

Processing and Application of High-Temperature Superconducting Coated Conductors

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Abstract: A game-changer in high-current density, large-diameter materials for cutting-edge electrical and energy applications, MBE-produced HTS-coated conductors efficiently transfer high currents at high temperatures with little energy loss. While outlining the processing methods and possible uses of HTS coated conductors, this review paper focuses on optimising the synthesis parameters and preparing for thin film deposition. The fundamentals of superconducting, material properties, and the structural features of HTS systems are discussed after an introductory section. Next, we'll go into the fundamentals of superconductivity, the properties of the materials used, and the design of HTS systems like YBCO and REBCO. This section goes into depth on thin film technologies as they are fundamental to the efficiency and excellence of films. Physical and chemical deposition techniques are examples of such technologies. We meticulously investigate critical processing parameters that influence the growth, structure, and superconducting properties of these films. Temperature, pressure, and the surrounding environment are all examples of such elements. Topics discussed include the importance of substrate selection, lattice matching, and interface engineering in creating high-quality epitaxial films. The research also details several methods for characterising the HTS thin films in order to evaluate their magnetic, electrical, and structural properties. There is an emphasis on novel performance-enhancing optimisation methods and a thorough examination of problems with low defect and poor repeatability in large-scale production. Finally, many transportation, medical, and power system uses of HTS coated conductors are discussed, highlighting their increasing importance in today's technological landscape.

Keywords: High-Temperature Superconductors (HTS), Coated Conductors, Thin Film Deposition, REBCO, YBCO, Synthesis Parameters, Superconducting Thin Films, Critical Current Density (J_c)

1. INTRODUCTION

Superconductivity, in which a material's resistance is zero below a threshold temperature and magnetic flux is entirely evacuated from the substance, is one of the most astounding occurrences in condensed matter physics. The discovery of superconductivity in 1911 sparked a great deal of interest in both science and technology, with potential uses that may transform electrical gadgets, magnetic systems, and energy transfer. However, because typical superconductors need an extremely low working temperature nearly absolute zero their usage has not been mainstream. The primary turning point in the late 1980s was the discovery of

superconductors with temperatures exceeding room temperature (0°C), which is regarded as a "high" temperature. Due to their superior superconducting qualities and thermal stability, rare-earth barium copper oxide (REBCO) and yttrium barium copper oxide (YBCO) systems have garnered a lot of interest (MacManus-Driscoll, J. L. 2021).

The development of HTS coated conductors has accelerated the transition of superconductors from lab research to commercial use. Coated conductors are obtained by placing an epitaxial thin-layer coating of superconducting materials on a flexible metallic substrate in order to conduct at a high current density without compromising the mechanical strength and stability of the substrate. These materials are being used to develop a next generation of energy technologies, such as power transmission cables, fault current limiters, high field magnets and energy storage systems. The parameters and processing used in the preparation of the superconducting thin films is essential for controlling the quality of the material that will be crucial for industrial applications of coated conductors. To prepare HTS coated conductors, the control of film thickness, composition and microstructure is key and these are achievable using thin film technology. A large amount of work has been done to study various physical and chemical deposition methods such as sputtering, chemical vapour deposition, pulsed laser deposition and metal-organic deposition for superior superconducting film production. All of these approaches have merits and drawbacks related to price, film assembly and scalability (Puig, T. 2022). These strategies need to be developed for practical applications with the desired properties of the superconductors such as a good ability to pin flux and a high critical current density.

One of the significant parameters in archiving of thin film technology is the accuracy of process parameters setting during the synthesis process, e.g. the synthesis rate and process control parameters like temperature, pressure, environment etc. They influence the nucleation and growth processes of the films and thus the crystallinity, phase purity and defect structure of the films. For instance, the temperature at which the deposition occurs influences the mobility of adatoms and leads to the formation of the desired superconducting phase; for instance, the partial pressure of oxygen is crucial in determining the proper oxide content and stoichiometry of oxide superconductors. Similarly, the epitaxial growth and strain of films are greatly influenced by the choice of substrates and the compatibility of the lattice matching of the film and substrate.

