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Study of Boron Based Superconductivity and Effect of High Temperature Cuprate Superconductors

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***Abstract**: This paper illustrates the main normal and Boron superconducting state temperature properties of magnesium diboride, a substance known since early 1950's, but lately graded to be superconductive at a remarkably high critical temperature Tc=40K for a binary synthesis. What makes MgB2 so special? Its high Tc, simple crystal construction, large coherence lengths, high serious current densities and fields, lucidity of surface boundaries to current promises that MgB2 will be a good material for both large scale applications and electronic devices. Throughout the last seven month, MgB2 has been fabricated in various shape, bulk, single crystals, thin films, ribbons and wires. The largest critical current densities >10MA/cm2 and critical fields 40T are achieved for thin films. The anisotropy attribution inferred from upper critical field measurements is still to be resolved, a wide range of values being reported, $\gamma = 1.2 \div 9$. Also there is no consensus about the existence of a single anisotropic or double energy cavity. One central issue is whether or not MgB2 represents a new class of superconductors, being the tip of an iceberg that waits to be discovered. Until now MgB2 holds the record of the highest Tc among simple binary synthesis. However, the discovery of superconductivity in MgB2 revived the interest in non-oxides and initiated a search for superconductivity in related materials, several synthesis being already announced to become superconductive: TaB2, BeB2.75, C-S composites, and the elemental B under pressure.*

I. INTRODUCTIN

High-temperature superconductors (abbreviated high-Tc or HTS) are materials that behave as superconductors at unusually high temperatures. The highest -Tc superconductor was discovered in 1986 by IBM researchers Karl Müller and Johannes Bednorz, who were awarded the 1987 Nobel Prize in Physics "for their important break-through in the discovery of superconductivity in ceramic materials".

Until 2008, only certain compounds of copper and oxygen (so-called "cuprates") were believed to have HTS properties, and the term high-temperature superconductor was used interchangeably with cuprate superconductor for compounds such as bismuth strontium calcium copper oxide (BSCCO) and yttrium barium copper oxide (YBCO). However, several iron-based compounds (the iron pnictides) are now known to be superconducting at high temperatures. Some cuprates have an upper critical field of 100 tesla. However, cuprate materials are brittle ceramics which are expensive to manufacture and not easily turned into wires or other useful shapes.

In 2004, bridging the gap unraveling the super hardness and the superconducting communities, Ekimov et al exposed the superconducting behaviour of a diamond sample resulting from annealing graphite with B4C at 2500-2800 K under 8-9 GPa for 5s. These authors planned also a mechanism for the transformation of graphite into diamond at high pressure and high temperature (HPHT), and made a careful characterization of the diamond polycrystal . Similar results be reported shortly after for polycrystalline and (100)-oriented single crystaldiamond films full-fledged by microwave plasma-assisted chemical vapour deposition (MPCVD), showing that “zero” resistivity could be experiential up to the boiling temperature of helium (4.2 K), that doping-induced superconductivity appeared above about 6 1020 B/cm3 and that Tc amplified with the Boron concentration.

Fig 1 Structure of Boron Isotope

II. LITERATURE REVIEW: PAST RESEARCH WORK ON THE CUPRATE SUPERCONDUCTORS

C. C. Tsuei et al. (Oct 15, 2000), have developed Pairing symmetry in the cuprate superconductors is an important and controversial topic. The recent development of phase-sensitive tests, combined with the refinement of several other symmetry-sensitive techniques, has for the most part settled this controversy in favor of predominantly d-wave symmetry for a number of optimally hole- and electron-doped cuprates. This paper begins by reviewing the concepts of the order parameter, symmetry breaking, and symmetry classification in the context of the cuprates. After a brief survey of some of the key non-phase-sensitive tests of pairing symmetry, the authors extensively review the phase-sensitive methods, which use the half-integer flux-quantum effect as an unambiguous signature for d-wave pairing symmetry. A number of related symmetry-sensitive experiments are described. The paper concludes with a brief discussion of the implications, both fundamental and applied, of the predominantly d-wave pairing symmetry in the cuprates.[2]

