High Temperature Superconductivity A Review

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Abstract— Superconductivity is a phenomenon of disappearance of electrical resistance below certain temperature. The phenomenon was discovered by Kammerling Onnes in 1911 in metallic mercury at 4K. Since then, quest is on to find materials which show the superconductivity phenomenon at higher temperatures. Earlier, some compounds called Cuprates were believed to show the High Temperature Superconductivity. But now certain compounds of iron are also believed to show superconductivity at higher transition temperatures. In this article, we briefly review the theory of high temperature superconductivity and some technological applications of High Temperature Superconductors.

Key words: Superconductivity, High Temperature

I. Introduction

Superconductivity refers to the phenomenon of disappearance of electrical resistance below a certain temperature called transition temperature T_c. High temperature superconductors (HTS) are the materials that have relatively high transition temperature. High transition temperature is generally considered as the temperature greater than the boiling point of liquid nitrogen i.e. 77 K. High temperature superconductivity was discovered in the year 1986 by J. Georg Bednorz and K Alex Muller. In the year 1987, a Yttrium based high temperature superconductor (YBaCuO) was discovered. It was followed by the discovery of a bismuth based HTS (BiSrCaCuO). Researchers have attempted to discover materials with high transition temperature. Now, Materials with transition temperature upto 133 K have been reported. Ultimate goal of all this research is room temperature superconductivity. Here in this article we review some concepts of high temperature superconductivity and its technological applications.

II. Comparison of High Temperature Superconductors with Conventional Superconductors

High Temperature Superconductors (or unconventional superconductors) differ from conventional superconductors like elemental mercury or lead in many important ways.

1) HTS have relatively high transition temperature than the conventional superconductors.
2) HTS can be thought of as doped Mott insulators while conventional superconductors are metals described by Fermi Liquid Theory.
3) Conventional Superconductors can sufficiently be explained by BCS Theory which explains Superconductivity on the basis of electron phonon interaction. However in HTS one is dealing with electron – electron interactions.
4) Conventional Superconductors can be Type – I superconductors, thus exhibiting complete Meissner effect. However all known HTS are Type – II superconductors only, which allow magnetic field to penetrate their interior in quantized units of flux.

III. Possible Mechanism of High Temperature Superconductivity

Conventional Superconductors can satisfactorily be explained by the BCS theory. However there is no widely accepted theory which explains all the properties of HTS and the phenomenon of high temperature superconductivity.

The Cuprate superconductors are generally considered to be quasi two dimensional materials. Their superconducting properties are determined by the electrons moving within the weakly coupled copper oxide layers. The parent state before doping either electrons or holes into the CuO_2 planes is an anti ferromagnetic insulator, having half-filling in the outer orbital and a very large on-site Coulomb repulsion that prevents double occupancy of both spin-up and spin-down electrons in the same valence states. The strong on-site Coulomb repulsion of the cuprates is in contrast to conventional superconductors with a metallic parent state so that the kinetic energy is much larger than the Coulomb repulsion. The on-site Coulomb repulsion in the cuprates decreases with increasing doping level. The combined effect of decreasing on-site Coulomb repulsion and increasing carrier mobility with increasing doping eventually leads to Cooper pairing and superconductivity.

There are two significant consequences due to the remnant of strong on-site Coulomb repulsion in the cuprates. One consequence is the preference for the $d_{x^2-y^2}$ - wave pairing symmetry because it gives rise to a spatially more extended pair wave function relative to the s-wave pairing, so that the strong on-site Coulomb repulsion can be tactfully avoided and the overall energy of the system is lowered. The other consequence is the occurrence of other phases coexisting with superconductivity in the ground state. Moreover, the physical properties at temperatures above the superconducting transition of most cuprates appear to differ significantly from the Fermi-liquid behavior of normal metals. There is a strong correlation between the transition temperature T_c and the $d_{x^2-y^2}$ orbital occupancy. In cuprates, the five d - orbitals of copper undergo energy splitting with $d_{x^2-y^2}$ being the highest energy d – orbital. It is the $d_{x^2-y^2}$ orbitals which contain the electrons responsible for superconductivity in High Temperature Superconductors. Their superconducting properties are affected if there is alteration in the occupancy of these levels. It has been proposed that in a doped system, the antiferromagnetic spin fluctuations give rise to the High temperature superconductivity. Spin fluctuation mechanism is possible only if the pairing wave function has d - wave symmetry.

Another model to explain high temperature superconductivity was interlayer coupling model, according to which a layered structure having s-wave symmetry type superconductors (conventional superconductors) can enhance the superconductivity by itself by introducing an additional tunnelling interaction between each layer. This model successfully explained the anisotropic symmetry of the order parameter as well as the emergence of the HTS.

Some of the experiments predicted the d-wave symmetry model and some supported the s-wave symmetry model of high temperature superconductivity.

IV. TECHNOLOGICAL APPLICATIONS OF HIGH TEMPERATURE SUPERCONDUCTIVITY

High Temperature Superconductors have high transition temperature. Since the critical magnetic field required to suppress the superconducting behavior is related to the transition temperature T_c as:

$$H_c(T) = H_c(0)(1 - \frac{T^2}{{T_c}^2})$$

i.e. higher the transition temperature, greater is the critical magnetic field required to suppress the superconductivity. So, technological applications of HTS are benefitted both from high T_c and high H_c.

High temperature superconductors currently known are mostly the brittle ceramics, expensive and difficult to form into wires, hence making their commercial applications limited. Since HTS can withstand higher magnetic fields, So HTS has application in scientific and industrial magnets, including use in NMR and MRI systems replacing Low Temperature Superconductors. Other applications of HTS include:-

1) In Electronics such as HTS microwave filters and superconducting analog to digital converters.
2) In Sensors: Extremely sensitive magnetic field sensors like "Superconducting Quantum Interference devices" (SQUIDS). In superconducting Bolometers , the sharp superconducting transition as a function of temperature is used as very sensitive thermometer which allows to measure with high sensitivity the heating of a thermally connected absorber under electro magnetic irradiation
3) Superconducting magnetic bearings
4) For power cables and transformers due to their low losses and reduced volume and weight owing to their potential for high power density.
5) In fault current limiters for preventing overloading of grid components.

Other promising future applications of high temperature superconductors include energy storage, induction heaters, magnetic levitation for high speed trains, generators and motors.

V. CONCLUDING REMARKS

This article provides an overview of High temperature superconductivity and lists some of the applications of High temperature superconductors. The researchers of high temperature superconductivity have always dreamt of enhancing the properties of high temperature superconductors for their use in industrial applications. Recent discovery of high temperature superconductivity in iron based compounds has drawn a great attention of the researchers all over the world. To further increase the superconducting transition temperature, T_c and to understand the HTS mechanism are two prominent issues being faced by the current study of high temperature superconductors.

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