the potential of pair formation, and the pairings are known as Cooper pairs [21] (as shown in fig. 4 [22]). Each pair's spacing between conduction electrons is designated as the coherence length (ξ) and is a material-related characteristic of superconductors [23].
- **ii.** Electron attraction is generated by crystal-lattice vibration (phonons). This theory section will undoubtedly need to be changed slightly for high-temperature superconductors.
- **iii.** An energy gap appears in the electron density of states near the Fermi surface. In an oversimplified image, resistance scattering of electrons in a superconducting material needs excitation across the energy gap, which cannot occur quickly [19].

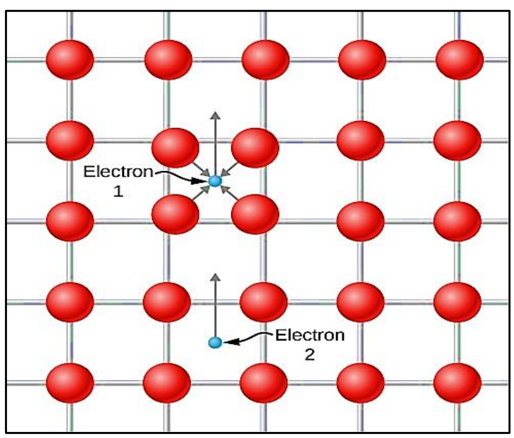

Figure 4: An illustration of the electron-phonon interaction. Electrons 1 and 2 form a Cooper pair.

The fundamental BCS theory is only valid for superconductors with weak electron-phonon interaction. There is still no credible explanation for what keeps the electrons coupled together in a Cooper pair after discovering Superconductivity in high-temperature copper oxide superconductors. The essential features of High temperature are very similar to those of traditional superconductors, namely zero electrical resistivity and magnetic shielding (Meissner effect). However, it was clear that such high critical temperatures could not be explained by electron-phonon coupling or the traditional BCS theory of Superconductivity; thus, it was speculated that pairing could be electronic or magnetic in origin. Cuprates superconductors vary from conventional superconductors by having a greater critical temperature. Still, they also have a highly complicated nature across all of their physical characteristics and display new principles of physics [24].

4. Physics of High-Temperature Superconductors (HTS)

After discovering Superconductors up to 1980, materials with critical temperatures ranging from 10 °K to 30 °K progressed gradually over decades. Hence these conventional superconductors materials were tough to commercialize until 1986. G. Bednorz and K. A. Müller of IBM Research Laboratory in Zurich, Switzerland, developed High-Temperature Superconductors materials (abbreviated High-Tc or HTS), which broke the 30 °K limitations stated by BCS theory and opened the path for commercial applications. As a result, the main goal of superconductivity research has been to achieve high temperatures [25]. Soon after, many new oxide-based superconductors were found with critical temperatures higher than 90 ºK. Fig. 5 illustrates the discovery year's corresponding to Tc of Superconducting material [26].

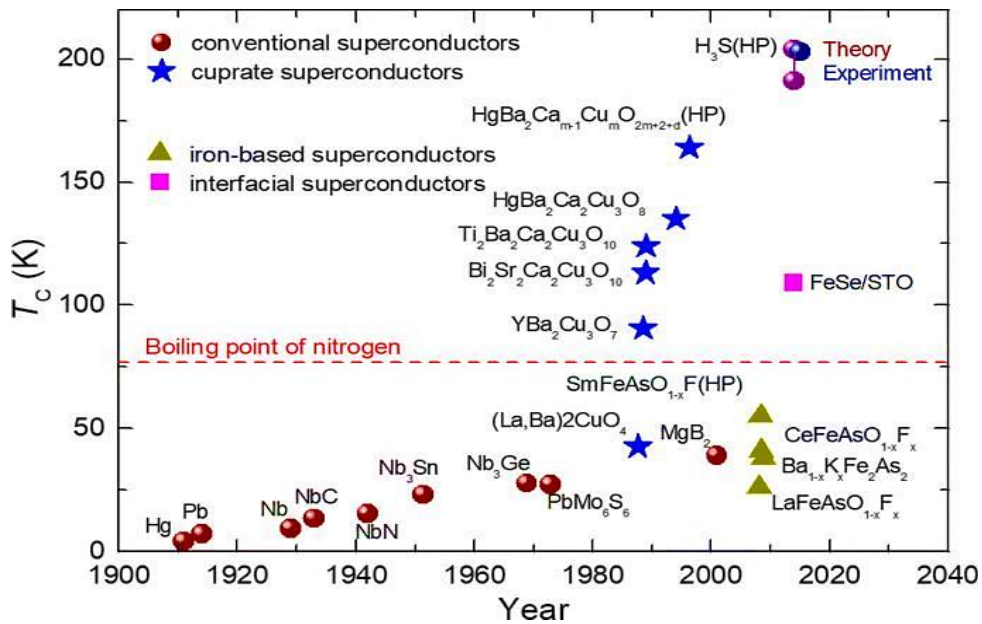

Figure 5: Discovery Time of Superconductors and Critical Temperature.

Advantages of HTS, they have a significant critical current density and an extensive critical magnetic field. This leads to increased current carrying capacity, and low resistivity allows for high energy density with minimal energy losses. Besides that, it uses LN_2 (Tc=77 ºK) for cooling rather than a more expensive LHe (Tc=4.2 ºK). LN_2 has shown to be a cost-effective option, and it is plentiful. It works as a coolant, allowing Superconductivity to be seen at lower temperatures.

High-Tc materials are easy to manufacture, and suitable raw materials, chemical precursors, and powders are available to anybody interested. It can revolutionize if we can develop materials that can be readily converted into wires/rods and desired forms rather than the conventional brittle ceramics, which are expensive and difficult to produce. Other features of Type-II superconductors materials Hc_1 and Hc_2 with technological significance are found in all high-temperature superconductors. And High-Tc displays short coherence lengths, deep penetration, and a large energy gap [27].

Recent Advances, the phrase high-temperature superconductor was identical with cuprite superconductor until Fe-based superconductors' discovery in 2008. The most well-known high-temperature superconductors at ambient pressure are Bi-Sr-Ca-Cu-O (BSCCO) and Y-Ba-Cu-O (YBCO).

Despite the excellent characteristics of High-Temperature Superconductors, scientists and researchers think that new materials or phenomena similar to Superconductivity may exist at room temperature, at an affordable and practical cost. It would be revolutionary to have a superconductor operating at room temperature. Room-temperature superconductors might replace regular conductors in almost all devices using electricity or magnetism if appropriate manufacturing techniques were available and prices were similar to standard conductors.

New materials are being developed, and progress has already been made. The 2016 Nobel Prize in Physics was given for theoretical study on topological insulator materials, showing comparable odd quantum characteristics. These materials are ideal insulators for the most part, yet they act as excellent conductors [28,29].

Attempts to make room-temperature superconductors have been done in the past. ***Eremets et al.*** (2018) [30] reported having reached Tc of (250 ºK or -23 ºC) in H_2S compound, a significant step nearer room temperature superconductivity. However, such high critical temperatures need very high pressures on the scale of 170 GPa, rendering it virtually useless for commercial purposes. Nonetheless, ***Eremet's*** concept promotes modern superconductivity techniques in which high oscillations are achieved at high temperatures in light materials while pressure maintains the material intact. Like much of the other research in HTS, this study is unproven. ***Eremets*** failed to demonstrate the Meissner effect, critical in superconductors. Superconductors that operate at room temperature are not far off. Their new applications are being investigated and commercialized.

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

This section will present some recent studies on the BSCCO compound that have received much attention in the latest years, both locally and internationally. Specifically, the literature survey focuses on preparing the High-Temperature Superconducting Bi-Pb-Sr-Ca-Cu-O compound using the Solid-State Reaction method, studying the effects of nanoparticle addition on BSCCO Superconductors, and the manufacture & characterization of the resulting mixture as a thin film using the Pulsed Laser Deposition Technique, this summarized in Table 1 below.

