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Theory and Applications of High Temperature Superconductor

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Abstract:

Since the discovery of superconductivity which is the physics of cooper pairs, fundamental research has strived to develop an understanding the physics behind this fascinating phenomenon. In the years that followed, numerous other superconductors and a set of unique properties were found and these properties distinguished superconductors from being other than perfect conductors. Superconductivity is being applied to many diverse areas such as: Military, Transportation, Medicine, Power production, Electronics, theoretical, experimental science, as well as in the other areas. After discovery of high temperature superconductors which can operate at liquid nitrogen temperature (77 K), superconductivity, is now available at much lower cost. Many stunning discoveries have been carried out like superconductivity in iron based materials and still now the journey towards room temperature is continued. This paper discusses the history, physics of superconductivity, applications, motivation and review of literatures.

HISTORICAL BACKGROUND OF SUPERCONDUCTIVITY

The liquefaction of helium was the key for discovering superconductivity in 1908 by H. K. Onnes . Later he studied the resistivity of metals at very low temperature using liquid helium as a coolant. In 1911, H. K. Onnes and his assistant Gilles Holst began to investigate the electrical properties of metal in extremely cold temperature as it was not known what limiting value of the resistance would approach at 0 K. Onnes passed a current through a very mercury wire and noticed that the resistance of mercury suddenly drops to zero at 4.2 K. H. K. Onnes initially thought that their apparatus had shorted out. Only later did he realize that the effect was real. Figure 1 is the graphic representation of resistance versus temperature in mercury wire as measured by Onnes. According to Onnes, "Mercury has passed into a new state, which on account of its extraordinary electrical properties unlike any known before, and this new state was called the superconducting state". The experiment left no doubt about the disappearance of the resistance of a mercury and H. K. Onnes called this newly

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discovered state, **Superconductivity**. Onnes received a noble prize in 1913 for his outstanding discovery of superconductivity.

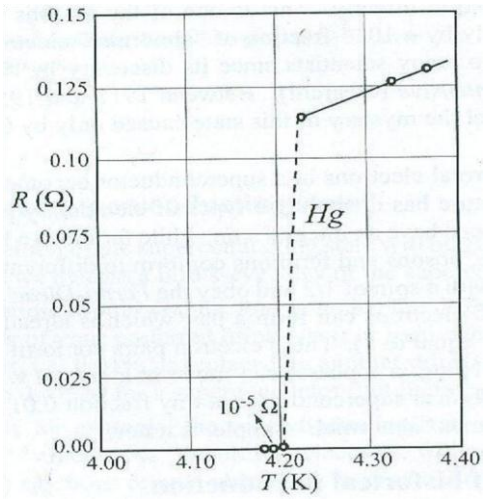

Figure 1: Variation of resistance with temperature for mercury [2]

Soon after this discovery, many other elemental metals were found to exhibit zero resistance when their temperatures were lowered below a certain characteristic temperature of the material, called the critical temperature, T_c. In 1913, lead appeared as a superconductor at 7 K and in 1941 niobium nitrate was found to superconductor at 16 K. A lot of work has been carried out to understand this phenomenon. The transition temperature rose to 23.2 K in Nb_3Ge during period 1911 to 1986. In 1957 scientists began to discover the mysteries of superconductivity.

Three American physicists John Bardeen, Leon Cooper, and Robert Schrieffer at the University of Illinois, made a model that provide good mental picture of superconductivity explaining most of their strange properties. The model is based on the advanced ideas of the quantum mechanics, but the main idea of the model suggests that electron in a superconductor condense into new quantum ground state and travel together collectively and coherently. A complete theory to understand the mechanism of this superconductivity which is known as microscopic theory or BCS theory was given by these American scientists and they received the noble prize in 1972. However BCS theory can only explain the superconducting properties of low temperature superconductors . A sudden breakthrough in transition

