EXPLORING THE APPLICATIONS OF HIGH TEMPERATURE SUPERCONDU-CTORS IN MODERN TECHNOLOGIES

S.V. Sharma

Regional Institute of Education, Ajmer (Rajasthan) India

ABSTRACT

High temperature superconductors are known for its remarkable properties and potential applications. This review study explores the theoretical considerations/mechanisms/theories, importance of emergence and applications of high temperature superconductors. High temperature superconductors have vital potential to transform various technological fields due to their extraordinary superconducting properties, especially high transition temperatures. Some current and potential applications of high temperature superconductors and their implications in respect to energy transmission, storage, and medical technologies are discussed. Understanding high temperature superconductors involves multiple theoretical frameworks and the interplay between charge carriers and electron phonon interactions. There has not been a single, universally accepted mechanism/theory that explains all aspects of high temperature superconductors. It is fascinating to mention over here that the role of charge carriers and electron phonon interactions in high temperature superconductors remains a focal point in the quest to unlock the full potential of high temperature superconductors for realistic applications in modern technologies. Despite significant advancements in the research of high temperature superconductors, several challenges such as understanding the mechanism, material complexity, cryogenic cooling, anisotropy and defects, large scale fabrication, commercial viability, environmental safety concerns and some open questions still persist.

Keywords: *Importance of emergence, Theoretical considerations, Challenges, Applications and High temperature superconductors.*

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1. INTRODUCTION

The landmark in the field of superconductivity occurred in the year 1911 when Heike Kamerlingh Onnes discovered superconductivity in mercury at an ultralow temperature (4.2 K) [1]. Over the years, researchers investigated a wide range of elements and compounds and other materials, including lead, niobium for discovering superconductivity in [2-52]. These materials exhibited fascinating properties; however, they all displayed a common limitation of extremely low transition temperatures to marked superconductivity [3-52]. A significant breakthrough occurred in the year 1986 when Bednorz and Müller reported a new family of superconductors, the high temperature superconductors (HTSs). This discovery of HTCs opened a new realm in the research of superconductivity by indicating that superconductivity could occur at relatively higher transition temperatures [4-52]. The HTSs represented a class of ceramic compounds primarily composed of copper oxides, barium carbonates and rare earth oxides. The development of HTSs like YBaCuO (Y123) has paved the way for new possibilities in terms of their applications in various scientific fields and modern technologies [2-52]. Also researchers have paid their synergetic efforts in formulating mechanism/theory for explaining superconductivity in high temperature superconductors [1-52]. Present review study attempted to explore the importance of emergence of high temperature superconductors, theoretical considerations/mechanism/theories, addressing challenges and unanswered questions in high temperature Superconductors along with applications of high temperature superconductors in modern technologies.

2. IMPORTANCE OF THE EMERGENCE OF HIGH TEMPERATURE SUPERCONDUCTORS:

- **Redefining High Temperatures:** High temperature superconductors can exhibit superconducting behaviour at temperatures above 90 K, which is achievable with relatively simple cryogenic equipment compared to the extremely low temperatures required by conventional superconductors whose transition temperatures are extremely low to marked superconductivity [1-52].
- **Practical Applications:** The ability to achieve superconductivity at higher temperatures brought forth a wide range of practical applications. High temperature superconductors have the potential to revolutionise power transmission, transportation, research and medical science & technologies. [1-52].

- **Enhanced Accessibility:** High temperature superconductors provided an accessible platform for researchers to conduct superconductivity experiments and explore research for investigating superconductors at higher temperatures [1-52].