Andrea Damascelli et al. (Apr 17, 2003), have developed the last decade witnessed significant progress in angle-resolved photoemission spectroscopy (ARPES) and its applications. Today, ARPES experiments with 2-meV energy resolution and 0.2° angular resolution are a reality even for photoemission on solids. These technological advances and the improved sample quality have enabled ARPES to emerge as a leading tool in the investigation of the high-Tc superconductors. This paper reviews the most recent ARPES results on the cuprate superconductors and their insulating parent and sister compounds, with the purpose of providing an updated summary of the extensive literature. The low-energy excitations are discussed with emphasis on some of the most relevant issues, such as the Fermi surface and remnant Fermi surface, the superconducting gap, the pseudogap and d-wave-like dispersion, evidence of electronic in homogeneity and nanoscale phase separation, the emergence of coherent quasiparticles through the superconducting transition, and many-body effects in the one-particle spectral function due to the interaction of the charge with magnetic and/or lattice degrees of freedom. Given the dynamic nature of the field, we chose to focus mainly on reviewing the experimental data, as on the experimental side a general consensus has been reached, whereas interpretations and related theoretical models can vary significantly. The first part of the paper introduces photoemission spectroscopy in the context of strongly interacting systems, along with an update on the state-of-the-art instrumentation. The second part provides an overview of the scientific issues relevant to the investigation of the low-energy electronic structure by ARPES. The rest of the paper is devoted to the experimental results from the cuprates, and the discussion is organized along conceptual lines: normal-state electronic structure, interlayer interaction, superconducting gap, coherent superconducting peak, pseudogap, electron self-energy, and collective modes. Within each topic, ARPES data from the various copper oxides (1) are presented.[4]

Cu = O (1)

D.J. Scalapino et al. (Mar 27, 2006), have developed the nature of the orbital structure of the pairs in the superconducting phase of the high-temperature superconducting cuprates remains one of the central questions in this field. Here we examine the possibility that the superconducting state of these materials is characterized by $dx2 - y2$ pairing. We begin by looking theoretically at why this type of pairing might be favored in a strongly correlated system with a short-range Coulomb interaction. Then we turn to the experimental question of how one would know if $dx2 - y2$ pairing was present.[3]

III. ADVANTAGES OF HIGH TEMPERATURE SUPER CONDUCTIVITY

The mercantile applications so far for high temperature superconductors (HTS) have been limited.

HTS can super conduct at temperatures upper the boiling point of the nitrogen liquid, which makes them cheaper to cool than low temperature superconductors (LTS). However, the trouble with HTS technology is that at present known high temperature superconductors are fragile ceramics which are luxurious to manufacture and not easily formed into wires or other useful shapes. Therefore the applications for HTS have been where it has some other essential advantages.

- Minimal thermal loss current leads for LTS devices (low thermal conductivity),
- RF and microwave filters (low resistance to RF), and
- Increasingly in particularist scientific magnets, particularly where size and electricity consumption are critical (while HTS wire is much more expensive than LTS in these applications, this can be offset by the relative cost and convenience of cooling); the ability to ramp field is desired (the higher and wider range of HTS's operating temperature means faster changes in field can be managed); or cryogen free operation is desired (LTS generally requires liquid helium that is becoming more scarce and expensive).

IV. THERMAL EXPANSION

Thermal expansion, analogous to compressibility, exhibits a pronounced anisotropy, with the c-axis responses substantially higher than a-axis, as illustrated in Fig. 2. The lattice parameter along c-axis increases twice compared to the lattice parameter along a-axis at the same temperature [Jorgensen]. This fact demonstrates that the out-of-plane Mg-B bonds are much weaker than in-plane Mg-Mg bonds. Band structure calculations clearly reveal that, while strong B-B covalent bonding is retained, Mg is ionized and its two electrons are fully donated to the B-derived conduction band [Kortus]. Then it may be assumed that the superconductivity in MgB2 is essentially due to the metallic nature of the 2D sheets of boron and high vibrational frequencies of the light boron atoms lead to the high Tc of this compound.[1]

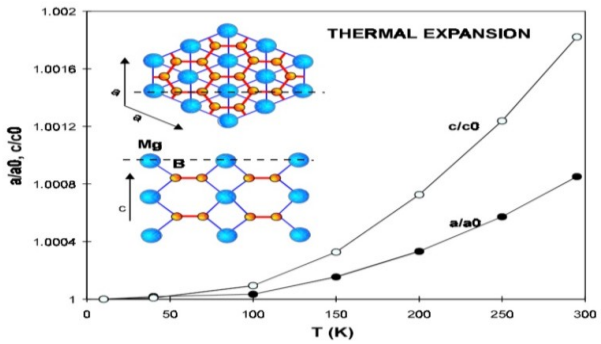

Fig 2. The normalized thermal expansion along a and c-axis. Inset shows the boron-boron and magnesium-boron bonds. The data thermal expansion data are taken from [Jorgensen].

