Research Paper Science

High Temperature Superconductor

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ABSTRACT

Superconductivity, as an interesting phenomenon that also has a number of technological uses, was studied by many people over the next few decades to figure out why it happens. The clues found in those years of experiments included the discovery that metals below the critical temperature also expel magnetic fields from their interiors—something that a simple loss of electrical resistance wouldn't cause by itself. Another important clue was the mid-20th-century finding that a material's critical temperature depends in a particular way on the masses of its ions.

KEYWORDS LTSHTS,type-I superconductors,Type-II superconductors,BCS,medical imagin (MRI), liquid nitrogen temperature.

Introduction:

The discovery of' "high-temperature" superconductors in the 1978s — materials that could lose resistance at temperatures of up to negative 145 degrees Celsius — led to speculation that a surge of new discoveries might quickly lead to room-temperature superconductors. Despite intense research, these materials have remained poorly understood [1].

HTS technology reduces electric losses and increases the efficiency of power equipment. This book by SwarnKalsi, a leading expert on the HTS subject, provides a survey of the HTS technology and the design rules, performance analyses, and manufacturing concepts for power application-related devices. It compares conventional and HTS technology approaches for device design and provides significant examples of devices utilizing the HTS technology today.

In high temperature superconductors, the BCS electron—phonon theory does not seem to apply directly. However, many people believe that electron pairing into Copper pairs still takes place, although phonons may not be responsible for the attractive interaction between them. In this case the constant should still be proportional to the charge carrier density of states at the Fermi surface; hence pressure can still increase the transition temperature [2].

'High-temperature' was a relative term: even the best of the materials would not transition to become superconducting — having no resistance to an electric current — until it was chilled below 90 K (roughly 210 °C below room temperature). But that was nearly four times higher than the transition temperature of any previously observed superconducting material, and shattered what had once seemed to be a solid theoretical upper limit of 30 K. Everyone in the ballroom knew that, whatever was going on, it was something profoundly new.

In 1990, 71 years after the discovery of superconductivity, George Bednorz and Karl Muller at IBM,Zurich demonstrated superconductivity in a perovskite structured lanthanum based cuprate oxidewhich showed a TC of 40 K for which the inventors also won Physical Noble prize in 1987. This wasa remarkable discovery as it later allowed chemical substitution in perovskite cuprates to push thetransition temperatures well beyond the liquid nitrogen temperature (70 K) which is a much cheaperand easily accessible medium as compared to liquid helium.

Superconductors are materials which, when cooled below room temperature, exhibit a sudden drop of electrical resistance of the material to exactly zero at a temperature called as critical temperature, TC. The phenomenon was discovered by Heike Kamerlingh Onnes in 191lwhen he was studying properties of mercury at liquid helium temperatures.Most first generation superconductors were elemental metals and metallic alloys. While most pure elemental materials like tin, aluminum were called as type-I superconductors, metallic alloys like niobium nitride, niobium-titanium, and niobium-germanium alloys were classified as type-II superconductors. However, most of these are superconducting at temperatures below 28 K.The onset of superconducting transition is also accompanied by abrupt changes in various physical

First-Generation Superconductors (IG HTS) The most commonly used materials in early HTS were bismuth-based, specifically Ti-2212 and Ti- 2223. These materials have come to be known as first generation (1G) superconductors and have been used to demonstrate a variety of HTS power devices including transmission cable, transformers, fault current controllers, motors and generators. Performance benefits of these HTS devices compared to conventional, non-superconducting devices have been demonstrated for all these applications [3].

High Temperature Superconductors (HTS) The discovery of ceramic-based high temperature superconductors in 1986 in Germany opened the possibility of applying superconductivity to electric power devices. The 'high' in HTS refers to the ability to achieve the superconducting state at temperatures attainable using inexpensive liquid nitrogen, approximately 70K. The reduced cooling needs of HTS offer performance advantages to electric power devices that did not exist with LTS [4].