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

Preparation of BSCCO as powder by Solid-State method			
Year	**parameters**	**Conclusion**	**Reference**
2012	Preparation of the BSCCO-2212 superconducting crystal and study its critical temperature	According to the results, the sample with the lowest Pb dopant ratio of 0 has the highest critical temperature of 60 °K. In contrast, samples with Pb dopant ratios of 0.2 and 0.4 had critical temperatures of 57 °K and 52 °K, respectively.	[31]
2015	Study the effect of Pb substitution on $Bi_2Sr_2CaCu_2O_{8+\delta}$ Nano powders' superconducting and normal state electrical characteristics	According to the findings, the $Bi_{2-x}Pb_xSr_2CaCu_2O_{8+\delta}$ (x=0; 0.4) samples displayed diamagnetic behaviour at Tc=76 °K and 78 °K when seen using a superconducting quantum interference device (SQUID). According to the four-point probe test, the sample partly doped with Pb has lower resistivity (more metallic) than the Pb-free sample in the normal condition.	[32]
2018	Preparation of the $(Bi, Pb)_2Sr_2CaCu_2O_8$ Polycrystalline materials and study its critical temperature	It was found that the highest value of Tc, defined as the onset temperature of the shielding effect in magnetic susceptibility tests, is 102 °K for x(Pb)=0.36. However, zero resistivity is only seen below Tc_{zero} = 72 °K owing to the weak connection between crystalline grains, the surface of which is destroyed by high-temperature reduction annealing.	[33]
2021	Study the influence of Pb substitution and annealing conditions on the BSCCO superconducting properties	It was found that the Bi-2212 phase exhibits a superconducting transition temperature Tc_{on} of 77 °K and Tc_{off} of 62 °K.	[34]
Preparation of BSCCO as Thin Film by PLD technique			

2011	Study the effect of annealing temperature on Superconducting properties of BSCCO thin films	As a consequence, for annealed films at 820 °C and 860 °C, the transition temperatures are 102 °K and 90 °K, respectively. When the annealing temperature is raised over 860 °C, the low phase increases, and the high phase vanishes.	[35]
2012	Study the effect of annealing time on Superconducting properties of BSCCO thin films	As a result of this study, BSCCO superconducting films were formed after 30 minutes of post-annealing at 850 °C show a critical temperature of 52 °K. BSCCO film annealed for two hours is non-superconducting, but it may be made superconducting by annealing for four or five hours at 920 °C.	[36]
2013	Study the effect of Substrate Temperature on Growth BSCCO Thin Films	It was observed when the substrate temperature was increased through (300, 320, 350, and 400) °C. BSCCO Thin films' transition temperatures were raised to (95, 97, 110, and 112) °K, respectively.	[37]
2014	Study the influences of deposition temperature, annealing time and deposition rate on preparing of BSCCO thin films	It was shown that BSCCO thin films of high quality with excellent c-axis orientation had a critical temperature of 110 °K and a critical current density of 6.2 $X10^6$ A/cm^2 at 20 °K in 0.5 T.	[38]
2017	Study the influences of heat treatment on superconducting properties of BSCCO thin films	It was shown that the intensity of thin-film/ Si peaks increased with rising Ta up to 840 °C, whereas the intensity of thin-film/ MgO peaks decreased with increasing Ta. This demonstrates that films developed on Si substrates have superior quality and a higher Tc than films formed on MgO substrates.	[39]
2018	Study the effects of Annealing Treatment and Elemental Composition on BSCCO Thin Films Grown	It was observed that raising the annealing temperature in the range of (850, 860, 870, 880) °C increased the intensity of the low Tc phase (2201 phase). Zero resistances were found in the range of 34-68 °K, with the optimal parameters leading to the most excellent critical temperature at 870 °C.	[40]

6. Emerging Applications of HTS

Electric Power: - Superconductors can help improve the efficiency of components for electrical applications through lower losses and minimize weight & size besides implies of their potential for high power density. Furthermore, this large-scale device's dependability is more critical in this case than in other possible application areas. HTS activists are still on their way to attempting to impress electricity companies about their reliability even over a long time [41,42].

Superconductors allow a range of applications to assist our ageing and highly burdened electric power system, such as generators, motors, transformers, energy storages, switches, power cables, synchronous condensers, and fault current limiters [43]. Power cable systems are the most developed and have attracted the most attention now. In general, **power cables** are approximately ten times more costly than overhead lines. As a consequence, they can only be used in urban areas. Experiments with LHe-cooled LTS cables in the 1970s were technically practical, but their use in power grids was only economically feasible for power transfers of 5 to 10 GVA. If the wires can be adapted to existing cable tunnels, the break-even threshold for LN_2-cooled HTS cables may be lowered to 300-500 MVA. This would enable a threefold improvement in power transmission while decreasing the voltage from 400 kV to 100 kV (see fig. 6 [44]). As a result, a refit like this is particularly appealing in urban areas with rising power consumption, where no more cables can be put into the cable tunnels. The voltage has been raised to the maximum amount that may be justified. In addition to this civilian use, the US Navy is also interested in lightweight small-sized cables for battleships [42,45].

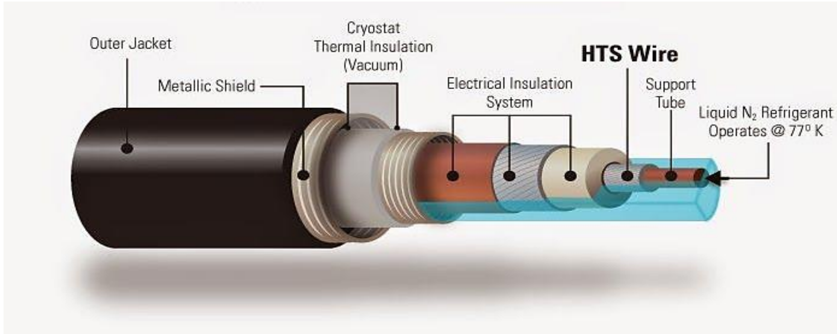

Figure 6: Typical HTS Cable Structure.

Transportation: - Superconductors constitute a new generation of transport technologies, including Magnets for levitation, propulsion, and guiding of high-speed ground vehicles (maglev); motors and generators for use in ships, aircraft, trains, and other ground vehicles; energy storage and propulsion devices for cars; and magnets for ship propulsion. Magnetic levitation "maglev" systems have attracted fantastic attention and have been the most thoroughly developed [46].

The word ***"Lavation"*** refers to a group of technologies that utilize magnetic levitation instead of wheels, axles, and bearings to move vehicles. Magnetic levitation is used to propel vehicles in maglev. A vehicle is floated up a short distance away from a "guideway" using maglev, which uses magnets to generate lift and propulsion [47].

High-speed maglev trains offer significant changes in human transport if they are widely adopted. Maglev trains go more smoothly and silently than wheeled public transportation systems. Because they don't rely on friction, they can accelerate and decelerate faster than wheeled transporters and are unaffected by weather. The energy required for levitation is usually a small proportion of total energy usage. The majority of the power is used to overcome air resistance (drag) (see fig. 7 [48]). Although traditional wheeled transportation may go at high speeds, maglev allows for more frequent usage of more incredible maximum speeds than conventional rail. This mode retains the rail transit speed record. Maglev trains may theoretically reach speeds of a different order of magnitude using vacuum tube train systems, but no such lines have ever been constructed. The economics of maglev trains vary from those of traditional wheeled trains due to variations in construction [49].

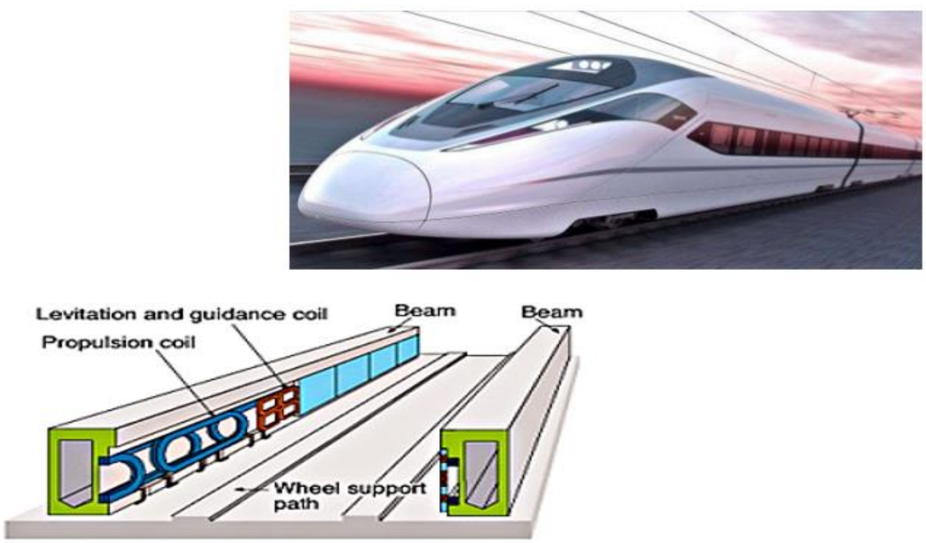

Figure 7: Sketched & Photographed of Magnetic Levitation Train.