V. EFFECT OF SUBSTITUTIONS ON CRITICAL TEMPERATURE

The substitutions are important from several points of view. First, it may increase the critical temperature of one compound. Secondly, it may suggest the existence of a related compound with higher Tc. And last but not least, the doped elements which do not lower the Tc considerably may act as pinning centers and increase the critical current density. In the case of MgB2, several substitutions have been tried up to date: carbon [Ahn], [Mehl], [Paranthaman (b)], [Takenobu], [Zhang (a)]; aluminium [Bianconi (b)], [Cimberle], [Li (b)], [Lorenz (b)], [Slusky], [Xiang], [Ogita], [Postorino]; lithium, silicon [Cimberle], [Zhao (a)]; beryllium [Felner], [Mehl]; zinc [Kazakov], [Moritomo]; copper [Mehl], [Kazakov]; manganese [Ogita], [Moritomo]; niobium, titanium [Ogita]; iron, cobalt, nickel [Moritomo]. In Fig. 3 is shown Tc versus the doping content, $0<x<0.2$, for substitutions with Al, C, Co, Fe, Li, Mn, Ni, Si, and Zn. The critical temperature decreases at various rates for different substitutions, as can be seen in Figs. 3 and 4. The largest reduction is given by Mn [Moritomo], followed by Co [Moritomo], C [Takenobu], Al [Li (b)], Ni, Fe [Moritomo]. The elements which do not reduce the critical temperature of MgB2 considerable are Si and Li [Cimberle]. Up to date, all the substitutions alter the critical temperature of magnesium diboride with an exception: Zn, which increases Tc slightly, with less than one degree [Moritomo], [Kazakov]. There are only two reports regarding Zn doping. Both agree with the fact that at a certain doping level Tc increases, but disagree with the doping level for which this fact occur. This may be due to the incorporation of a smaller amount of Zn than the doping content. Anyway, Zn doping deserves further attention. In Fig. 4 is shown Tc versus doping level $0<x<0.82$ for substitutions with C [Zhang], [Takenobu] and Al [Bianconi], [Xiang], [Slusky], [Lorenz (b)], [Li (b)],

[Cimberle]. The critical temperature variation versus x for Al reflects the existence of structural transitions at different doping levels, the slopes dTc/dx from different reports being in agreement with each other. The investigation of Tc and lattice parameters with Al substitution in Mg1-xAlxB2, lead to the conclusion that MgB2 is near a structural instability that can destroy superconductivity [Slusky]. Critical temperature decreases smoothly with increasing x from $0<x<0.1$, accompanied by a slight decrease of the c-axis parameter. At $x\approx1$ there is an abrupt transition to a non-superconducting isostructural compound which has a c-axis shortened by about 0.1 Å. The loss of superconductivity associated with decreasing the c-axis length with no change in the cell symmetry suggests that the structure parameters of MgB2 are particularly important in its superconductivity at high Tc. In the case of C doping the two reports [Zhang], [Takenobu] disagree with the value of the critical temperature at different doping levels. This may be due to the fact that carbon was not completely incorporated into the MgB2 structure in the report of Zhang [Zhang (a)]. Also, the existence of different critical temperatures for the starting MgB2 at zero doping levels may give different Tc(x) behaviours. As it was pointed out previously, we believe Mg nonstoichiometry leads to different critical temperature dependencies versus the applied pressure, therefore we may expect different Tc(x) behaviours as a function of small Mg nonstoichiometry. However, in order to have a clear picture about the effect of substitutions on MgB2 more data in a wider range of doping levels are necessary.[1]

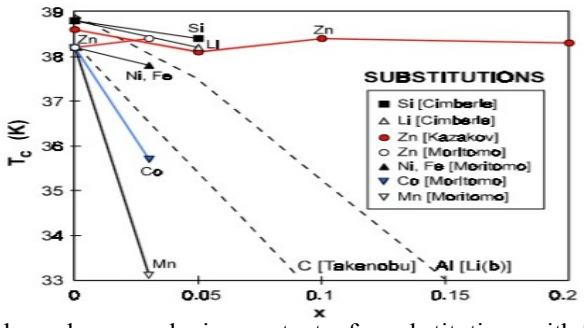

Fig 3. Critical temperature dependence on doping content x for substitutions with Zn, Si, Li, Ni, Fe, Al, C, Co, Mn ($0<x<0.2$)