3. THEORETICAL CONSIDERATIONS OF HIGH TEMPERATURE SUPERCONDUCTORS:

High-temperature superconductivity has been the subject of extensive research [1-52], leading to the development of several theoretical frameworks/theories aimed at comprehending the underlying mechanisms of occurrence of superconductivity in high temperature superconductors. Key components of this comprehension revolve around the roles of charge carriers and electron-phonon interactions. To better grasp these concepts, various theoretical considerations/mechanisms/theories [1-52] are discussed briefly below:

- **BCS Theory:** Originally developed for conventional superconductors, the Bardeen Cooper Schrieffer (BCS) theory describes superconductivity as a result of electron pairing due to attractive electron phonon interactions. However, this theory doesn't fully explain high temperature superconductors [19].
- **Resonating Valence Bond Theory**: This theory, proposed by Anderson, suggests that high temperature superconductivity arises from a quantum mechanical phenomenon where electrons are entangled in a unique way, forming resonating valence bonds. While it provides a fresh perspective, it doesn't offer a complete explanation for all high temperature superconductors [28].
- **Doping and Charge Carriers:** 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 by forming Cooper pairs [1-52]
- **Strongly Correlated Electron Systems:** Many high temperature superconductors are characterized by strong electronic correlations, which challenge conventional theories. The Hubbard model and tJ model are used to understand these systems, emphasizing the role of electron to electron interactions [1-52].
- **Electron phonon Interactions:** Phonons and Lattice Vibrations: In conventional superconductors described by the BCS theory, electron phonon interactions play a significant role. Phonons, which are quantized lattice vibrations, mediate the attractive interactions between electrons [1-52].
- **Polaron Formation:** In high temperature superconductors, 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 [1-52].
- **Anharmonicity:** Anharmonic phonon interactions can lead to exotic behaviours, and understanding these in high temperature superconductors and similar compounds is vital for explaining high temperature superconductivity [1-52].

4. ADDRESSING CHALLENGES AND UNANSWERED QUESTIONS IN HIGH TEMPERATURE SUPERCONDUCTORS:

Despite significant advancements in the study of high temperature superconductors, several challenges and open questions still persist [1-52]. These challenges highlight the need for a unified mechanism/theory to explain high temperature superconductivity:

- **Understanding the Mechanism:** The mechanism behind high temperature superconductivity in high temperature superconductors is not fully understood. Researchers are still working to develop a comprehensive theoretical framework that explains the unconventional behaviour of high temperature superconducting materials at relatively high temperatures. A unified theory for high temperature superconductivity is lacking.
- **Material Complexity:** High temperature superconductors have a complex crystal structure with multiple layers and elements. Synthesizing and processing these materials with high reproducibility remains challenging. Researchers are investigating new synthesis techniques and optimizing existing methods to improve material quality and performance.
- **Cryogenic Cooling:** Many high temperature superconductors require cryogenic cooling to maintain their superconducting state. This poses practical challenges, particularly in terms of energy consumption and maintenance in real world applications. Developing new cooling technologies and materials with higher critical temperatures is a key goal.
- **Anisotropy and Defects:** Anisotropic properties within the crystal structure of high temperature superconductors can lead to limitations in its performance. Understanding and controlling anisotropy is crucial to optimize its use in various applications. Additionally, defects in the crystal lattice can hinder superconductivity. Researchers are exploring ways to reduce and control defects in these materials.
- **Material Cost:** Most of high temperature superconductors contains rare-earth elements and other expensive components, making it costly to produce. Reducing material costs while maintaining or improving performance is very much essential for extensive adoption in practical applications.

- **Large Scale Fabrication:** Scaling up the production of high temperature superconductors based components, such as superconducting cables for industrial applications remains still a challenge. Developing cost effective and efficient manufacturing processes is very critical and vital.
- **Commercial Viability:** While high temperature superconductors show huge promise, their commercial feasibility and acceptance in various industries, including energy, healthcare and transportation, face challenges. Hence, high temperature superconductors must prove to be reliable, cost-effective and easy to put into practice on a large scale.
- **Environmental and Safety Concerns:** High temperature superconductors often use rare and environmentally sensitive materials. Addressing these concerns and developing sustainable practices in the production and disposal of high temperature superconducting materials are becoming very much essential.

5. APPLICATIONS OF HIGH TEMPERATURE SUPERCONDUCTORS IN MODERN TECHNOLOGIES:

High temperature superconductors have vital potential to transform various technological fields due to their extraordinary superconducting properties, especially high transition temperatures. Some current and potential applications of high temperature superconductors and their implications in respect to energy transmission, storage, and medical technologies are discussed briefly below [1-52]:

Energy Transmission:

- **Efficient Power Lines:** High temperature superconductors can be used to make efficient power transmission lines. They can carry electric current with zero resistance, significantly reducing energy losses during transmission [1-52].
- **Grid Integration**: Integrating high temperature superconductors based superconducting cables into existing power grids can increase their capacity and reliability [1-52].