The Medical Diagnostics & Imaging: - The most common use of Superconductivity in medicine are:

Magnetic Resonance Imaging (MRI)

MRI into the medical system has significant benefits in displaying soft tissue features of the organism's body like blood, organs, vessels, and bone. When a strong magnetic field is applied to the body, various bodily tissues may be easily differentiated (see fig. 8 [50, 51]). This fact is exploited by MRI, which generates images of cross-sectional slices of the body in which the different tissues and disorders associated with them can be identified. In many instances, MRI can diagnose a range of interior diseases without the need for invasive treatments like exploratory surgery or excessive x-ray exposure. As a result of these advantages, exploratory surgery is becoming much less common than exploratory surgery or excessive x-ray exposure. As a result of these advantages, exploratory surgery is becoming much less common [52].

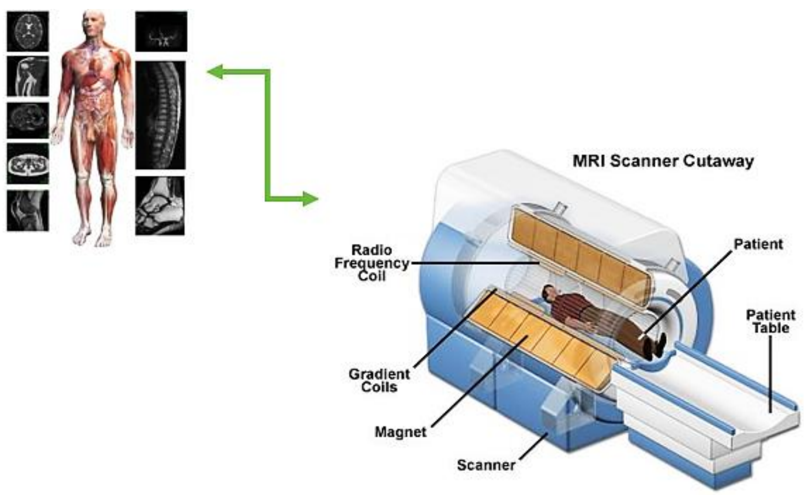

Figure 8: MRI scanner for medical applications.

In addition, MRI is more costly than rival imaging technologies such as ultrasound and x-ray CT scanning because the heart of the MRI system is made of Superconducting magnets. This Superconducting magnets significantly outperform ordinary copper magnets in magnetic field strength and stability, which are required for excellent picture quality. As are necessary for MRI, the typical field levels cannot be achieved with conventional magnets. High magnetic field homogeneity and stability are also required for the resolution, accuracy, and speed needed for cost-effective clinical imaging, and superconductors offer a unique solution to these problems. As a result, MRI has become an essential medical diagnostic tool because it gives a higher image quality for soft tissues than other diagnostics. Also, it's the only economically viable superconducting application in the world [52].

Superconducting Quantum Interference Devices (SQUID)

(SQUID) is a very sensitive detector used for detecting relatively weak signals, such as changes in the electromagnetic energy field of the human body. This detector can see magnetic fields as low as (5×10^{-18} Tesla). A SQUID can also sense energy changes 100 billion times slower than the electromagnetic energy necessary to move a compass needle [53, 54].

The superconducting materials used for low-temperature SQUIDs were pure niobium or lead alloys. To keep Superconductivity, the detector is cooled using liquid helium. High-temperature SQUIDs are manufactured from high-temperature superconductors like (YBCO, BSCCO) and cooled using LN_2, which is less expensive and more widely accessible. They are not as sensitive as low-temperature designs, but they are enough for specific applications [55].

They are excellent for sensitive applications in research, biological analyses, and medical testing where the magnetic fields present cannot be detected with conventional instruments due to their great sensitivity. SQUIDs are employed in medical diagnostics to see tiny signals in the human brain or heart by detecting the magnetic fields produced by neurological currents (see fig. 9 [56]). Construction of extremely sensitive gradiometers, magnetometers, and voltmeters are among the other uses [57, 58].

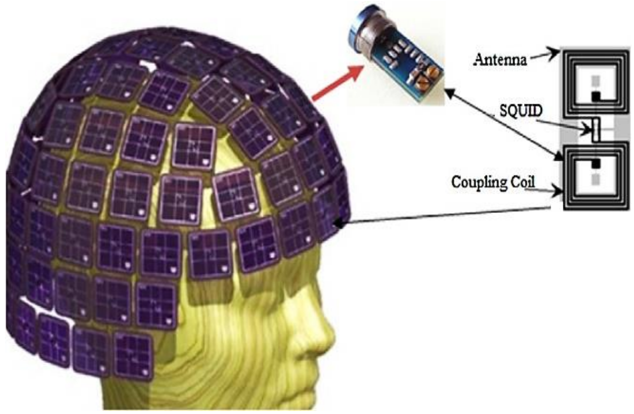

Figure 9: SQUID detector and the graphic connection of the coil in a Superconducting state.

Communications: - Presently, TV, radar, radio, and telephone contacts are restricted to a minimum frequency range in the electromagnetic spectrum as the world transitions from analogue to digital communications. Commercial stations have been at odds with rising prices for a limited number of frequency slots. Superconductivity can open up tens of thousands of additional satellite broadcast channels by allowing the millimeter and submillimeter regions of the electromagnetic spectrum to be opened up. Scientific applications involving switching devices, transmission & distribution, filters, parametric amplifiers, satellite dishes, shielding, and other receiver parts provide significant performance gains in commercial and military applications.
HTS filters have been widely used in mobile communications networks during the last decade. They improve signal-to-noise ratios, making it possible to provide dependable service with fewer, more widely spread cell towers [59] (see fig. 10 [60]).

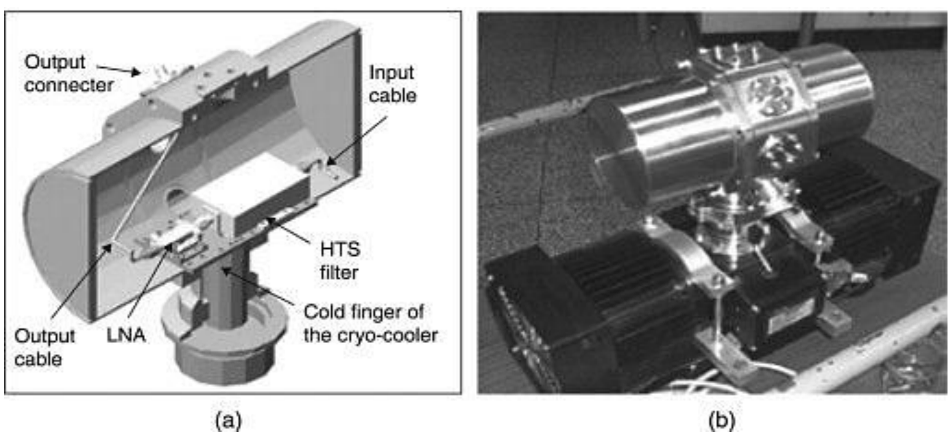

Figure 10: The HTS receiver's front-end microwave filter system, as sketched and photographed.

Scientific research: -Today's cutting-edge scientific research facilities are testing the boundaries of human understanding and investigating discoveries that may lead to new techniques ranging from nuclear fusion's clean, plentiful energy to computing at speeds far faster than silicon technology's theoretical limit. Because of their diverse structural characteristics, engineering materials are essential in daily life. Apart from these characteristics, they play a necessary function due to their physical features. Electrical, thermal, magnetic, and optical properties are some of the most important physical properties of materials. Engineering materials have a wide range of electrical properties, and their use in electrical applications is varied [61].

7. Bi-based Cuprate

Bismuth Strontium Calcium Copper Oxide (BSCCO, abbreviated *bisko*) was the first high-temperature Superconductor made without a rare earth element. Owing to its advantages, BSCCO is becoming more widely used in various fields of high-temperature superconductors.

BSCCO is a type of A cuprate superconductor that shares a two-dimensional layered Perovskite structure with the superconducting copper-oxide (CuO_2) planes. It is a unique generation of superconductors found around 1988 by ***Hiroshi Maeda*** [62] and coworkers at the National Research Center for Metallic materials in Japan; even at the time, they were unable to evaluate its detailed structure and composition. Several teams soon realized Bi-2212, including Dupont's ***Subramanian et al.*** [63] and AT&T Bell Labs' ***Cava et al. Tallon et al.*** [64], working in a government research center New Zealand, did not find the n = 3 member for another month or so. Since then, these materials have only seen modest advancements. The replacement of approximately 15% of the Bi with Pb, which significantly increased the production and quality of Bi-2223, was a crucial early advance.