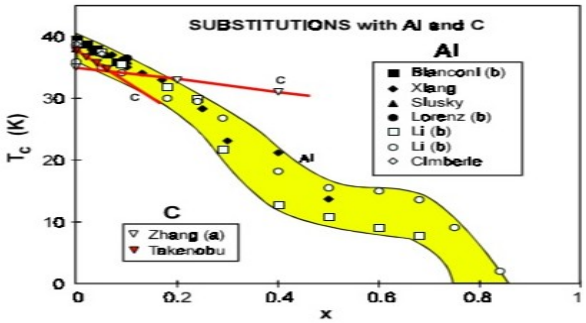

Fig 4. Critical temperature dependence on doping content x for substitutions with Al and C.

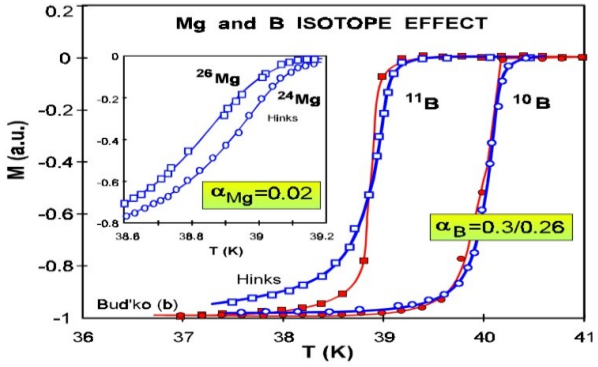

Fig 5 The relative magnetization versus temperature for B isotopically substituted samples. Inset shows Mg isotope effect.

VI. CHEMICAL CONSTITUENTS OF CUPRATE SUPER CONDUCTORS

Cuprate loosely refers to a material that can be viewed as containing copper anions. Examples include tetrachlorocuprate ([CuCl4]2-), the superconductor YBa2Cu3O7, and the organocuprates ([Cu(CH3)2]-). The term cuprates derives from the Latin word for copper, cuprum. The term is fundamentally used in three contexts - oxide materials, anionic coordination complexes, and anionic organo copper compounds.