2. FUNDAMENTALS OF SUPERCONDUCTIVITY

Superconductivity is a quantum mechanical phenomena in which some materials exhibit a total expulsion of magnetic fields and a total lack of electrical resistance when the temperature is lowered below a specified point known as the critical temperature (T_c). Because of their special condition, superconductors should not waste any energy while creating an endless current, making them very desirable for a variety of technological uses. The creation of Cooper pairs pairs of electrons with opposing momentum and spin that operate coherently without dispersing through the crystal lattice causes a reduction in resistance. In normal superconductors this coupling happens by means of the Bardeen–Cooper–Schrieffer (BCS) mechanism which involves the bonding of the electrons by lattice vibrations (phonons) (Selvamanickam, V. 2022). The BCS model is able to explain many features of the low temperature superconductors, such as the energy gap, the superconductive transition temperature and the electromagnetic response of the superconductors.

One of the most important features of superconductors is the Meissner effect which is the difference between the superconductor and a perfect conductor. Once the material is in the superconducting state, all magnetic flux forces it out of itself with a resulting zero magnetic field in the bulk of the material. This is a basic effect of the superconductivity and is a consequence of the formation of long-range quantum coherence. If the magnetic field is turned up so that it is greater than the critical magnetic field, an external magnetic field can influence superconductors and stop them from being superconductors. Superconductors can be classified in two types based on their magnetic properties: Type I and Type II. Type I superconductors undergo a rapid loss of superconductivity at values of the magnetic field above the critical value and a Meissner effect at maximum extension. Type II superconductors, on the other hand, are the ones that exhibit the mixed or the vortex phase between two critical magnetic fields, and are superconducting even in the presence of magnetic flux entering as quantised vortices. This property makes use of these Type II superconductors more practical in real applications in higher magnetic field, in particular, HTSCs.

The next important parameter in superconductivity is the critical current density (J_c), the maximum amount of current a superconductor can carry without being able to conduct electricity. When this is exceeded, dissipative processes are activated that involve magnetic vortices in motion, and result in an energy loss. Therefore, one of the main objectives of

research on superconducting materials is to enhance J_c . The concept of flux pinning, in which flaws or inhomogeneities in the material serve as pinning centers that immobilise vortices without permitting any motion when current or a magnetic field are applied, is closely connected to this. To maintain high current-carrying capacity, especially in high field applications, the flux pinning mechanism is crucial. HTS devices employ materials, such as cuprate-based materials, whose superconductivity occurs at temperatures far higher than those expected by the traditional BCS theory (Trillaud, F. 2021). These materials have anisotropic characteristics, multilayer crystal formations, and significant electron correlation. In addition to phonon-mediated interactions, the pairing interaction in HTS is believed to entail more complex interactions than in typical superconductors. The processing of HTS materials and the creation of HTS devices must take into account the anisotropic qualities of HTS materials, which also result in some electrical and magnetic characteristics being different in various directions. Additionally, HTS materials are more sensitive to flaws, grain boundaries, etc. due to their short coherence length and high critical magnetic field value. Additionally, HTS materials are highly vulnerable to flaws, grain boundaries, etc. due to their short coherence length and relatively high critical magnetic field.

3. HIGH-TEMPERATURE SUPERCONDUCTORS: PROPERTIES AND MATERIALS

A distinct class of materials known as high-temperature superconductors (HTS) exhibit superconducting characteristics at temperatures far higher than those of normal superconductors, which are usually glass-like liquid nitrogen (77 K). This feature has contributed greatly to their technical significance by reducing their cooling costs and providing new and valuable applications. Complex Ceramic Compounds used in HTS are the most popular one, namely Yttrium barium copper oxide (YBCO) and Rare earth barium copper oxide (REBCO). The main locations of superconductivity in these compounds are the copper oxygen (CuO_2) layers, which have layers of perovskite-like crystal structures. These planes and their interplay are important to the superconducting properties and performance of the material.