BSCCO provides the high critical temperature (Tc) value and has shown more stability in superconducting Behavior way that positively oxygen failure in compared to YBCO compound and its showed either an essential Josephson influence and anisotropic (dimensional) characteristics [65, 66].

7.1 Crystal Structure of BSCCO System

BSCCO compound has the chemical formula $\mathbf{Bi_2Sr_2Ca_{n-1}Cu_nO_{2n+4+x}}$. The metallic ion numbers commonly describe specific kinds of BSCCO ('n' values). It is usually divided into four distinct structures. There have been, Tc=33 °K (n=1, **Bi-2201** phase, $Bi_2Sr_2CuO_{6+\delta}$ compound), Tc=96 °K (n=2, **Bi-2212** phase, $Bi_2Sr_2CaCu_2O_{8+\delta}$ compound), Tc=108 °K (n=3, **Bi-2223** phase, $Bi_2Sr_2Ca_2Cu_3O_{10+\delta}$ compound) and Tc=104 °K (n=4, **Bi-2224** phase, $Bi_2Sr_2Ca_2Cu_4O_{12+\delta}$ compound) [67]. The crystallography unit cell of the BSCCO crystalline structure is shown in fig.11 following [68].

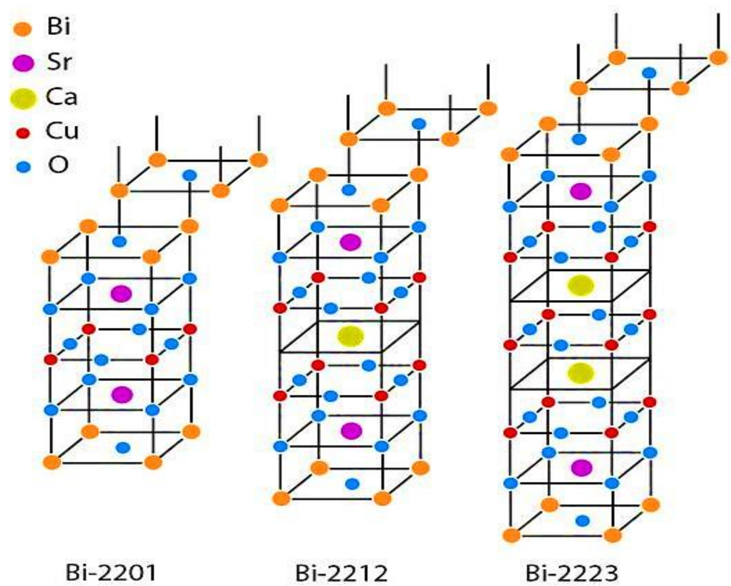

Figure 11: The crystal unit cells of BSCCO family in different phases.

Three layers make up the crystallography unit cell of a BSCCO structure. They are the "storage layer" (i.e., SrO and BiO layer) which stores electrons, the "Superconducting layers" (i.e., CuO) immediately above it that allows doping to change the properties of superconductors, and the "Isolating layer" (i.e., CaO and CuO) that above that forms the Josephson junction between them. Though the BSCCO structure is almost identical, Bi-2212 has two repeating units, but Bi-2201 has one fewer CuO_2 in each half and no Ca layer, and Bi-2223 has an additional CuO_2 and Ca layer on each side [69].

We chose the Bi-2212 phase in our work; its Tc is relatively high and easy to synthesize. They are thermodynamically suitable for a wide temperature range and within the stoichiometric content inside the Bi_2O_3-SrO-CaO-CuO structure. The Bi-2223 phase is only stable with a narrow temperature range and exhibits phase equilibrium with fewer BSCCO systems chemicals [70].

The Bi-2212 phase provides a lot of advantages over the Bi-2223 phase. Which include, among other things, a much longer single-phase area for $Bi_xSr_{3-y}Ca_yCu_2O_{8+\delta}$ where (x= 2 - 2.35) and (y= 0.7 - 1), which allows for comparatively quick production with higher degrees of phase purity and homogeneous than the Bi-2223 phase, as well as enhanced moisture stability. Nevertheless, when evaluating its potential for devices running at 77 °K, its lower critical temperature presents a significant drawback. However, because these High-Tc materials are being investigated for narrow applications at temperatures below 65 °K, the research of the Bi-2212 phase Superconductor and its production utilizing simple and effective methods is still essential at this time [71].

In the specific instance of Bi-2212, the compound becomes a Superconductor at $\delta = 0.05$ sand has a maximum Tc of about 90 °K at $\delta = 0.16$ & reveals no more superconductivity above $\delta = 0.27$ [72].

BSCCO Compound is classified as a Type-II superconductor. At 4.2 °K, the upper critical field Hc_2 in Bi-2212 polycrystalline samples was (200 ± 25 Tesla) (compared to 168 ± 26 Tesla in YBCO polycrystalline samples). Although having a greater upper critical field than YBCO, BSCCO has a considerably lower H* (usually a factor of 100 more down), limiting its utilization in high-field magnets [73].

BSCCO has a promising usage since it is readily melt processed to produce highly textural material. It offers regular superconducting current distribution along conductors such as silver sheeted tapes, wires, and long roadways [74].

8. Appropriate Methods for Preparing BSCCO Compound

One of the major problems facing researchers nowadays is creating molecules with the necessary content, structure, and characteristics. Various methods are being developed to obtain high-quality materials at a low price and in the fastest time possible. The fabrication of Compounds requires understanding crystal chemistry, thermodynamic parameters, crystalline phase, and reaction mechanism [75].

Many interested researchers were focused on enhancing the characteristics of Bi-based superconductors soon after their discovery. It is self-evident that partially replacing bismuth (Bi) with lead (Pb) improves superconducting characteristics like Jc & Tc. The particular topic of several interactions is to enhance structural stability, describe the nature of charged particles, the influence of doping concentration on the state's superconducting characteristics, the replace of distinct elements in the system, and to analyze a set of related factors, thus playing a significant role and introducing much interest in this field [76, 77].

The synthesis method must be carefully determined to regulate a chosen material's composition, structure, and morphology. It has been discovered that Bi-2212 may be prepared in a range of methods, including Solid-state synthesis, Melt process, Spray pyrolysis, and Sol-gel synthesis, etc.

The present research uses the Solid-State Reaction method to prepare the (Bi, Pb-2212) composite as a target material and Pulsed Laser Deposition Technique (PLD) to grow a BSCCO as a thin film [78].

8.1 Solid-State Reaction Method

The solid-state reaction technique is the most commonly used for preparing solid polycrystalline materials from a complex mix of raw materials. Solid particles do not react at room temperature during ordinary time scales. They must be heated to substantially higher temperatures, generally 1000 to 1500 °C, for the reaction to proceed at a reasonable pace. Reaction parameters, structural characteristics of the reagents, surface area of the materials, their reactivity, and the thermodynamic free energy change involved with the process are all variables that influence the efficiency and rate of a solid-state reaction. This technique mainly utilizes complex oxides, carbonates, nitrates, hydroxides, oxalates, alkoxides, and other metal salts to create composites [79].

The components are combined at the atomic scale in the liquid phase method, and then the lattice grows. Although the liquid phase approach provides more excellent uniformity, produces smaller particles, and needs minimal heat treatment, the solid-state reaction route technique is preferred for large-scale layered structure fabrication and gives nearly the single phase. It necessitates low-cost, widely accessible precursors, a more straightforward preparation method, and improved uniformity. Furthermore, there are no sample losses, while the specimen is highly porous in the sol-gel method contracts during sintering [80] [81]. In general, the advantages of the solid-state method over all other synthesis routes are that (1) it provides greater homogeneity, (2) it produces larger yields of the desired product, and (3) it is simple to make [82].