The high temperature superconducting materials are of category of Type-II superconductors and show a gradual change in transition temperature as a function of the magnetic field. There has been intensive research on developing a theory for high temperature superconductivity and consequently a few mechanisms have been proposed, out of which following two are well accepted.

First mechanism is based on the anti-ferromagnetic spin fluctuations in a doped system such as curates. Spin fluctuation tests yield information on the symmetry of the pairing wave function which, for cuprates, should be of the type dx2-y2. The second model is the interlayer coupling model which states that superconductivity in a layered structure consisting of BCS-type symmetry i.e. s-wave [5].

Symmetry can be enhanced by itself. Preparation of high-T_c superconductors Superconductors are materials that conduct electricity with 100 percent efficiency, losing nothing to resistance. They were discovered exactly 100 years ago by the Dutch physicist Heike Kamerlingh Onnes, just after he developed a method to liquefy Helium gas at —4 degrees above tile absolute zero of temperature (i.e., at 4 Kelvin, which is

equivalent to 269 Celsius). Currently used in medical imaging (MRI), highly efficient electrical generators and high field magnets, superconductors have the potential to become a truly transformative technology; energy transmission would be just one beneficiary. However, this promise is hampered by one thing: superconductors work only at extremely low temperatures. Although research over the past 35 years has developed "high-temperaturesuperconductors" that work at warmer temperatures, even the warmest of them—the cuprates—musi chilled half-way to the absolute zero of temperature (0 Kelvin) before they will superconduct.

Bardeen, Cooper, and Schrieffer showed that, when certain materials cool below their critical temperature, their ion lattices can distort enough for the electrons' attraction to it to overcome their own mutual repulsion. This makes it possible for the electrons to flow together as a unit whose energy and momentum are so different from any state of independent electron motion that lattice collisions cannot transfer enough momentum or energy to remove any electrons from the collective motion. The material thus becomes superconductive, its electron flow proceeding without resistance [6].

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Mercury was historically the first to show superconductivity, and it is an example of a Type superconductor (Fig 1). The superconducting transition of niobium (Fig 2) was observed 1 measuring the inductance of a coil which was wrapped around the sample. At the superconducting transition, the magnetic field is expelled by the Meissner effect and the inductance drops. Lanthanum Barium-Copper Oxide Superconductor, this ceramic material was the first of a' new class of high temperature superconductors (Fig 3). It is made by randomly substituting some barium atoms into the lattice of lanthanum- copper-oxide in what is termed a solid solution. In Fig 4, we have plotted for Yttrium-Oxide-Copper Oxide. This ceramic material was the first of the high temperature superconductors to make the phase change at a temperature above the liquid nitrogen temperature (77 K) [7].