temperature from 23.2 K in Nb_3Ge at 35 K in LaBaCuO system reported by Bednorz and Muller in 1986 opened a new field of high temperature superconductivity . In February 1987, a perovskites ceramic material $YBa_2Cu_3O_{7-\delta}$ was found to superconductor at 90 K. This was the first superconductor which had critical temperature more than nitrogen temperature (77 K). This discovery was very significant because now it became possible to use liquid nitrogen as a coolant. As these materials superconduct at high temperature than their lower counterparts they are referred as **High Temperature Superconductors (HTSc)**. Since then tremendous amount of work has been done to understand the mechanism of these superconductors, known as cuprate perovskites, side by side effort has been made to increase the transition temperature in the High T_c Cuprates. From about 1993, the highest superconductor was a ceramic material $HgBa_2Ca_2Cu_3O_{8+\delta}$ with critical temperature 138 K . The discovery of superconductivity in an intermetallic MgB_2 with T_c = 39 K in 2001 also spurred renewed interest due to its potential in magnetic application . In February 2008, it therefore came as a surprise when Hideo Hosono of the Tokyo institute of technology reported the discovery of superconductivity in an element that contains iron: fluorine- doped $LaO_{1-x}F_xFeAs$. Replacing the lanthanum in $LaO_{1-x}F_xFeAs$ with samarium leads superconductors that work at 55 K . One of the exiting aspects of these new Fe based superconductors is that they belong to a comprehensive class of materials where many chemical substitutions are possible. This versatility has been opened up new research avenues to understand the origin of the superconductivity and should also enable the superconducting properties to be tailored for commercial technologies. The history of superconductors is only just now beginning and still it is continued. The next important step in understanding superconductivity occurred in 1933 when Meissner and Ochsenfeld discovered an effect.

MEISSNER EFFECT

A magnetic phenomenon which discovered by Walter Meissner and Robert Ochsenfeld in 1933 is a very fundamental feature of superconductivity. In this phenomenon they revealed that superconductors are more than the perfect conductors of electricity and they also have an interesting magnetic property of excluding a magnetic field. A superconductor will not allow a magnetic field to penetrate its interior. This effect, called the Meissner Effect, is the one of the properties of

superconductors most easy to demonstrate, and also the most dazzling.

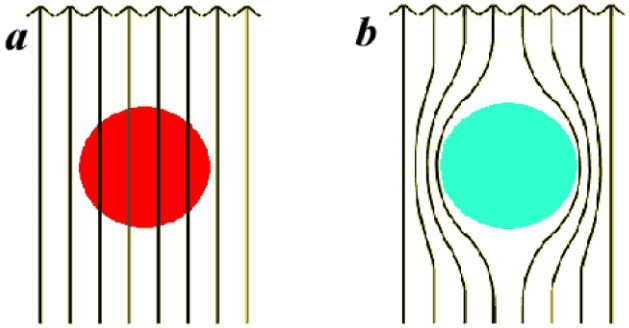

Figure 2: (a) Magnetic field lines penetrate through a superconductor at a temperature above its critical superconducting transition temperature ($T > T_C$). b) When the superconductor is cooled below its critical transition temperature ($T < T_C$), magnetic field lines are expelled from the interior of the superconductor due to the Meissner Effect.

Figure 2 is an image of magnetic field lines from a magnet levitating above a superconductor.

THEORIES OF CONVENTIONAL SUPERCONDUCTIVITY

. London' Theory

In 1935, the first theoretical model to understand the superconducting properties was proposed by F. London and H. London. They formulated two equations to describe the zero resistance and the magnetic flux line exclusion. London‟s analysis revealed that magnetic field lines penetrate the superconducting material but decay exponentially into the superconducting sample over a characteristic „penetration depth‟ λ. A. B. Pippard showed that the surface current flowing at a particular point would be a function of the magnetic field within a certain distance and the distance is known as coherence length(ξ). London and Pippard equations relate the current density in a superconductor to the magnetic vector potential precisely .

. Ginzburg- Landau Theory

This theory was given by Ginzburg and Landau in 1950. By this theory, the thermodynamic properties of superconductors were explained and authors utilized the idea of Landau‟s theory of second order phase transition. Ginzburg and Landau formulated two equations, which expressed the superconducting current and the order parameret !γ^2! density of superconducting

electrons. The solutions of these equations provide several features of superconductors, as a characteristic minimum length over which the wave function can significantly change, known as „ coherence length" (ξ) of the material. This theory also gave the difference between type-1 superconductors (ξ >λ) and type-11 superconductors (ξ<λ) .