The following is a summary of the strategy used in the Solid-State Reaction Technique:

i. **Reagents:** These are the solid reactants where solid crystalline elements are made. The reaction parameters and expected specific product dictate the reactant chemicals employed. Before weighing, the substances are thoroughly dried. Fine-grained materials should be utilized whenever feasible since an increase in the surface area raises the reaction rate.

ii. **Weighing and Mixing:** The particles are mixed after being weighed out in the appropriate quantities. An agate mortar and pestle are often used to mix tiny amounts. A sufficient amount of a toxic organic liquid – ideally acetone or alcohol – is added to the reaction mixture to assist homogeneity. This creates a paste, which is extensively combined. The organic liquid slowly volatilizes throughout the grinding and mixing operation, and it typically evaporates entirely within 10 to 15 minutes. Mechanical mixing using a grinding machine is generally used for more than 20 g, and the procedure may take several hours.

iii. **Container materials:** A suitable container material that is chemically inert to the reactants at the influence of heat employed is required for the following reaction at high temperatures. Platinum and gold, both noble metals, are often used. Crucibles or foil boats may be used as containers. Other metals, such as Nickel (below 600 - 700 °C), may be utilized for low-temperature operations.

iv. **Heat treatment:** The heating programmed to be employed is highly dependent on the reactants' shape and reactivity. The nature of the reactant chemicals is carefully examined while controlling temperature or the environment. For heat treatment, a suitable furnace is needed. Before heating, it is preferable to pelletize samples to enhance the contact areas between the grain [83].

8.2 Pulsed Laser Deposition Technique (PLD)

The mechanism of pulsed laser deposition is a highly complex phenomenon compared to the ease whereby the system is set up. The general design of experiments for laser ablation thin film deposition is the same as any physical vapor deposition method. The PLD system comprises a vacuum chamber, a substrate holder with precise temperature control (heater), and rotational source materials (target). A typical PLD setup is shown schematically in Fig. 12 [90]. The 2nd-harmonic Nd: YAG laser beam, which generates pulses with an output wavelength of (532 nm), is utilized for target ablation in the PLD study. Changing the laser output energy or focusing the beam may change the laser flounce [84, 85].

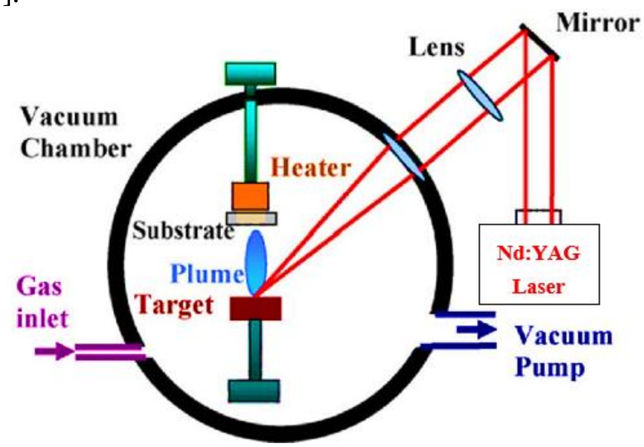

Figure 12: Schematic representation of the PLD system.

Thus, the PLD process may be divided into the following stages [86]: -

i. **Laser-Target interaction: -** In this stage, the laser beam is directed towards the target's surface. All elements on the target surface are quickly heated to their evaporation temperature when the energy density is relatively high, and the pulse length is sufficiently short. Materials are separated from the target and removed using the same composition as the target. The rate of immediate ablation is strongly dependent on the fluencies of the laser that is irradiating the target. Many complicated physical processes, including collisional, thermal, and electronic excitation, exfoliation, and hydrodynamics, are involved in ablation mechanisms.
In brief, laser-target interaction is determined by laser characteristics like pulse duration, intensity wavelength, and target properties like vaporization energy, absorption depth, specific heat, and thermal conductivity. Due to laser-target interactions, plasma with high energy species is produced by ablated materials.

ii. **Dynamic behaviour of the ablation materials: -** According to gas-dynamic principles, the released elements tend to move towards the substrate placed in front of the target in this stage, resulting in the forward peaking phenomena. The size of the laser spot and the plasma temperature significantly impact the homogeneity of the deposited layer. Another parameter that controls the angular dispersion of ablated materials is the target-to-substrate distance. It was also found that placing a shield near the substrate may minimize the spreading.

iii. **Ablation materials adhesion on the substrate: -** This stage is necessary for determining the thin film's quality. The expelled high-energy elements collide with the surface of the substrate. These energetic elements cause some surface atoms to sputter, forming a collision zone between the incident flow and the sputtered atoms. After this thermalized area (collision region) is created, the film expands quickly. The site acts as a source of particle deposition. When the deposition rate exceeds the rate of particles provided by sputtering, thermal equilibrium is rapidly achieved. The film develops on the substrate surface at the cost of direct ablation particle flow.

iv. **Nucleation and Film Growth: -** Nucleation and growth of crystallization thin films depend on multiple factors, including the density, energy, degree of ionization, and the type of the compressing material, and also the temperature and the physiochemical characteristics of the substrate. The nucleation method depends on the interfacial energies between the three phases present - substrate, the compressing material, and the vapour. A nucleus's lowest-energy form resembles a cap. The driving force, i.e., the deposition rate and the substrate temperature, determines the critical size of the nucleus. They produce isolated patches (islands) of the film on the substrates for the giant nuclei, which expand and merge due to the tiny super-saturation. The essential nucleus decreases as the super-saturation rises until its height reaches an atomic diameter and form becomes a two-dimensional layer. For foreign substrates that are not fully wetted, layer-by-layer nucleation will occur.

8.3 Suitable Substrates for BSCCO Thin Film

The term "***Substrate***" refers to the foundation material on which processing is done. This surface may make new films or material layers, such as the deposited [87].

The selection of substrates for HTS thin films is difficult because there is no perfect substrate for High-Tc Superconductor materials.

For the suitable substrate selection of Superconducting films, several factors must be considered [88]:

Chemical Compatibility: - the substrate should be chemically inert at the common deposition conditions of an oxygen-rich surrounding environment and high temperatures (650 - 850 °C). In general, oxide substrates such as $SrTiO_3$, MgO, and $LaAlO_3$ are preferable over metal substrates. There must be no interdiffusion between both the substrate and the HTS film. Inter diffusion may be prevented by depositing buffer layers on the primary substrate that do not react with the HTS films. HTS films with high Jc values over (1 MA/cm^2) may be produced on Metals, Silicon, and Sapphire utilizing oxide buffers such as Si, CeO_2, YSZ, MgO, Y_2O_3, or $SrTiO_3$.

Thermal Expansion: - to ensure sufficient film adhesion and prevent film breaking during thermal cycling, HTS films and substrates must have a good thermal expansion match. This criterion is fundamental because of the brittleness and high tensile stress of HTS films.

Lattice Mismatch: - is the source of defects in the buffer layer and the film (dislocations, islands, etc.) on the growth of the thin films. The most significant characteristics for HTS can only be achieved if the HTS films' texture is as high as feasible. Epitaxial development on single crystalline or texturized substrates is thus desired. The most significant factor is the crystallography structure of the surface layer or the surface of a buffer layer on the substrate. The atoms on the substrate must match those on the first HTS sheet. HTS films must grow c-oriented (the substrate surface is parallel to the a-b plane of the orthorhombic HTS structure) and in the a-b plane for excellent superconducting characteristics. The lattice mismatch value can be calculated by,

$$\boldsymbol{\varepsilon} = \frac{\mathbf{a\ (film) - a\ (substrate)}}{\mathbf{a\ (substrate)}}$$

Where **a** is the cell parameter.

The best HTS thin films to now, as measured by several criteria, are: critical current density, shape, and stability over time are epitaxial on their substrates. The controlled crystallographic direction of the film is relatively fundamental required for epitaxial growth. In general, this necessitates matching the lattice characteristics of the film and substrate and atomic position, and crystallographic orientation. The better specific features match, the more potential high-quality epitaxial growth will occur. Size availability and cost are other essential factors to consider when choosing a substrate, mainly if the films will be used commercially. Furthermore, to be acceptable for crystalline material, which is the most suited method for large-diameter-crystal development, the substrate materials must have melting temperatures below ~ 2100 °C [89].

Silicon substrate (Si) is chosen for this work. It has obtained a broad interest in BSCCO films deposition due to its modest dielectric constant, good thermal Expansion when matching with BSCCO, and availability. Table 2 lists the physical properties of the Si-substrates utilized in our research. However, it gives the correct deposition parameters; high-quality BSCCO films may be effectively deposited on it [90-94].

Table 2: Distinctive Properties of Si-substrate.

Substrate	Silicon (Si)
Crystal Structure	Crystalline (Cubic), a=5.430710 ˚A
Type	P-type
Orientation	<111>
Polishing	Single side polished
Thickness	0.5 mm
Density	2.4 (g/cm^3) at 25 °C
Thermal Expansion Coefficient	≤ 100 $/cm^2$
Melting Point	1420 °C
Boiling Point	3265 °C
Resistivity	0.05 ~ 0.1 Ω.cm

9. Conclusions

The paper presented the development of Superconductivity over the last century, from its discovery to high-temperature Superconductors as well as its types. The paper 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. Thirty-four years have already been passed since the discovery of high-temperature materials. 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 future with the 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.