The most outstanding property of the HTS materials is their high T_c (cooling temperature) which are generally in the order of 77K to higher than 130K depending on the composition and structure of the materials. In addition to T_c , there are other important factors such as the critical current density (J_c) and critical magnetic field (H_{c2}) that are quite high for HTS compared to

those of conventional superconductors. The properties of the HTS materials make them very suitable for high power and high field applications (van Nugteren, J. 2018). In addition to the aforementioned high electrical and magnetic anisotropy, HTS materials also possess large mechanical anisotropy. This anisotropy property happens because of their layered structure which makes it tough for uniform superconducting performance to be achieved, particularly in polycrystalline form, where they are used. In addition to determining their physical properties, the materials for HTS are also known to be complicated crystal structure, which can be influenced easily by the composition and content of oxygen of the material. Superconducting characteristics in cuprate superconductors can be significantly impacted by oxygen vacancies or non-ideality of the atomic ratio. Oxygen plays a crucial role in preserving the charge balance inside the CuO_2 planes and is essential for the creation of superconducting charge carriers. In order to optimise input performance, stringent oxygenation control during the synthesis and post-deposition processes is crucial. Furthermore, the transition temperature and electrical characteristics of the HTS materials are directly impacted by the degree of doping (or, by doping different components, the degree of oxygen deprivation).

The coherence length, which is typically on the scale of a few nanometres, is another distinctive property of HTS materials. Therefore, superconductivity can be destroyed by the sheer existence of small flaws, grain boundaries, or contaminants. Although there are challenges associated with this sensitivity, it also provides the opportunity to enhance performance by designing the flaws. For instance, artificial pinning sites such as columnar defects and/or nanoparticles can raise the critical current density and flux pinning (Obradors, X. 2019). Applications like high magnetic field applications are particularly crucial because, if the flux pinning is insufficient, the movement of magnetic vortices in the field causes energy losses. Furthermore, HTS materials have a great capacity for superconductivity in harsh circumstances due to their large upper critical magnetic fields, which frequently surpass many tens of tesla.

4. COATED CONDUCTORS: CONCEPT, STRUCTURE, AND MATERIALS (E.G., REBCO/YBCO)

Coated conductors have a great deal of promise to transform superconductivity into a special material for high-performance, large-scale applications. Unlike typical type superconducting wires based on a metallic alloy, coated conductors are created as multilayer structures consisting of a thin layer of superconducting film developed over a thin flexible metallic base

material. This design guarantees that the intrinsic fragility of ceramic high-temperature superconductors (HTS) is addressed and enables the fabrication of a long-length conductor with outstanding electrical performance and great mechanical strength. Coated conductors, which may be used in energy storage, high field magnets, and power cables, were created in response to the need for a combination of superior superconducting qualities, structural flexibility, and endurance. A metallic substrate, one or more buffer layers, and a superconducting layer make up the fundamental structure of a coated conductor (Goyal, A. 2019). The conductor's mechanical structure is called the substrate, and it is usually made of stainless steel, nickel-based alloys, or a high-strength alloy. They should be compatible with the ensuing deposition processes, have acceptable mechanical qualities, and be thermally stable. However, buffer layers are added to most metallic substrates because they lack sufficient crystallinity and the right crystallographic orientation to produce a high-quality superconducting film. Buffer layers are thin intermediary layers that prevent diffusion, provide chemical isolation, and provide an appropriate lattice-matched surface for the superconductive film's epitaxial development.

It makes use of a layer of related substances called rare-earth barium copper oxide (REBCO), typically yttrium barium copper oxide (YBCO) minerals, which are the mainstays that transport the electrical current without resistance or hesitation. For the best superconducting qualities, they are placed in strongly orientated thin layers. The critical current density (J_c) is greatly affected by misalignment or the existence of grain boundaries in the superconducting layer, making epitaxial growth crucial. Therefore, throughout the manufacturing process, it is crucial to achieve a high crystallographic alignment of the individual layers in the coated conductor structure. Usually, advanced texturing techniques like roll assisted biaxially textured substrates (RABiTS) and ion beam aided deposition (IBAD) are used to create a suitable template for epitaxial growth. The most popular materials in coated conductor technology are REBCO materials because to their high critical temperature, which is typically about 90 K, and their ability to withstand high magnetic fields. The REBCOs' typical chemical formula is $REBa_2Cu_3O_{4-\delta}$, where "RE" denotes a rare-earth element, such as yttrium, gadolinium, samarium, etc. Because it influences the charge carrier density of the CuO_2 planes, the oxygen content, or δ , plays a crucial role in the superconducting characteristics. For the best superconducting characteristics to be achieved, precise control of the oxygen stoichiometry is

therefore crucial during the production and post-deposition annealing processes (Maiorov, B. 2020).