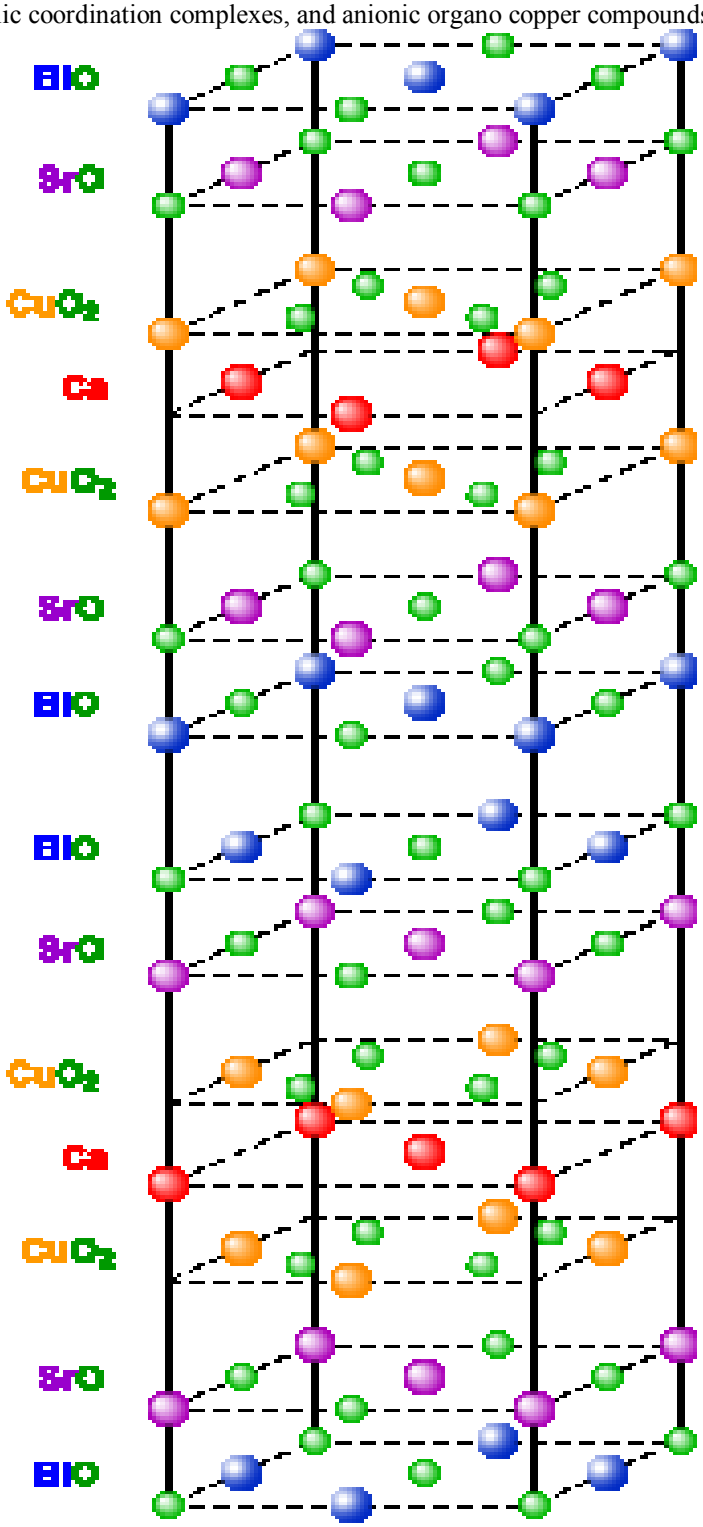

Fig 6 the unit cell of high temperature superconductor BSCCO-2212

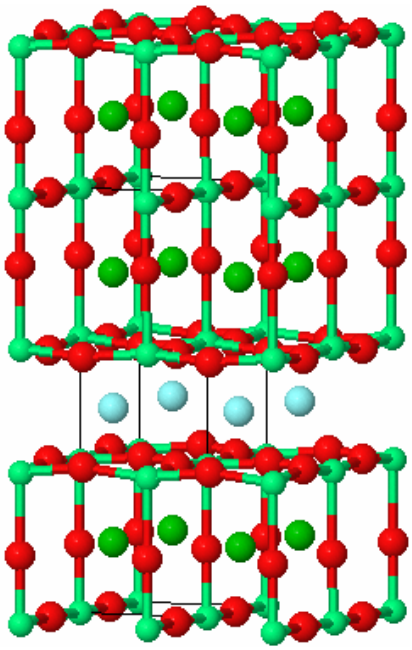

Fig 7 Structural features of the high-Tc cuprate superconductors

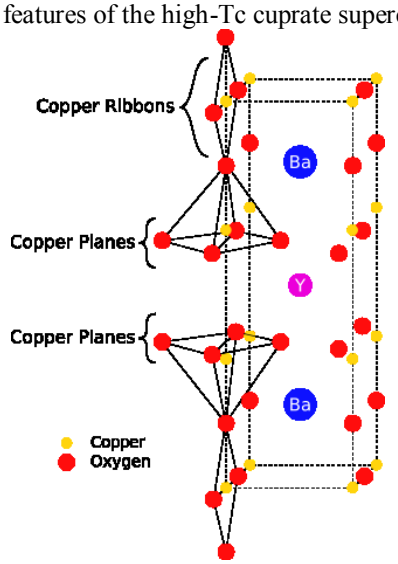

Fig 8 Yttrium Barium Copper Oxide

VII. POSSIBLE MECHANISM

There are 2 representative theories for HTS. Primarily, it's been urged that the HTS emerges from hymenopterans insect magnetic force spin fluctuations during a doped system. Consistent with this theory, the pairing waves operate of the cuprate HTS ought to have (dx2-y2) similarity. Thus, determinant whether or not the pairing wave operate has d-wave symmetry is crucial to check the spin fluctuation mechanism. That is, if the HTS order parameter (pairing wave function) doesn't have d-wave symmetry, and so a pairing mechanism associated with spin fluctuations will be dominated out. (Similar arguments will be created for iron-based superconductors however the various material properties enable a distinct pairing symmetry.) Secondly, there was the layer coupling model, consistent with that a superimposed structure consisting of BCS-type (s-wave symmetry) superconductors will enhance the electrical conduction by itself.