The paper also focused on the "BSCCO compound," the first high-temperature Superconductor created without a rare earth element. Because of its significant advantages have 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. Simply said, it will allow us to produce high-efficiency equipment and technologies that herald advanced and new uses to improve human life and activities.

Acknowledgement
This work is supported by a Researches Fund of the University of Technology in Baghdad, Iraq. The authors gratefully thank the Applied Science Department and the Pulsed Laser Deposition Laboratory personnel for their assistance in preparing and analyzing our films.

Conflict of Interest

The authors declare that they have no conflict of interest.

References

[1] J. J. Ramsden, "What is Nanotechnology?," *Nanotechnol. Perceptions*, vol. 1, no. 1, pp. 3–17, 2005.
[2] A. J. Haider, F. I. Sultan, "Structural, Morphological and Random Laser Action for Dye-ZnO Nanoparticles in Polymer Films, "*International Journal of Nanoelectronics and Materials*, no. 11, pp. 97–102, 2018.

[3] A. J. Haider, F. I. Sultan, M. J. Haider, and N. M. Hadi, "Spectroscopic and Structural Properties of Zinc Oxide Nanosphere as Random Laser Medium," *Applied Physics*, pp. 125-260, 2019.
[4] A. J. Haider, R. A. Al-Rasool, A. A. Al-Tabbakh, "Structural, Morphological and Optical Properties of $LiCo_{0.5}Ni_{0.45}Ag_{0.05}O_2$ thin films," *AIP Conference Proceedings 1968*, pp. 0-8, 2019.
[5] A. P. Nikalje, "Nanotechnology and its Applications in Medicine," *Med. Chem. (Los. Angeles).*, vol. 5, no. 2, 2015.
[6] M. M. Kandil, E. Nuclear, and R. R. Authority, "The Role Of Nanotechnology in electronic Properties Of Materials." *Research Gate*," no. February 2020.
[7] M. Allsopp, A. Walters, and D. Santillo, "Nanotechnologies and Nanomaterials in Electrical and Electronic Goods: A review Of Uses and Health Concerns," *Greenpeace Res. Lab.*, no. 9, pp. 1–22, 2007, [Online]. Available: http://www.nanometer.ru/2007/12/26/nanomaterial_5521/PROP_FILE_files_1/nanotech_in_electronics_2007.pdf.
[8] H. T. Hussein, R. S. Zamel, M. S. Mohamed, and M. K. A. Mohammed, "High-Performance Fully-Ambient Air Processed Perovskite Solar Cells using Solvent Additive," *J. Phys. Chem. Solids*, vol. 149, p. 109792, 2021.
[9] A. R. Plummer, "Introduction to Solid State Physics," *Phys. Bull*., vol. 18, no. 7, pp. 233–233, 1967.
[10] M. Tinkham, "Introduction to Superconductivity.pdf." 3th ed., McGraw-Hill in New York, p. 454, 1996.
[11] K. P. Dahal, "Superconductivity: A Centenary Celebration," *Himal. Phys.*, vol. 2, pp. 26–34, 2011.
[12] R. A. Ismail, N. Hasan, and S. S. Shaker, "Preparation of $Bi_2Sr_2CaCu_2O_x$ Thin Film by Pulsed Laser Deposition for Optoelectronic Devices Application," *Silicon*, 2021
[13] T. R. Lemberger and J. Draskovic, "Theory of the Lower Critical Magnetic Field for A Two-dimensional Superconducting Film in A no uniform Field," *Phys. Rev. B-Condense. Matter Mater. Phys.*, vol. 87, no. 6, pp. 1–14, 2013.
[14] W. Meissner and R. Ochsenfeld, "A New Effect Concerning the Onset of Superconductivity," *Naturwissenschaften*, vol. 21, pp. 787–788, 1933.
[15] W. Fan, "Classification of Superconductors on Tc Map," 2009, [Online]. Available: http://arxiv.org/abs/0904.4726.
[16] V. Nahirnyak, "The Vortex Transport Properties of the Superconducting Films," pp. 1–9, 2004.
[17] M. A. Grado Caffaro and M. Grado Caffaro, "Some Comments on London Theory for Superconductors," *Act. Passive. Electron. Components*, vol. 16, no. 2, pp. 97–100, 1994.
[18] O. Klein, "Theory of Superconductivity," *Nature*, vol. 169, no. 4301, pp. 578–579, 1952.
[19] X. Chen, Z. Xu, J. Wang, Z. Jiao, and Q. Zhang, "Oxidation State of Copper and Superconductivity in the Hg-Ba-Ca-Cu-O System," *Chem. Phys. Lett.*, vol. 258, no. August, pp. 1–5, 1996.
[20] S. L. Liu, "The Activation Energy U (T, H) in Y-Based Superconductors," *J. Supercond. Nov. Magn.*, vol. 21, no. 3, pp. 199–203, 2008.
[21] T. Pavlidis, M. Ganten, B. Lehner, M. Düx, and M. Loew, "Tenoplastik Der Langen Bizepssehne Bei großem Defekt der Rotatorenmanschette," *Z. Orthop. Ihre Grenzgeb.*, vol. 141, no. 2, pp. 177–181, 2003.
[22] M. Tinkham, "Resistive Transition of High-Temperature Superconductors," *Phys. Rev. Lett.*, vol. 61, no. 14, pp. 1658–1661, 1988.
[23] H. B. Zeng, Z. Y. Fan, and H. S. Zong, "Superconducting Coherence Length and Magnetic Penetration Depth of a P-Wave Holographic Superconductor," *Phys. Rev. D - Part. Fields*, Gravit. Cosmol., vol. 81, no. 10, pp. 1–6, 2010.
[24] F. De Aquino, "Superconducting State Generated by Cooper Pairs Bound by Intensified Gravitational Interaction," pp. 1–10, 2012.
[25] G. V Gettliffe, N. K. Inamdar, R. E. M. Enter, and R. Masterson, "High-Temperature Superconductors as Electromagnetic Deployment and Support Structures in Spacecraft," no. June, pp. 0–8, 2012.
[26] D. Duan, H. Yu, H. Xie, and T. Cui, "Ab Initio Approach and Its Impact on Superconductivity," *J. Supercond. Nov. Magn.*, vol. 32, no. 1, pp. 53–60, 2019.
[27] C. K. Landrock and B. Kaminska., "High-Temperature Polymer Capacitors for aerospace applications," *High Temp. Polym. Capacity. Aerosp. Appl. Des. Autom. Test Eur. Conf. Exhib.*, no. 1, pp. 1349–1352, 2010.
[28] D. Thouless, M. J. Kosterlitz, and F. Duncan, "For Theoretical Discoveries of Topological Phase Transitions and Topological Phases of Matter," *R. Swedish Acad. Sci*., vol. 50005, no. 50005, pp. 1–26, 2016.
[29] N. Hasan, D. Reirert, S. Schmidt, V. Tympel, F. Schmidl, T. Wolf, and P. Seidel, "Characterizing the

Josephson Effect on Ba-122 Single-Crystal Junctions," *J. Supercond. Nov. Magn.*, vol. 32, no. 9, pp. 2727–2732, 2019.

[30] A. P. Drozdov, P. P. Kong, V. S. Minkov, S. P. Besedin, M. A. Kuzovnikov, S. Mozaffari, L. Balicas, F. F. Balakirev, D. E. Graf, V. B. Prakapenka, E. Greenberg, D. A. Knyazev, M. Tkacz & M. I. Eremets, "Superconductivity at 250 °K in lanthanum hydride under high pressures," *Nature*, vol. 569, no. 7757, pp. 528–531, 2019.

[31] Nurmalita, "The Effect of Pb Dopant on The Critical Temperature of BSCCO-2212 Superconducting Crystal," *Journal Natural*, FMIPA Universitas Syiah Kuala, vol.11, no.2, pp. 22–24, 2012.

[32] F. Astuti, M. A. Baqiya, and Darminto, "Effect of Pb Substitution on Superconducting and Normal State Electrical Properties of $Bi_{2-x}Pb_xSr_2CaCu_2O_{8+\sigma}$ Nanopowders," *Mater. Sci. Forum*, vol. 827, pp. 235–239, 2015.