BCS Theory

BCS theory arose out of the desire to create a microscopic model which described how a material could exhibit no electrical resistance or extinguish a magnetic field. This theory proposed by Bardeen, Cooper, and Schrieffer in 1957, eventually earning them the Nobel Prize in physics in 1972 . The BCS theory explains the electron phonon interactions, which can lead to an electron- electron attraction to form a Cooper pair and their response to superconductivity. Cooper pairs form due to Froehlich interaction. The phonon (vibration in lattice) allows them to overcome the coulomb repulsions between them, and also causes these cooper pairs to have opposite spins and linear momentum. This allows them to be thought of a single particle with zero spin, which also means they act against the Pauli exclusive principal. At absolute zero all electrons would be in cooper pairs. The electron pairing is favorable because it has the effect of putting the material into a lower energy state, a new boson state and that will also reduce the Fermions density of states.

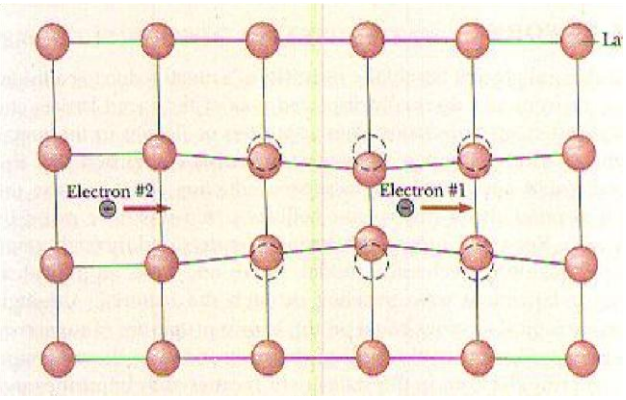

Figure 1 Electron- Phonon- electron interaction

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TYPE OF SUPERCONDUCTORS

Type -I Superconductors

Certain metals such as tin, mercury, titanium, lead, aluminum, and others become superconducting, i.e. their electric resistance completely disappears when they cooled below their critical temperature. These metals were the first superconductors to be discovered and have been later named type-1 superconductors.

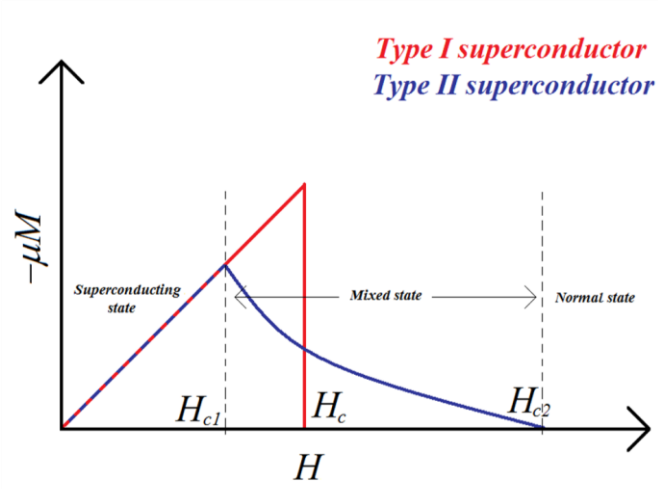

Figure 1.4: Induced Magnetization with applied magnetic field in Type-1 and Type-II superconductors

Type 1 superconductors are mostly pure metals and they have critical fields too low for use in superconducting magnets. These superconductors show complete Meissner effect and can only be understand by using BCS theory.

Type -II Superconductors

Abrikosov in 1957 was given a significant contribution towards the theory of superconductivity when he published a paper which describing some new phenomenon related to Ginzburg- Landau theory, quite different from the behavior of the earlier type-1 superconductors. He noticed that the existence of some new materials, which exhibited a continuous increase in flux penetration stating at a first critical field H_{c1} with reaching $B= \mu_0 H$ at a second critical field H_{c2}, instead of showing a discontinuous disappearance of superconductivity at the

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thermo-dynamical field H_c. Some type-II superconductors are:

YBCO, BSCCO, Fe- based superconductors. At the field between H_{c1} and H_{c2} the field begins to intrude into the material and in this position material is said to be in the mixed state, with some of the material in the normal state and part still superconducting.