Energy Storage:

- **Magnetic Energy Storage:** High temperature superconductors can be employed in magnetic energy storage systems, leading to an extremely efficient and compact technique for storage of electrical energy. Such energy storage systems can be utilised in renewable energy integration, grid stabilization and uninterruptible power supplies [1-52].
- **Flywheel Energy Storage:** Superconducting flywheels using high temperature superconductors based bearings, can store energy in form of kinetic energy for various applications [1-52].

Medical Technologies:

- **Magnetic Resonance Imaging (MRI):** High temperature superconductors based superconducting magnets are used in manufacturing high field MRI machines in medical science. Such machines provide images of higher resolution with faster scans, and improved diagnostic capabilities [1-52].
- **Magnetoencephalography (MEG)**: Magnetoencephalography machines measure the magnetic fields generated by neuronal activity in the brain, benefit from high temperature superconductors in their sensors. MEG detects records and analyzes the magnetic fields produced by electrical currents in the brain [1-52].

Transportation:

- **Magnetic Levitation (Maglev) Trains:** High temperature superconductors can be used in developing magnetic levitation train systems. Such trains float above the tracks due to the repulsive force between superconducting magnets and the guide way, resulting in very high speed of the trains [1-52].

Research and Scientific Equipment:

- **Particle Accelerators:** High temperature superconductors based superconducting materials can be used in particle accelerators such as synchrotrons and colliders which are essential for fundamental research in physics and materials science [1-52].

Power Electronics:

- **Superconducting Fault Current Limiters (SFCLs):** High temperature superconductors can be used to make SFCLs that protect power systems from electrical faults by limiting fault currents which enhances the stability of the electrical grid [1-52].

Aerospace and Defence:

- **Magnetic Shields:** Superconducting materials can produce extremely effective magnetic shields. Such shields have significant applications in aerospace for shielding sensitive equipment in defence technologies [1-52].

6. CONCLUSION

It is concluded from the present review study that high temperature superconductors hold enormous promise and potential to transform various technological fields due to their extraordinary superconducting properties, especially high transition temperatures and could play a pivotal role in addressing contemporary energy and healthcare challenges and opening up new possibilities in technology and transportation. However, huge challenges and open questions are still remained to be addressed. To fully harness their potential, researchers are actively working to elucidate the underlying physics, improve material properties and address practical issues. A plausible choice for development of a unified mechanism/theory for explaining superconductivity in high temperature superconductors is yet to be formulated.

