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Exploring the Structural and Superconducting Properties of High Temperature Oxide Superconductors

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Abstract: ***Present review study explores the structural and superconducting properties of the ErBaCuO based high temperature oxide superconductors. The study also delves into the crystal structure, emphasizing the role of oxygen content in determining its superconducting behavior. It also highlights the synthesis methods used, such as solid state reactions and advanced deposition techniques, which significantly influence the materials performance. Furthermore, the study discusses the potential applications of ErBaCuO based superconductors in fields like energy transmission and medical technologies, while addressing challenges in understanding the mechanisms of high temperature superconductivity.***

Keywords: Structural and Superconducting Properties of ErBa2Cu3O7-δ Superconductors and Mechanism

1. Introduction

In 1911, Heike Kamerlingh Onnes discovered remarkable phenomenon of superconductivity in mercury at a low temperature of 4.2 K [1]. Over the years, researchers explored discovering superconductivity in an ever-widening range of elements and compounds and various materials, including lead, niobium [2]. These materials displayed intriguing properties with a limitation of extremely low temperatures to evident superconductivity [3]. A breakthrough occurred in the year 1986 when Bednorz and Müller investigated a new family of superconductors, the cuprate high temperature superconductors (HTSCs). This investigation opened a new area in superconductivity for relatively higher transition temperatures [4]. The HTSCs represented a class of ceramic compounds primarily composed of copper oxides.ErBa2Cu3O7-δ (Er123) was subsequently developed as a part of this family of HTSCs, characterized by its perovskite-like crystal structure and the distinctive presence of rare earth element erbium (Er) within its lattice. The development of HTSCs like Er123 has paved the way for new possibilities in various scientific fields and applications [5-8]. Present study attempted to explore the review of the structural and superconducting properties of ErBaCuO based high temperature oxide superconductors with stoichiometry ErBa2Cu3O7-δ (Er123) [1-51]. It also reviews the significance of Er123 in terms of addressing challenges in understanding the mechanisms of high temperature superconductivity [1-51].

2. Structure

Er123 adopts a perovskite like structure, which consists of copper oxide layers separated by layers of other elements. One of the defining factors in the behaviour of ErBa2Cu3O7-δ. Where δ is the oxygen content. This parameter (δ) plays a crucial role in controlling the superconducting and other properties [9-11]. Consequently, understanding and precisely controlling δ is crucial in harnessing the superconducting potential of ErBa2Cu3O7 [12]. The crystal structure consists of repeating unit cells [13]. These unit cells stack together to form the overall crystal lattice. At the core of Er123's structure are the copper oxide CuO2 planes. In these planes, copper atoms are intricately coordinated by oxygen atoms in a 2D array. The movement of electrons within these planes is fundamental to the superconducting phenomenon. Integral to its composition is the rare earth element erbium (Er), which contributes to its name and is strategically positioned within the crystal lattice. ErBa2Cu3O7-δ compound exhibits an orthorhombic structural symmetry, featuring three unequal axes at right angles to each other [15]. The stacking sequence of the repeating unit cell is of paramount significance. It comprises of CuO2 layers interleaved with layers containing barium (Ba) and erbium (Er) atoms, as well as oxygen atoms. These layers act as charge reservoirs for sustaining superconductivity [16-24].