A method for electrochemical synthesis of a superconducting boron compound MgB2, which contains the steps of:

Preparing a powder mixture of magnesium chloride, sodium chloride, and potassium chloride and magnesium borate at a molar ratio of 10 :(10−x): x: 2, wherein x is between 3 and 7;

putting the powder mixture into a reaction vessel having a platinum wire at one end and a carbon rod at an opposite end, said platinum wire being connected to the negative electrode of a direct current via a gold wire fixed to the platinum wire and said carbon rod being connected to the positive electrode of the power supply via a gold wire fixed to the carbon rod;

heating the reaction vessel at a temperature of 400° C. or below under an inert gas atmosphere to dry the powder mixture; heating the reaction vessel at a temperature of 400° C. or above under an inert gas atmosphere to melt the powder mixture and; applying a direct current voltage through the power supply to the two gold wires to establish current in the powder and precipitate superconducting boron compound MgB2 onto the platinum wire.

The reaction temperature for obtaining MgB2 in the method of the invention is at least 400° C., preferably between 400 and 800° C., more preferably between 400 and 700° C., and most preferably between 400 and 600° C.

Commercial grades of magnesium chloride (MgCl2), sodium chloride (NaCl), potassium chloride (KCl) and magnesium borate (MgB2O4) in powder form are weighed at a molar ratio of 10:(10−x):x:2 in a total quantity of two grams and mixed uniformly. The value or x, or the quantity of potassium chloride is adjusted to lie between 3 and 7. The thus prepared mixture is hereunder referred to as a powder sample.

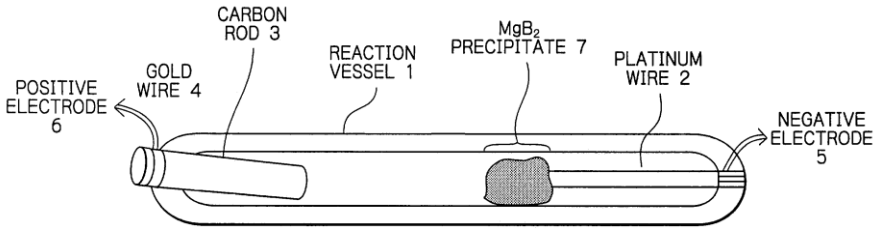

Fig 9 shows the structure of a reaction vessel used to precipitate MgB_2 in the invention

As Fig. 5 shows, the powder sample is put into a box-type reaction vessel 1 that is made of aluminum oxide and which measures 100 mm by 10 mm by 10 mm, with a wall thickness of about 1 mm. A platinum wire 2 having a diameter of 1 mm is guided on the inner surface of the bottom of the reaction vessel and fixed to an end of it in the longitudinal direction. Similarly, a carbon rod 3 having a diameter of 5 mm is fixed to the other of the reaction vessel. A gold wire 4 having a diameter of 0.3 mm is thermo compressed to each of the platinum wire and the carbon rod.

The reaction vessel containing the powder sample is put into a quartz tube (not shown) having a diameter of about 40 mm, which is filled with argon gas. The quartz tube is then inserted into an electric furnace. A dc power supply is provided and the gold wire on the platinum wire 2 is connected to the negative electrode 5 and the gold wire on the carbon rod 3 is connected to the positive electrode 6. As argon gas is flowed at a rate of about 1 L/min, the powder sample is heated to 400° C. or below and left to stand for 1 hour until it dries.

Subsequently, the powder sample is heated up to 400° C. or above until it melts. A voltage of 5 V dc is applied to the two gold wires and when a current is found to be flowing in an amount of several tens of milliamperes, the powder sample is left to stand for an additional one hour. Thereafter, the powder sample is reverted to room temperature and recovered into the atmosphere, giving a black precipitate of MgB2 as it is deposited on the platinum wire 2.

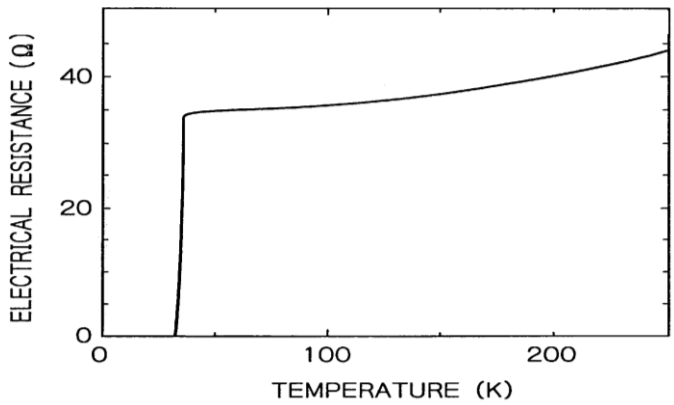

Fig 10 is a graph showing the temperature dependency of the electrical resistance of a sample that was prepared by the invention from magnesium chloride ($MgCl_2$), sodium chloride (NaCl), potassium chloride (KCl) and magnesium borate (MgB_2O_4) as they were weighed at a molar ratio of 10:7:3:2 in a total quantity of two grams.