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REFERENCES

[1] H. Kamerlingh Onnes, Akad, Van Wetenschappen (Amsterdam) (1911) 14, 112, 616.
[2] J.G. Bednorz, and K.A. Muller, Z. Phys. (1986) 189, P94.
[3] S.N. Putti1n, et al, Nature (1993) 302. 220.
[4] A. Schelling, et al, Nature, 303, 50 (1993).
[5] B.T. Matthias, Physics Today (1993) 23.
[6] M.K. Wu. J.R. Ashburn. g. Torn, P.H. Hor, B.L. Meng, L.Gao, and Z.J. Huang. Y.Q. Wang and C.B. Chu, Phys. Rev. Lett. (1987) 90, 908.
[7] H. Maeda, et al, Jpn. J. Appl. Phys. Lett. (1988) 27, L209.
[8] Z.Z- Sheng and A.M. Herman, Nature 332, 55 (1988) 3S2. 138.
[9] C.N.R. Rao and B. Raveau, Acc. Chen. Boo. (1989) 22, 106.
[10] P.P. Freitas, et al, Phys. Rev. B (1987) 36,833.
[11] M. Hikita and M. Suzuki. Phys. Rev. B (1990) l, 134.
[12] L.G. Aslamozov and A.I. Larkin, Fiz. Trerd. Tela. (1968)10. 1104.
[13] K.W. Blazey, Springer series in Solid State Sciences. (1990) 90, 262.
[14] A. Gould. Physica C (1988) 15S. 555.
[15] F.London and H.London, Proc. Roy. Soc. Ser. A (1935)149 71.
[16] A.B. Pippard. Proc. Roy. Soc. Ser. A (1956)216, 547.
[17] V.L. Ginsburg and L.D. Landau, JEPT. (1950) 20, 1064.
[18] A.A. Arbikosov, JEPT (1957) 32, 1442.
[19] J. Bardeen, et al, Phys. Rev. (1957) 106, 162.
[20] B. Batlogg, et al, Phys. Rev. Lett. (1988) 60,754.
[21] J.M. Ferreira, et al, Phy. Rev. B (1988) 37, 1580.
[22] C.M. Srivastava, et al, J. Physics. (1988) 30, 1.
[23] J.B. Goodenough and A. Manthiram, Studies of High Temperature Superconductors, Ed. A. Narlikar (Nova Science Publishers, New York (1980)3,1.
[24] D. Allender, et al, Phys. Rev., B 91973) 7, 1020.
[25] C. M. Varma, et al, Solid State Commun. (1987) 62, 681.
[26] V.L. Kresin, Phys. Rev., B (1987) 35, 8716.
[27] J.R. Schrieffer, et al, Phys. Rev. Lett. (1988) 60, 944.
[28] P.W. Anderson, Science (1987) 235, 1196.
[29] P. Prelovsek, et al, J. Phys.C (1987) 20, L229.
[30] L.J., De Jongh, Physica C(1988) 152. 171.
[31] A.W. Sleight, et al, Solid State Commun. (1975) 17, 27.
[32] L.F. Matteiss, et al, Phy. Rev, B (1988) 37, 3748.
[33] R.J. Cava, et al, Nature (1988) 332. 814.
[34] Y. Tokura, et al, Nature(1989) 337, 345.
[35] J. Akimitsu, et al, Jpn. J. Appl. Phys (1988) 87, 27, L1859.
[36] P. H. Hor, et al, Phys. Rev. Lett. (1987) 58, 1891.
[37] P. Marsh, et al, Nature (1988) 334.141.
[38] R.J. Cava, et al, Nature (1988) 336. 211.
[39] A. Santoro, et al, Physica C (1988) l56, 693.
[40] N. Sudhakar et al, Solid State Commun. (1991) *77*, 529.
[41] S.V. Sharma, Bulletin of Pure & Applied Sciences (Physics), 31(2012) D-1, 51-58.
[42] S. V. Sharma, Ind. J. Cryogenics (1995) 20, 21-28.
[43] S.V. Sharma, International Journal of Science and Research (IJSR) (2024) 13(10), 531-533.
[44] R.G. Sharma, Superconductivity: Basics and Applications to Magnets, Springer Series in Material Science

(2015)14, 1-427.
[45] T. Kruaehong, et al, Journal of Materials Science and Applied Energy (2019) 8 (3) 460-468.
[46] Adir Moysés Luiz, Superconductivity – Theory and Applications, Published by InTech Janeza Trdine (2011) 9, 51000 Rijeka, Croatia.
[47] Ivan A. Troyan,1 et al, Progress, problems and prospects of room-temperature superconductivity (2024) arXiv:2406.11344 (cond-mat.supr-con).
[48] S.V. Sharma, High Temperature Oxide Superconductors, Laxmi Prakashan, First Edition (ISBN: 878-818524-88-8).
[49] S.V. Sharma, J. Material Science Letters 12, 137-141 (1993)
[50] S. V. Sharma, Bulletin of Pure & Applied Sciences Sec. D -Physics 20, 7 (2004)
[51] Ohtsuka, Taiichiro. (1999). Introduction to Superconductivity. Chapter 1: Historical Evolution on the Understanding of Superconductivity. TEION KOGAKU (Journal of Cryogenics and Superconductivity Society of Japan). 34. 134-143. 10.2221/jcsj.34.134.
[52] Li, B. et al, Phys. C Supercond. Appl. (2012) 482, 50–57.