The microstructure of the REBCO thin films is another important component that affects the performance of coated conductors. A well-formed film has a high proportion of crystallographic alignment, a limited population of grain boundaries, and defect control. However, certain kinds of flaws can function as effective pinning centers to transport large current densities in magnetic fields when they are appropriately engineered. To improve flux pinning and performance, techniques such adding artificial pinning centers and secondary phase nanoparticles have been thoroughly studied.

5. THIN FILM TECHNOLOGY AND FABRICATION TECHNIQUES

The development of High-temperature Superconducting (HTS) Coated Conductors relies heavily on thin-film technology to meet the exacting requirements for material composition, thickness, crystallographic orientation, and structure in order to get the best possible superconducting qualities. Unlike multilayered designs that are realised in bulk materials, such multilayered structures need precisely tailored thin films in which each layer performs a distinct role in structure, electrical characteristics, and chemistry. For HTS systems based on REBCO and YBCO compounds in particular, depositing high-quality epitaxially grown thin films is essential to achieving high critical current density (J_c) and stability during operation. Therefore, it is crucial to create thin film deposition processes that progress coated conductor technology and to have precisely regulated and customisable process parameters (Rupich, M. W. 2019). The deposition techniques that are appropriate for use in superconductors cover a wide range of physical and chemical techniques. Material can be transferred from a solid source to a substrate using physical deposition processes including evaporation, sputtering, or laser ablation. Since PLD is the most effective method for preserving the stoichiometry of complicated oxide materials, it has become more popular for the production of thin films of HTS materials. "Laser induced plasma deposition" is the foundation of PLD. PLD is a technique in which a target material's surface is struck by a high-energy laser pulse, producing a plasma plume that deposits onto a heated substrate. Although this method's scalability is restricted, it offers good thickness and compositional control, making it suitable for research-scale production of high-quality films.

Magnetron sputtering is another significant physical deposition technique that utilises atom ejection by ion bombardment in a plasma, which takes place beneath the target material inside a magnetic field. This technique guarantees good film adhesion, uniform film coating across vast surface areas, and compatibility with industrial operations. It is widely utilised for superconducting films and deposited buffer layers. Molecular beam epitaxy (MBE) is a highly controlled physical technique that achieves atomic level accuracy in film formation under extremely specific high-voltage circumstances. Although MBE films offer superior structural quality, they are too costly and complicated to be used for anything more than basic research. For the production of HTS thin films, the chemical deposition method is a cost-effective substitute with the benefits of high accuracy, high speed, big size, etc. The technique of forming a solid layer by interacting a gaseous material with a heated substrate is known as chemical vapour deposition, or CVD. Metal-organic chemical vapour deposition (MOCVD) is one of the best methods for depositing complicated oxide superconductors. These techniques have several advantages, including high throughput, homogeneity, and the capacity to create enormous numbers. Liquid metal-organic precursors are applied to substrates using solution-based methods like the sol-gel process or metal-organic deposition (MOD), which are then heated to generate crystalline layer. The techniques outlined are reasonably easy and affordable, although they can be difficult to optimise for excellent film quality (Foltyn, S. R. 2019).

The superconducting and structural characteristics of HTS thin films are undoubtedly influenced by the method of production. Important factors such the deposition rate, substrate temperature, deposition environment, and post-deposition annealing atmosphere must be carefully regulated in order to accomplish proper phase formation and crystallographic alignment of the thin film. For example, a crucial factor in creating oxide materials with a certain composition and superconducting qualities is the partial pressure of oxygen. On the other hand, for the formation of well-oriented epitaxial films, the temperature of the substrate plays a crucial role in the mobility of atoms. Defects, secondary phase production, and a drop in superconducting efficiency can result from any departure from ideal circumstances. In coated conductor topologies, a thin film is used as a buffer and protective layer in addition to the superconductor layer. In order to get a good lattice fit and a chemically stable interface between the superconducting film and electrode, buffer layers typically composed of cerium oxide or yttria-stabilized zirconia materials are used.