. ERA OF HIGH TEMPERATURE SUPERCONDUCTORS

The history of high Tc superconductors (HTSc) was begins in IBM research laboratory (1986) with the discovery of Ba-La-Cu-O superconductor having the critical temperature 36 K by Karl Muller and Johannes Bednorz. This opened a new mode of high T_c superconductivity namely "High Temperature Superconductivity" as they has been broken the barrier point of 30 K imposed by BCS theory. Soon after this event, many other oxide based superconductors were discovered having the T_c greater than 90 K and they are shown below in Figure 5 with T_c and their respective discovery year.

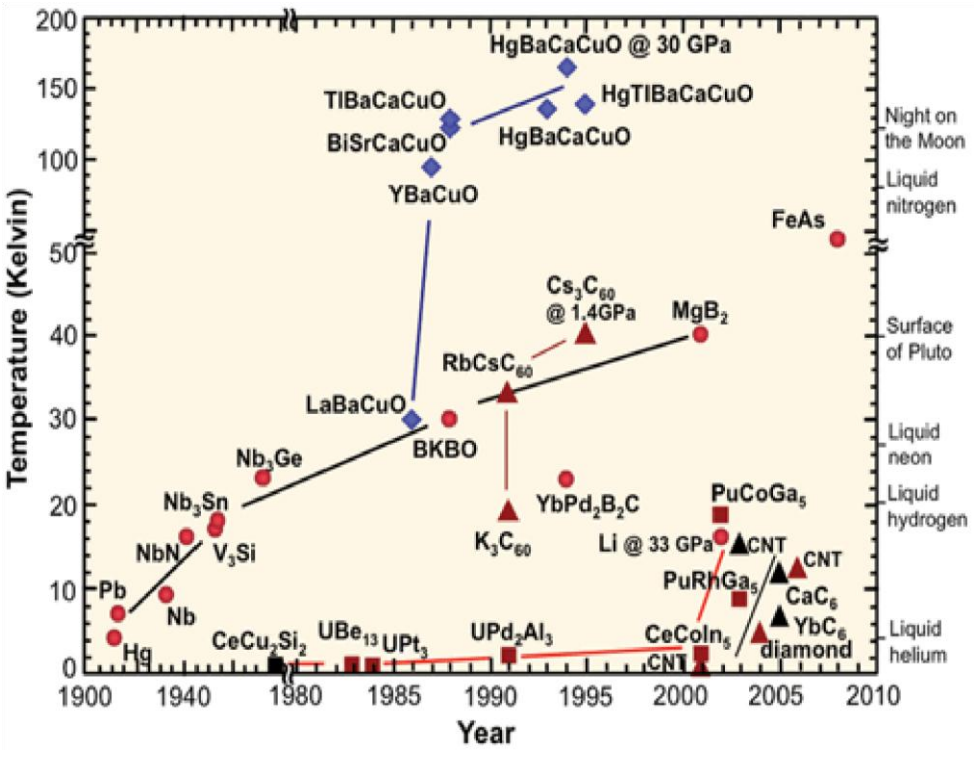

Figure 5: History of Superconductivity

They have their structure derived from ideal perovskites structure (therefore termed as defect perovskites structure), either through an intergrowth or by an ordered removal of oxygen atoms. HTSc have layered crystal structure consisting of one or more CuO_2 layers. There is a transfer to and from the CuO_2 layers which is induced by doping near insulator phase existing in all oxide high T_c superconductors.

1 History and progress

LBCO: LBCO (Lanthanum Barium Copper Oxide) was the first oxide based HTSc material developed in 1986 having T_c of 35 K. It is the only insulating material in HTSc family. This discovery provides the path for the additional research in high T_c superconductivity on cuprate materials with structure similar to LBCO .

***YBCO*:** YBCO (Yttrium Barium Copper Oxide) was discovered in the year 1987 by Paul Chu in the University of Houston and it shown the highest T_c of 93 K. It is the first the first material to break the liquid nitrogen temperature (77 K). YBCO is highly studied as it is the cleanest and most ordered crystals and shows strong electron- electron interaction .