[33] K. Sugawara, C. Sugimoto, T. Luo, T. Kawamata, T. Noji, M. Kato and Y. Koik, "Superconductivity above 100 °K in the Bi-2212 phase of $(Bi, Pb)_2Sr_2CaCu_2O_8$," *J. Phys. Conf. Ser.*, vol. 1054, no. 1, 2018.

[34] A. Mani, "Evolution of Superconducting Properties of Coexistent Bi-2212 and Bi-2223 phases in BSCCO," vol. 59, no. May, pp. 391–397, 2021.

[35] S. Malik, M. H. Suhail, G. Y. Hermiz, and A. J. Haider, "Effect of Annealing on Superconducting Properties of $Bi_{1.6}Pb_{0.4}Sr_2Ca_2Cu_{2.2}Zn_{0.8}O_{10}$ Thin Films by pulsed Laser Deposition," *Iraqi Journal of Physics*, no. 1, pp. 8–13, 2011.

[36] A. N. Jannah, S. A. Halim, K. Pilah, and N. Sembilan, "Superconducting YBCO and BSCCO Thin Films Prepared by Pulsed Laser Deposition and Post Annealing," vol. 2, no. 2223, pp. 9–15, 2012.

[37] G. Y. Hermiz, M. H. Suhail, and S. M. Shakouli, "Effect of Substrate Temperature on Growth $Bi_{1.6}Pb_{0.4}Sr_2Ca_2Cu_{2.}4Zn_{0.6}O_{10}$ Thin Films Prepared by Pulsed Laser Deposition," *Energy Procedia*, vol. 36, pp. 881–887, 2013.

[38] N. T. Mua, A. Sundaresan, N. K. Man, and D. D. Dung, "Influence of Preparation Conditions on Superconducting Properties of Bi-2223 Thin Films," *Bull. Mater. Sc*i., vol. 37, no. 1, pp. 19–25, 2014.

[39] S. F. Oboudi and M. Q. Mustafa, "Synthesis and Characterization of Ag Nanoparticles Addition on BPSCCO Superconducting Thin Films," *Adv. Nanoparticles*, vol. 05, no. 01, pp. 75–82, 2016.

[40] M. M. Abbas and A. R. Abdulridha, "Influences of Heat Treatment on Superconducting Properties of $Bi_{1.7}Pb_{0.3}(NanoTi_{0.2})\ Sr_2Ca_2Cu_3O_{10+d}$ Thin Film Deposited on Different Substrates," *Energy Proce*dia, vol. 119, pp. 367–375, 2017.

[41] A. N. Jannah, A. H. Shaari, and H. Abdullah, "Effects of Annealing Treatment and Elemental Composition on $Bi_{1.6}Pb_{0.4}Sr_2Ca_2Cu_3O_y$ Thin Films Grown by Pulsed Laser Deposition," *J. Phys. Sci*., vol. 29, pp. 25–3, 2018.

[42] R. Hott, "Application Fields of High-Temperature Superconductors," *High Temp. Supercond. 2*, no. 3, pp. 35–48, 2004.

[43] F. Applications, "Council on Superconductivity," *Furth. Appl. Supercond*., p. 37, 2009.

[44] E. Tsotsopoulou, A. Dyśko, Q. Hong, A. Elwakeel, M. Elshiekh, W. Yuan, C. Booth, and D. Tzelepis, "Modelling and Fault Current Characterization of Superconducting Cable with High-Temperature Superconducting Windings and Copper Stabilizer Layer, " *Energies*, vol. 13, no. 24, 2020.

[45] W. V. Hassenzahl, D. W. Hazelton, B. K. Johnson, P. Komarek, M. Noe, and C. T. Reis, "Electric Power Applications of Superconductivity," *Proc. IEEE*, vol. 92, no. 10, pp. 1655–1674, 2004.

[46] J. Waldram, "Applications of Superconductivity," *Supercond. Met. Cuprates*, pp. 344–372, 2018.

[47] E. K. Suppiah and H. Wahid, "Magnetic Levitation Technologies and Its Potentials in the Advancement of Aircraft' s Take-Off System," vol. VI, no. Viii, pp. 235–241, 2019.

[48] P. Engineering, "Superconducting Materials Learning Outcome History of Superconductivity.", 2011.

[49] M. Yadav, N. Mehta, and A. Gupta, "Review of Magnetic Levitation (MAGLEV): A Technology to Propel Vehicles with Magnets," *Glob. J. Res. Eng. Mech. Mech.*, vol. 13, no. 7, pp. 29–42, 2013.

[50] Z. M. Wang, "Superconducting Magnet of Magnetic Resonance Imaging System," *2013 IEEE Int. Conf. Appl. Supercond. Electromagnet. Devices, ASEMD 2013*, pp. 530–533, 2013.

[51] M. S. H. Al-Tamimi and G. Sulong, "Tumor Brain Detection Through MR Images: A Review of Literature," *J. Theor. Appl. Inf. Technol.*, vol. 62, no. 2, pp. 387–403, 2014.

[52] J. L. Pool, "Magnetic Resonance Imaging," *Biomed. Instrum. Technol.*, vol. 36, no. 5, pp. 341–346, 2002.

[53] H. Lueken, "Superconducting Quantum Interference Device Magnetometry," *Methods Phys. Chem.*, vol. 1, no. 1, pp. 763–795, 2012.
[54] J. R. Kirtley and J. P. Wikswo, "Scanning Squid Microscopy," *Annu. Rev. Mater. Sci.*, vol. 29, no. August 1999, pp. 117–148, 1999.
[55] S. Schmidt, S. Döring, N. Hasan, F. Schmidl, V. Tympel, F. Kurth, K. Iida, H. Ikuta, T. Wolf, and Paul Seidel, "Josephson Effects at Iron Pnictide Superconductors: Approaching Phase-Sensitive Experiments," *Phys. Status Solidi Basic Res.*, vol. 254, no. 1, pp. 1–15, 2017.
[56] B. I. Oladapo, S. A. Zahedi, S. C. Chaluvadi, S. S. Bollapalli, and M. Ismail, "Model Design of a Superconducting Quantum Interference Device of Magnetic Field Sensors for Magneto cardiographs," *Biomed. Signal Process. Control*, vol. 46, pp. 116–120, 2018.
[57] S. J. Swithenby, "SQUID Magnetometers: Uses in Medicine," *Phys. Technol.*, vol. 18, no. 1, pp. 17–24, 1987.
[58] A. J. Haider, F. I. Sultan, M. J. Haider, and N. M. Hadi, "Spectroscopic and Structural Properties of Zinc Oxide Nanosphere as Random Laser Medium," *Appl. Phys. A Mater. Sci. Process.*, vol. 125, no. 4, p. 0, 2019.
[59] S. K. Kolli, S. Velpula, and K. K. Yenubari, "Superconductors in the Field of Communication and Study Various Electric Properties," *Int. J. Sci. Res.*, vol. 6, no. 7, pp. 973–976, 2017.
[60] Y. S. He and C. G. Li, "Microwave Filters Using High-Temperature Superconductors," *High-Temperature Supercond.*, pp. 390–424, 2011.
[61] M. Kumar, "Superconductivity Applications and Challenges," vol. 6, no. 1, pp. 281–284, 2017.
[62] H. Search, C. Journals, A. Contact, M. Iopscience, and I. P. Address, "High Tc Without Rare Earth," vol. 2019.
[63] M. A. Subramanian, C. C. Torardi, J. C. Calabrese, J. Gopalakrishnan, K. J. Morrissey, T. R. Askew, R. B. Flippen< U. Chowdhry, and A. W. Sleight, "A New High-Temperature Superconductor: $Bi_2Sr_{3-x}Ca_xCu_2O_{8+y}$," *Science (80)*, vol. 239, no. 4843, pp. 3–5, 1988.
[64] S. A. Sunshine, T. Siegrist, L. F. Schneemeyer, D. W. Murphy, R. J. Cava, B. Batlogg, R. B. van Dover, R. M. Fleming, S. H. Glarum, S. Nakahara, R. Farrow, J. J. Krajewski, S. M. Zahurak, J. V. Waszczak, J. H. Marshall, P. Marsh, L. W. Rupp, Jr., and W. F. Peck, "Structure and Physical Properties of Single Crystals of the 84 °K Superconductor $Bi_{2.2}Sr_2Ca_{0.8}Cu_2O_{8+\delta}$," *Phys. Rev. B*, vol. 38, no. 1, pp. 893–896, 1988, [Online]. Available: http://prb.aps.org/abstract/PRB/v38/i1/p893_1%5Cnhttp://prb.aps.org/pdf/PRB/v38/i1/p893_1%5Cnhttp://link.aps.org/doi/10.1103/PhysRevB.38.893.
[65] N. Hasan, H. Hafeath, and A. Ahmed, "Synthesis and Characterization of the Bulk YBCO-Target of Superconducting Material," *Mater. Today Proc.*, vol. 42, no. xxxx, pp. 2268–2272, 2021.
[66] M. J. Haider, D. S. Ahmed, M. R. Mohammad, and A. J. Haider, "Modification of Functionalized Multi-Walled Carbon Nanotubes by Olive Oil as Economic Method for Bacterial Capture and Prevention," *Biosci. Biotechnol. Res. Asia*, vol. 14, no. 4, pp. 1513–1522, 2017.
[67] S. K. Durrani, A. H. Qureshi, S. Qayyum, and M. Arif, "Development of Superconducting Phases in BSCCO and Ba-BSCCO by Sol Spray Process," *J. Therm. Anal. Calorim.*, vol. 95, no. 1, pp. 87–91, 2009.
[68] T. Jacobs, "Unraveling the Cuprate Superconductor Phase Diagram," PhD, Intrinsic Tunneling Spectroscopy and Electrical Doping, Department of Physics, Stockholm University, Sweden, ISBN 978-91-7649-434-9, 2016.
[69] V. F. Shamray, A. B. Mikhail ova, and A. V. Mitin, "Crystal Structure and Superconductivity of Bi-2223," *Crystallography. Reports*, vol. 54, no. 4, pp. 584–590, 2009.
[70] B. A. Glowacki, "Preparation of $Bi_2Sr_2CaCu_2O_{8-x}$, "*Phys. C*, vol. 13, pp. 584–591, 2000.
[71] L. S. Zaremba and W. H. Smoleński, "Optimal Portfolio Choice Under a Liability Constraint," *Ann. Oper. Res.*, vol. 97, no. 1–4, pp. 131–141, 2000.
[72] B. Keimer, S. A. Kivelson, M. R. Norman, S. Uchida, and J. Zaanen, "From Quantum Matter to High-Temperature Superconductivity in Copper Oxides," *Nature*, vol. 518, no. 7538, pp. 179–186, 2015.
[73] A. I. Golovashkin, O. M. Ivanenko, Yu. B. Kudasovb, K. V. Mitsena, A. I. Pavlovskyb, V. V. Platonovb, and O. M. Tatsenkobeto, "Low-Temperature Measurements of Hc_2 in HTSC using Mega Gauss Magnetic Fields," *Phys. B Phys. Condense. Matter*, vol. 177, no. 1–4, pp. 105–108, 1992.
[74] A. U. Sokolnikov, "THz Applications," *THz Identify. Def. Secure. Purp.*, pp. 147–191, 2013.
[75] S. Acharya, "Studies on Superconductor Nano Composite of $Bi_2Sr_2CaCu_2O_8/BiFeO_3$," Master of Technology (Res), National of Institute of Technology, Department of Physics, Rourkela, July 2012.
[76] A. H. Qureshi, M. Arshad, S. K. Durrani, and H. Waqas, "Impact of Pb Substitution on the Formation of