6. PROCESSING PARAMETERS AND GROWTH CONDITIONS (TEMPERATURE, PRESSURE, ATMOSPHERE)

In order to obtain optimal performance, high-temperature superconducting (HTS) thin films show a highly sensitive dependency on processing parameters and circumstances. Temperature, pressure, and ambient environment are the three most significant factors that influence superconducting characteristics, phase formation, and structural integrity. Because HTS materials like REBCO and YBCO are highly sensitive to stoichiometry and crystallographic alignment, even a little alteration in processing conditions can have an effect on film quality. To get high-performance coated conductors, it is crucial to understand growth conditions and how they relate to material behaviour. The temperature is the most important factor among the several that affect nucleus formation and crystallisation growth in thin film deposition. Grain size, crystallinity, and epitaxial alignment may all be determined by the substrate temperature, which also controls the mobility of the adatoms on the material's surface. Low atomic mobility at low temperatures results in weakly crystallised or amorphous films, which have poor superconducting characteristics. Conversely, too high temperatures might result in undesirable reactions, layer interdiffusion, or substrate and buffer layer deterioration (Matsumoto, K. 2020). Thus, to ensure effective phase formation and lattice ordering, an ideal temperature range is required. For REBCO-based films, the deposition temperatures range from 700°C to 850°C, where atomic diffusion is adequate to provide high-quality epitaxial growth. Phase purity is also crucial, and achieving it requires post-deposition annealing, which incorporates additional oxygen and raises the critical temperature and current density.

Pressure is another critical factor that has a significant impact on film growth, particularly in the deposition processes of magnetron sputtering and pulsed laser deposition. The mean free path and kinetic energy of the particles travelling from the particle source to the substrate are influenced by operating pressure. However, at low pressures, particles have more energy, which improves film densification. However, because these particles have high energy, it can be challenging to remove them from the film, which could result in flaws. Increased collisions in the gas phase at high P cause the energy of the particles in the gas phase to decrease, resulting in surface smoothing but a loss of crystallinity. In order to achieve a balance between surface morphology and structural quality, it is necessary to adjust the working pressure. Because oxygen partial pressure directly impacts the material's oxygen stoichiometry and superconducting characteristics, oxide superconductors are especially sensitive to it. The most

crucial factor affecting the chemical makeup and phase stability of HTS films during deposition is ambient gas. A sufficient oxygen atmosphere that permits the proper oxygen concentration required for the oxide to be kept in the crystal lattice is essential for high-quality YBCO oxide superconductors (Zhang, Y. 2021). The concentration of these carriers decreases, the critical temperature drops, and the superconducting characteristics deteriorate with low oxygen concentrations. Conversely, a highly regulated or excessive oxygen environment may result in the creation of secondary phases or less-than-ideal structures. To appropriately manage the chemical proportion during film growth, they almost invariably utilise a controlled environment, which typically contains oxygen or oxygen/inert gas composites.

7. SUBSTRATE ENGINEERING AND CHARACTERIZATION OF HTS THIN FILMS

The preparation of the substrate, which influences the structural, electrical, and superconducting characteristics of the thin film materials deposited on it, is crucial to the fabrication of high temperature superconducting (HTS) thin films. In coated conductor technology, the substrate's crystal structure not only serves as a mechanical support but also determines the superconducting film's crystallographic orientation and epitaxy quality. Appropriate substrates are crucial for the usage of HTS materials, such as REBCO and YBCO, because of their highly anisotropic features and the requirement that the crystal structures be perfectly aligned. To decrease substances and minimise strain, the ideal substrate must have strong mechanical strength, high temperature stability, and chemical compatibility in addition to a lattice structure that closely mirrors that of the superconducting material. Stainless steel or other types of nickel alloys are used for many practical applications as they are strong and adaptable (Coll, M. 2020). However, the crystal structure is lacking in the substrates and therefore the HTS film product is not epitaxially grown. This limitation is overcome by using advanced texturing techniques such as Rolling-Assisted Biaxially Textured Substrates (RABiTS) and Ion Beam Assisted Deposition (IBAD) techniques to give the desired crystallographic orientation. These techniques allow films that are highly orientated along the biaxial direction of the surface to be fabricated, thus providing better seeds for the growth of highly orientated buffer layers and films, as well as extremely high orientation buffer layers. Long length coated conductors of a consistent performance can easily be fabricated based on these customized substrates.