The reaction mechanism behind the precipitation of MgB2 is as follows:

- Pt electrode (−): Mg2++2B3++8e→MgB2 (e is an electron)
- C electrode (+): 4O2−→2O2+8e
- Adding together: MgB2O4→MgB2+2O2

Note that magnesium chloride, potassium chloride and sodium chloride have a catalytic effect for lowering the melting point.

VIII. PROCEDUR AND CONCLUSION

1 - Short-Range Coulomb Interaction

Screening is that the damping of electrical fields caused by the presence of mobile charge carriers. it's a crucial a part of the behavior of charge-carrying fluids, like ionized gases and conductivity electrons in semiconductors and metals. in an exceedingly Fluid composed of electrically charges constituent particles every combine of particles interacts through the Coulomb force.

$$\mathbf{F} = \frac{q_1 q_2}{4\pi\epsilon_0 |\mathbf{r}|^2}\hat{\mathbf{r}}$$

C. C. Tsuei et al., have developed we tend to gift phase-sensitive proof that the electron-doped cuprates Nd1.85Ce0.15CuO4-y (NCCO) and Pr1.85Ce0.15CuO4-y (PCCO) have d-wave pairing symmetry. This proof was obtained by perceptive the half-flux quantum result, employing a scanning SQUID magnifier, in c-axis-oriented films of NCCO or PCCO epitaxial adult on tri crystal [100] SrTiO3 substrates designed to be pissed off for a dx2-y2 order parameter. Samples with 2 different configurations, designed to be unfrustrated for a d-wave superconductor, don't show the half-flux quantum result.

2 - Half – Flux quantum effect

The presence or absence of the half-integer flux quantum result in controlled orientation tri crystal grain boundary rings could be a general check of the section of the superconducting order parameter. One such check proves that this result is symmetry dependent, which the order parameter in YBa2Cu3O7-ς has lobes and nodes per d-wave symmetry. Our measurements show that the flux within the 1/2 whole number state is quantity to Φ0/2 at intervals ± third. This puts limits on the fanciful part of the superconducting order parameter in YBa2Cu3O7-ς.

$$\sigma = \frac{I_{\text{channel}}}{V_{\text{Hall}}} = \nu \frac{e^2}{h},$$

Where,

I channel = is the channel current
V Hall = is the Hall voltage
e = is the elementary charge
h = is the plank's constant

N.P. Armitage et al., have developed we tend to gift associate degree angle-resolved emission doping dependence study of the n-type cuprate superconductor Nd2-xCexCuO4±δ, from the half-filled Mott dielectric to the Tc = 24K superconductor. In Nd2CuO4, we tend to reveal the charge-transfer band for the primary time. As electrons square measure doped into the system, this feature's intensity decreases with the concomitant formation of near- EF spectral weight. At low doping, the Fermi surface is associate degree electron-pocket (with volume ∼ x) focused at (π,0). Additional doping results in the creation of a replacement hole like Fermi surface (volume ∼1+x) focused at (π,π). These findings shed light-weight on the Mott gap, its doping evolution, yet because the abnormal transport properties of the n-type cuprates.

3 - Fermi Surface

In condensed matter physics, the Fermi surface is AN abstract boundary helpful for predicting the thermal, electrical, magnetic, and optical properties of metals, semimetals, and doped semiconductors. the form of the Fermi surface springs from the cyclist and symmetry of the crystalline lattice and from the occupation of electronic energy bands. The existence of a Fermi surface may be a direct consequence of the Pauli law of nature that permits a most of 1 lepton per quantum state.