BSCCO: BSCCO (Bismuth Strontium Calcium Copper Oxide) was the first high temperature superconductor which did not contain a rare earth element. It is a cuprate superconductor which shares a two dimensional layered Perovskites structure with the superconducting copper oxide plane. General formula for BSCCO is $Bi_2Sr_2Ca_{n1}Cu_nO_{2n+4+x}$ with specific transition temperature ranging from T_c = 20 K (n=1, 2201 phase), 85 K (n=2, 2212 phase), 110 K (n=3, 2223 phase) and 104 K (n=4, 2224 phase) [21].

TBSCCO: TBSCCO (Thallium Barium Calcium Copper Oxide) was discovered in the same year as BSCCO. It is next higher member of HTSc family and general formula is

$Ti_2Ba_2Ca_{n-1}Cu_nO_{2n+2+x}$ with transition temperature ranging from T_c= 85 K (n=1, 2201 phase), 110 K (n=2, 2212 phase) and 127 K (n=3, 2223 phase). In this superconductor, CuO_2 layers are thicker and closer together in comparison to BSCCO system.

***HBCCO*:** HBCCO (Mercury Barium Calcium Copper Oxide) is the highest member of the HTSc family (2009) till date. It has general formula $Hg_1Ba_2Ca_{n-1}Cu_nO_{2n+2+x}$ with specific

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transition temperature ranging from T_c= 94 K (n=1, 1201 phase), 128 K (n=2, 1212 phase) and 134 K (n=3, 1223 phase).

Recently, iron- based superconductors with critical temperatures as high as 56 K have been discovered. After more than twenty years of intensive research the origin of high-temperature superconductivity is still not clear, but it seems that instead of electron- phonon attraction mechanisms, as in conventional superconductivity, one is dealing with genuine electronic mechanisms (i.e. by antiferromagnetic correlations), and instead of s- wave pairing, d- wave are substantial.

CUPRATE PEROVSKITE SUPERCONDUCTORS

There are many types of high temperature superconductors like LSCO, YBCO, BSCCO etc, but BSCCO is most recent the widest among these due to its unique properties. BSCCO is the important category of high T_c superconductors which shares a two dimensional layered (perovskites) structure where the superconducting phenomenon varies in copper oxide plane and also do not contain any rare earth element.

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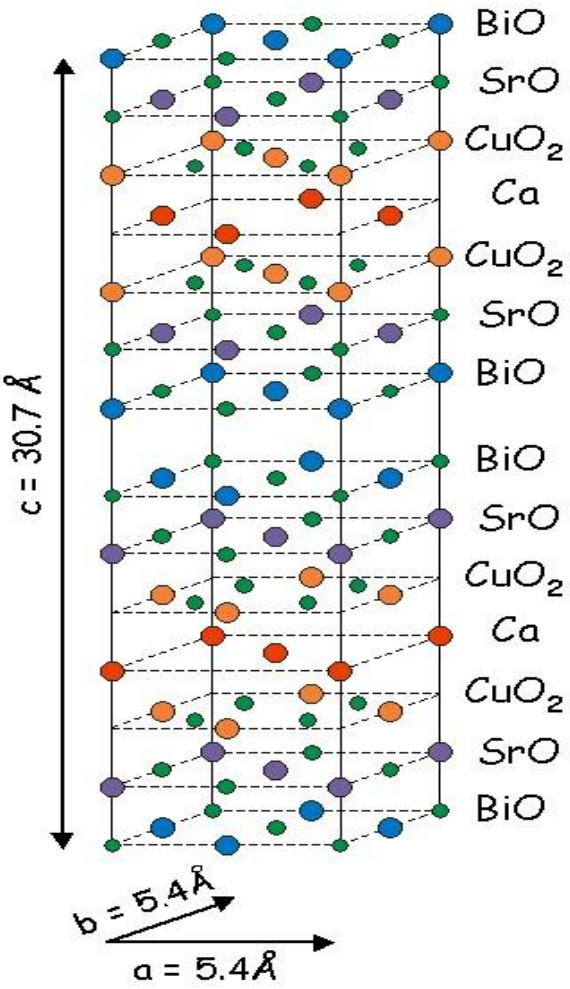