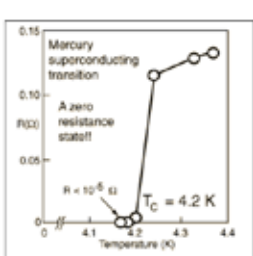


Fig.1 — Mercury Superconducting Transition

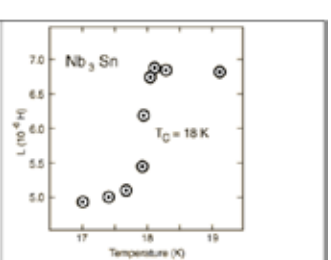


Fig .2 — Niobium— Superconductor

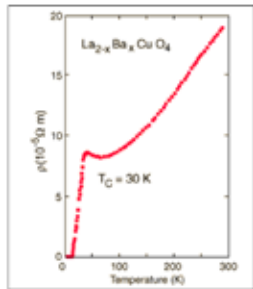


Fig.3 — Lanthanum—Barium—Copper Oxide Superconductor

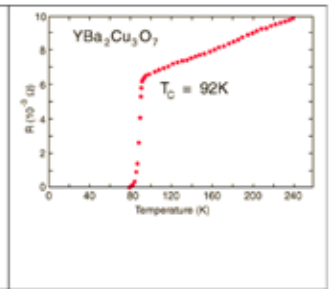


Fig.4 — Yttrium—Oxide—Copper Oxide

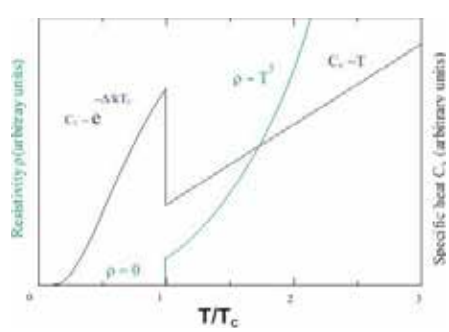
Magnetic fields allow to suppress superconductivity and thus to access the underlying electronic properties called the normal state. When superconductivity is suppressed, it is possible to probe the Fermi surface of the system with transport and magnetization measurements. We are hence able to access the ground state upon which superconductivity grows. Magnetic field suppresses superconductivity by unbinding the two electrons involved in a Cooper pair. The higher the binding energy of the Cooper pair, the greater the intensity of the magnetic field required to break it apart. The binding energy of a Cooper pair is proportional to the critical temperature T_c. Hence, for low T_c superconductors (such as tin or lead), a commercially available magnet is usually more than enough to suppress superconductivity. However, in the case of high-T_c cuprates, world-class high magnetic fields are required to access the normal state. Those high magnetic fields are produced in special facilities such as the LNCM1 here in Toulouse

The simplest method for preparing high-T_c superconductors is a solid-state thermo chemical reaction involving mixing, calcination and sintering. The appropriate amounts of precursor powders, usually oxides and carbonates, are mixed thoroughly using a ball mill. Solution chemistry processes such as coprecipitation, freeze-drying and sol-gel methods are alternative ways for preparing a homogeneous mixture. These powders are calcined in the temperature range from 900°C to 1050°C for several hours. The powders are cooled, reground and calcined again. This process is repeated several times to get homogeneous material. The powders are subsequently compacted to pellets and sintered. The oxygen stoichiometry in this material is very crucial for obtaining a superconducting $YBa_2Cu_3CB_{7-x}$ compound. At the time of sintering, the semiconducting tetragonal $YBa_2Cu_3O_6$ compound is formed, which, on slow cooling in oxygen atmosphere, turns into superconducting $YBa_2Cu_3O_7$-

`Conclusion:

Properties such as heat capacity, which can be associated with a phase transition. For instance as shown in figure 1, while in the non-superconducting (normal) regime, the electronic heat capacity is proportional to the temperature i.e. Cv T, at TC, it shows an abrupt jump and does not remain linear in the superconducting regime, varying as Cv T-aT where a is. a constant. The nature of phase transition depends upon the type of superconductor.

Figure:5



The BCS theory (named after J. Bardeen, L. Cooper and J. Schrieffer, who elaborated it) which describes superconductivity as a condensation ofelectron pairs, known as Cooper pairs. The formation of such a pair relies on the electron-phonon interaction which is found to be attractive below a certain energy scale. BCS superconductors are thus known to be phonon mediated, meaning that exchange of phonons between two electrons provide the glue for the pair formation [8].

Summary

Superconductors are the materials which show a sudden drop of electrical resistance at a certain temperature when cooled below room temperature. While most superconductors of early generation were low TC materials, next generation superconductors, layered oxides based on perovskite structure, were called as high TC as materials showing TC in the excess of liquid N2 temperature.These have been successfully fabricated in various forms and examined at various places across the world. While the BCS theory explains the origin the superconductivity in the low TC superconductors quite well, a well agreed theory for the high TC ceramic oxides is yet to evolve. These have found applications in magnetically levitated trains and magnetic resonance imaging for medical applications.

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