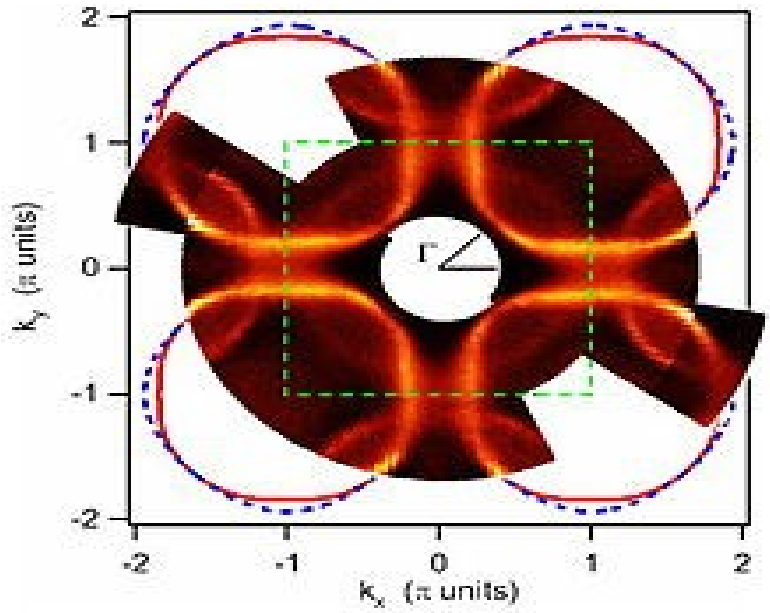

Fig 11 the Structure of Fermi Surface

Huanbo Zhang et al., have developed A appraisal of experimental knowledge reveals a universal relationship between Tc /Tc,max and hole content among the p-type high-Tc cuprate superconductors. every individual compound is characterised by the worth of its most Tc,Tc,max whereas the variation of Tc/Tc,max with the outlet content is freelance of the compound thought of. The universal curve is characterised by a upland, instead of a para daring, with sharp bends at each side. The Tc versus hole content curve contains a shut reference to hole contents determined by ordered arrangements of holes within the two-dimensional CuO2layer.

G. Aeppli, et al., have developed Polarized and international organisation polarized nucleon scattering was wont to live the wave vector – and frequency-dependent magnetic fluctuations within the traditional state (from the superconducting transition temperature, Tc = thirty five kelvin, up to 350 kelvin) of single crystals of La1.86 Sr 0.14 CuO 4.The peaks that dominate the fluctuations have amplitudes that decrease as T -2 and widths that increase in propotion to the thermal energy, KT (where KB is Boltzmann's constant) ,and energy transfer intercalary in construction. The nearly singular fluctuations area unit in line with a close-by quantum crisis.

Abhay N. Pasupathy et al., have developed distinctive the mechanism of electrical conduction within the high – temperature cuprate superconductors is one amongst the most important outstanding downside in physics. we have a tendency to report native measurements of the onset of superconducting pairing within the high-transition temperature (Tc) superconductor Bi2Sr2CaCu2O8+δ employing a lattice - trackimg spectrometry technique with a scanning tunneling magnifier. we will confirm the temperature dependence of the pairing energy gaps, the electronic excitations within the absence of pairing, and also the impact of the native of coupling electrons to bosonic excitations. Our measuring reveals that the strength of pairing is decided by the bizarre electronic excitations of the traditional state, suggesting that robust electron-electron interactions instead of the low energy (<0.1 volts) electron-boson interactions area unit liable for electrical conduction of cuprastes.

Cyril Proust et al., have developed the transport of warmth and charge within the over doped cuprate superconductor Tl2Ba2CuO6+δ was measured all the way down to cold. within the traditional state, obtained by applying a field of force larger than the higher vital field, the Wiedemann-Franz law is verified to carry utterly. within the superconducting state, an outsized residual linear term is ascertained within the thermal conduction, in quantitative agreement with BCS theory for a d-wave superconductor. this can be compelling proof that the electrons in over doped cuprates kind a Fermi liquid, with no indication of spin-charge separation.

4 - Wiedemann-Franz law

In physics, the Wiedemann–Franz law is the ratio of the electronic contribution of the thermal conductivity (κ) to the electrical conductivity (σ) of a metal, and is proportional to the temperature (T).

$$\frac{\kappa}{\sigma} = LT$$

ACKNOWLEDGMENT

I hereby declare that the work, which is being presented in the paper, entitled Study of boron based superconductivity and effect of high temperature cuprate superconductors in partial fulfillment is a record of my own review investigations carried under the Guidance of Mr. Prof. (Dr.) D.P. Jayapandian, Dean and Head Department of physics and Dr.Piyush Mashi Assistant Professor Dept. of Physics, Sam higginbottom institute of agriculture, technology and science , Allahabad India.

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