High-Tc Superconducting Phase in BSCCO System Derived Through Sol-Gel Process," *J. Therm. Anal. Calorim.*, vol. 94, no. 1, pp. 175–180, 2008.

[77] S. Döring, D. Reifert, N. Hasan, S. Schmidt, F. Schmidl, V. Tympel, F. Kurth, K. Iida, B. Holzapfel, T. Wolf, and P. Seidel, "Excess Currents in Planar $Ba(Fe_{1-x}Co_x)_2As_2/TiO_x/Pb$ Josephson Junctions," *Phys. Status Solidi Basic Res.*, vol. 252, no. 12, pp. 2858–2866, 2015.

[78] E. Horder, "Explosive Eructation's.," *Lancet*, vol. 160, no. 4129, p. 1079, 1902.

[79] Y. Ben Smida, R. Marzouki, S. Kaya, S. Erkan, M. Faouzi Zid, and A. Hichem Hamzaoui, "Synthesis Methods in Solid-State Chemistry, " *Synth. Methods Cryst.*, no. October, 2020.

[80] B. Heeb, S. Oesch, P. Bohac, and L. J. Gauckler, "Microstructure of Melt-Processed $Bi_2Sr_2CaCu_2O_y$ and Reaction Mechanisms During Post Heat Treatment," *J. Mater. Res.*, vol. 7, no. 11, pp. 2948–2955, 1992.

[81] B. Lehndorff, D. Busch, R. Eujen, R. Fischer, B. Fischer, and H. Piel, "Preparation and Characterization of Silver Sheathed BSCCO-2223 Tapes," vol. 5, no. 2, pp. 1251–1254, 1995.

[82] D. H. Li, S. F. He, J. Chen, C. Y. Jiang, and C. Yang, "Solid-State Chemical Reaction Synthesis and Characterization of Lanthanum Tartrate Nanocrystallites under Ultrasonication Spectra, " *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 242, no. 1, 2017.

[83] C. Gautam and A. Madheshiya, "Fabrication Methods of Lead Titanate Glass Ceramics and Dielectric Characteristics: A review," *J. Mater. Sci. Mater. Electron.*, vol. 31, no. 15, pp. 12004–12025, 2020.

[84] M. Al-Kinani, A. Haider, and S. Al-Musawi, "Study the Effect of Laser Wavelength on Polymeric Metallic Nanocarrier Synthesis for Curcumin Delivery in Prostate Cancer Therapy: In Vitro Study," *J. Appl. Sci. Nanotechnology.*, vol. 1, no. 1, pp. 43–50, 2021.

[85] A. J. Haider, A. J. Mohammed, S. S. Shaker, K. Z. Yahya, and M. J. Haider, "Sensing Characteristics of Nanostructured SnO_2 Thin Films as Glucose Sensor," *Energy Procedia*, vol. 119, pp. 473–481, 2017.

[86] H. U. Krebs, M. Weisheit, J. Faupel, E. Süske, Th. Scharf, Ch. Fuhse, M. Störmer, K. Sturm, M. Seibt, H. Kijewski, D. Nelke, E. Panchenko, and M. Buback, "Pulsed Laser Deposition (PLD) - A Versatile Thin Film Technique BT - Advances in Solid State Physics," *Adv. Solid State Phys.*, vol. 43, pp. 505–518, 2003.

[87] J. M. Rzaij, "Characterization of CuO Thin Films for Gas Sensing Applications," *Iraqi J. Phys.*, vol. 14, no. 31, pp. 1–12, 2019.

[88] V. Michaela, "Preparation and Properties of the Mercury Based Thin Films of Very High Tc Superconductors and Their Possible Applications in Cry electronics," to cite this version: HAL Id: tel-00275549," 2008.

[89] R. K. Singh and D. Kumar, "Pulsed Laser Deposition and Characterization of High-Tc $YBa_2Cu_3O_{7-x}$ Superconducting Thin Films," *Mater. Sci. Eng. R Reports*, vol. 22, no. 4, pp. 113–185, 1998.

[90] S. F. Grid and T. Si, "General Description of Silicon Wafers, Substrates, and Sample Supports," [Online]. Available: https://www.nanoandmore.com/pdf_downloads/accessories/General. Description of Silicon Wafers, Substrates and Sample Supports.pdf, 2021.

[91] S. Abdulridha, S. Tuma, and O. Abdulrazaq, "Study of the Partial Shading Effect on the Performance of Silicon PV Panels String," *J. Appl. Sci. Nanotechnology.*, vol. 1, no. 1, pp. 32–42, 2021.

[92] A. M. Jasim, J. H. Khlaief, and R. S. Zamel, "Effect of Secondary Ionization Coefficient on the Breakdown Voltage in Nitrogen Gas, " *J. Phys. Conf. Ser.*, vol. 1795, no. 1, 2021.

[93] H. H. Kadhim, N. Hasan, A. J. Haider, and F. Q. Mohammed, "Characterization of Thin Films Superconductor Materials and Study of Electrical Properties," *TMREES Conference Series: Technologies and Materials for Renewable Energy, Environment and Sustainability*, vol. X, no. X, 2021.

[94] A. A. Abdul Hussein, N. Hasan, A. M. Abdul Hussein, and F. Q. Mohammed, "Synthesis of Bulk Superconductors Using the Sol-Gel Method", *TMREES Conference Series: Technologies and Materials for Renewable Energy, Environment and Sustainability*, vol. X, no. X, 2021.