3. Synthesis and Structural Characterization

A distinctive feature of ErBa2Cu3O7-δ research involves its oxygen sensing properties utilizing the hotspot phenomenon [25, 26]. The choice of synthesis method and fabrication techniques of ErBa2Cu3O7−δ (Er123) can significantly influence the material's structural, electrical, magnetic and superconducting properties. A.R. Jurelo et al [21] synthesed polycrystalline ErBa2Cu3O7 doped with Pr using a solid-state reaction method. They utilized starting materials such as Er2O3, Pr6O11, BaCO3, and CuO. In another research study [22], pellets of ErBa2Cu3xFexO-7 were synthesized using the same solid-state reaction method. It involves mixing high purity (99.99%) powders of erbium oxide (Er2O3), barium carbonate (BaCO3), copper oxide (CuO), and oxygen (O2) sources. The precursor powders are thoroughly mixed and heated at high temperatures (above 900°C) in an oxygen atmosphere to ensure the incorporation of oxygen in the ErBa2Cu3O7-δ lattice [36]. Melt Textured Growth technique used to fabricate bulk ErBa2Cu3O7-δ samples with improved grain connectivity. It involves melting precursor materials in a controlled atmosphere followed by a controlled cooling process for growth of large single grain domains [37]. Pulsed Laser Deposition technique has been used to create epitaxial films of Er123 on substrates. A high energy pulsed laser ablates a target composed of Er123, and the ablated material condenses on a substrate to form a thin film [38]. Chemical Solution Deposition is another approach useful for complex oxide materials such as ErBa2Cu3O7-δ [39, 40]. Hydrothermal synthesis utilizes high temperature, high pressure water to promote the growth of ErBa2Cu3O7-δ crystals. Precursor materials are placed in a high-pressure autoclave with water, and the system is heated to promote crystal growth [41]. Co-Precipitation combines chemical precipitation and solid-state reaction to form precursor materials for ErBa2Cu3O7-δ [42]. Zone Melting allows for the purification of ErBa2Cu3O7-δ materials by selectively melting and solidifying the sample [43].

4. Mechanisms of Superconductivity

High-temperature superconductivity in materials such as ErBa2Cu3O7-δ has been the subject of extensive research, leading to the development of several theoretical frameworks [1-51]. The Bardeen Cooper Schrieffer (BCS) theory describes superconductivity for conventional superconductors. In conventional superconductors, electron phonon interactions mediated by phonons play a significant role. [23]. Resonating Valence Bond (RVB) Theory was proposed by Anderson, suggests that high temperature superconductivity arises from a quantum mechanical phenomenon [32]. High temperature superconductivity is often associated with the introduction of charge carriers' holes or electrons into the crystal lattice, usually by doping. These charge carriers are believed to play a crucial role in facilitating superconductivity [46]. The Hubbard model and tJ model are used to understand these systems, emphasizing the role of electron to electron interactions [47]. In high temperature superconductors like ErBa2Cu3O7-δ, electron phonon interactions are more complex due to the layered structure. The formation of polarons, where electrons are coupled to lattice distortions, is thought to be important in these materials. Anharmonic phonon interactions can lead to exotic behaviours, and understanding these in ErBa2Cu3O7-δ and similar compounds is vital for explaining high temperature superconductivity [49].

5. Significance of ErBa2Cu3O7-δ Superconductors

ErBa2Cu3O7-δ high temperature oxide superconductors for example, can exhibit superconducting behaviour at temperatures above 90 K, which is achievable with relatively simple cryogenic technique as compared to the extremely low temperatures required by conventional superconductors [7]. The ability to achieve superconductivity at higher temperatures brought forth a wide range of practical applications. ErBa2Cu3O7-δ superconductor and its family of materials have the potential to revolutionize power transmission, transportation, and medical technologies. Their use in high efficiency power cables, levitating trains, and MRI machines showcases their real-world implication [7]. ErBa2Cu3O7-δ superconductor provided an accessible platform for scientists to conduct experiments and explore superconductivity at higher temperatures [8].

6. Exploring the Versatility of ErBa2Cu3O7-δ superconductors in Modern Technologies

ErBa2Cu3O7-δ high temperature superconductors have the potential to revolutionize various technological fields due to their amazing properties, applications and potential to transform energy transmission, storage, medical technologies, transportation, and various scientific fields. Researchers have been continued to explore the possibility of high temperature superconductors to play a crucial role in addressing contemporary energy and healthcare challenges and opening up new possibilities in technology and transportation [1-51].

7. Addressing Challenges and Unanswered Questions

Despite advancements in researches of ErBa2Cu3O7-δ high temperature superconductors, several challenges and open questions are continued to be debated. For example understanding the mechanism of high temperature superconductors, anisotropy and defects, material complexity, phase diagram, commercial viability, environmental and safety concerns are challenges and open questions need to be answered with a full-fledged and plausible theory to explain high temperature superconductivity in general and ErBa2Cu3O7-δ high temperature superconductors in particular [1-51].

8. Conclusion

It is concluded from the present study that the structural and superconducting properties of ErBa2Cu3O7-δ superconductors play a crucial role in advancement of research of high temperature superconductors and understanding their mechanism. It is also concluded that addressing challenges in marching towards room temperature superconductors still remains a matter of great concern.

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