Buffer layers are very important in the manufacture of a superconducting film that is put over a metallic film on the substrate. These layers are used to obtain epitaxial growth, minimum lattice mismatch and to avoid chemical diffusion from the substrate. The materials used as buffers are cerium oxide, magnesium oxide and yttria-stabilized zirconia, which are used in sputtering and chemical vapour deposition. The thickness, crystallographic orientation and composition of the buffer layers also have to be well controlled to ensure a smooth, flawless surface structure upon which the HTS layer can grow. When designing a buffer architecture, certain characteristics of the superconducting material and properties of the film are significantly improved. One of the frequently encountered problems while forming a thin film will be mismatch between lattice of the film and the substrate. A significant mismatch might result in strain, dislocation, etc., creating a structural flaw that will deteriorate the superconducting qualities (Haugan, T. J. 2018). Therefore, selecting the right substrate and buffer layers to minimise the mismatch is essential to producing high-quality epitaxial films. Additionally, it is crucial that layers be compatible with one another in terms of thermal expansion since any discrepancy in the thermal expansion coefficient might lead to tension and breaking of the layers when they are withdrawn from the deposition temperature. A suitable multilayer design with sufficient mechanical stability can counteract these disadvantages.

8. CHALLENGES, OPTIMIZATION STRATEGIES, AND APPLICATIONS OF HTS COATED CONDUCTORS

Although the benefits of HTS coated conductors for a variety of cutting-edge technological applications have been demonstrated, their widespread use in a variety of commercial applications is still restricted by unresolved scientific and engineering problems. Getting consistent and high-quality film growth over extended conductor lengths is challenging. Coated conductors are produced as continuous tape, and maintaining the uniform superconducting behaviour (critical current density) and consistent crystallographic alignment of superconducting films across extended distances is challenging. Any sample's critical current density (J_c) can be negatively impacted by a little inaccuracy in the deposition circumstances that introduces defects like as non-superconducting inclusions, fissures, or grain boundaries. Additionally, there are certain challenges with mechanical dependability and durability in handling and operating stress due to the ceramic characteristics of HTS materials, which are embedded in the flexible metallic substrates.

Defect control is another crucial problem for HTS-coated conductors. Superconducting characteristics may suffer from excessive or uncontrollably produced flaws, even if certain imperfections may be advantageous for performance as flux pinning sites. The weak connections that obstruct current flow are in-grain barriers, particularly those with a large misorientation angle. This issue is further complicated by the material's anisotropic nature, which means that REBCO characteristics change when the crystal has a different orientation. Additionally, long-term deterioration and chemical instability may arise from the chemical stability of the interface between the substrate, buffer layers, and superconducting film, especially in high-temperature or high-field environments (Wee, S. H. 2022). Scale-up and the expense of HTS-coated conductors continue to be significant limitations. The method is intricate and involves a number of sophisticated processing stages, including substrate texturing, buffer layer deposition, superconducting film development, and protective coating. Numerous high-quality deposition methods exist, such as molecular beam epitaxy and pulsed laser deposition, but they are expensive and difficult to scale up to industrial scales. Because of this, coated conductors are less competitive in commercial markets due to their comparatively higher manufacturing costs compared to traditional conductors.

9. CONCLUSION

One of the most significant advances in the research of superconductivity is the use of high-temperature superconductors (HTS) coated conductors, which offer a practical and practical approach to incorporate superconducting material performance into a cutting-edge technological system. This review has highlighted the significance of thin film technique, material selection, and strict control of processing parameters as critical to the performance of HTS coated conductors. Even in harsh operating conditions, REBCO films may achieve high critical current density and operational stability thanks to engineered substrates and optimised buffer layers. In the meanwhile, it has been shown that growth conditions (temperature, pressure, and atmosphere) play crucial roles in controlling film quality, phase formation, and the microstructural characteristics of the formed film or surface. Despite notable advancements, commercialisation still faces challenges with defect control, scale-up, and cost-effective production. Yet, these limitations are being overcome by continuous improvements in manufacturing techniques, by employing specially designed substrates, or by incorporating artificial flux pinning centers. The future development of other characterisation and modelling techniques, as well as high processing yield HTS coated conductors, is also expected to

significantly enhance the performance and repeatability of HTS coated conductors. Materials for their vast applications such as energy storage, medical imaging, energy transmission, power transmission, and transportation systems can transform the science of the future. As a result of continuous research, the improvement of synthesis techniques and material properties, HTS coated conductors are expected to play a very important role in the development of sustainable and energy-efficient technology. With this revolutionary technology in the near future, the future of the HTS applications will be decided by the OVE to be brought by the material optimisation and processing techniques.

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