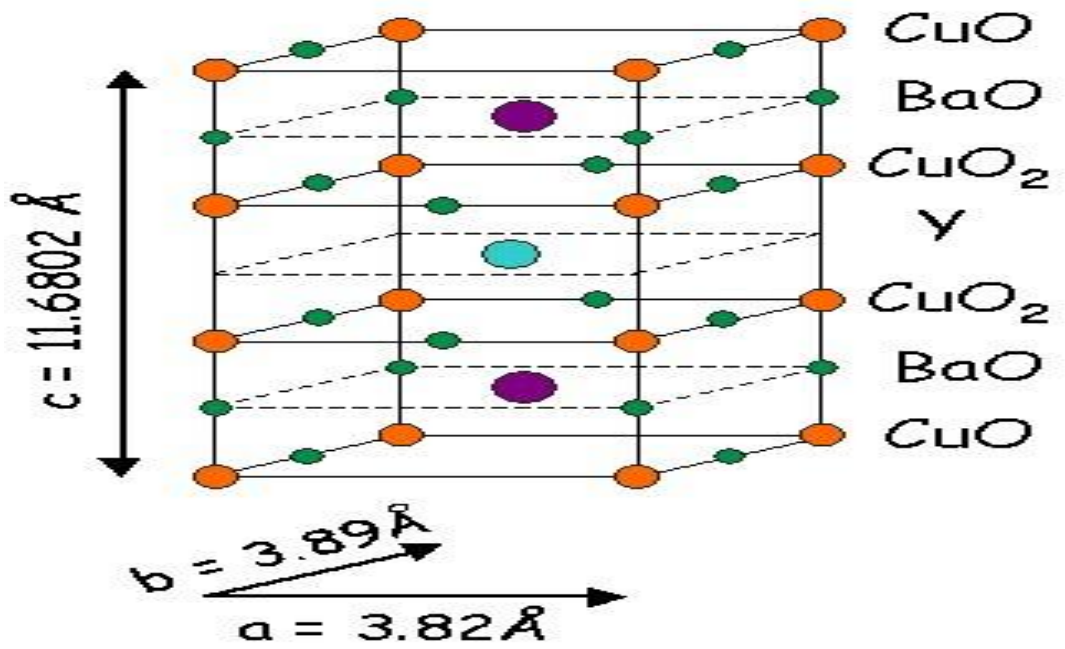

Figure6 : Crystal structure of BSCCO (2212) and YBCO (123) Superconductor [22]

It shows more stability in superconducting behavior with respect to oxygen loss in comparison to YBCO. BSCCO has high T_c value and exhibit both an anisotropic behavior and intrinsic Josephson Effect. It is generally categorized into three different structure according to their „n" values as T_c = 20 K (n= 1, 2201), T_c = 95 K (n=2, 2212), and T_c = 110 K (n=3, 2223) [23]. Crystal structure of BSCCO structure contains three layers i.e. reservoir layer (SrO and BiO layer), superconducting layer (CuO) and insulating layer (CaO and CuO). The "reservoir layer" reserves the electron, just above it contains superconducting layer where doping can be possible to vary the properties of the superconductors, and above this layer, insulating layer exist, where CuO and CaO plane form the Josephson junction between them. All type of BSCCO structure are almost same, BSCCO 2212 comprises two repeating units whereas BSCCO-2223 has an extra CuO_2 layer and Ca layer in each half, while BSCCO-2201 has one less CuO_2 in its top and bottom half and no Ca layer [21].

The discovery of YBCO (in 1987) followed that of LSCO within a year and it breaks the boundary of 77 K. It has cleanest & most ordered crystal that"s way it has been studied. But studies of YBCO can also quite confusing

due to the presence of two CuO planes; the chain plane & the square plane. By analogy with the other HTSc families, it is thought that the superconductivity originates in the square plane, but it is hard to isolate the behavior of the planes.

HIGH- T_c SUPERCONDUCTIVITY IN IRON BASED COMPOUNDS

New Discovery

In 2008 HTSC again came into spotlight, Hosono et al discovered superconductor, which was based on iron- arsenic compound . This was the discovery of high- T_c superconductivity in a completely new class of materials that came to be known as iron pnictides. That was very interesting, because iron is famous for its ferromagnetism. This new discovery has attracted a tremendous interest in the materials science community opening a new route for high- T_c research in addition to that of the cuprates. However, this has also brought new challenges on both theoretical and experimental sides and added a new problem for material scientists in addition to longstanding problem for cuprates.

Different families of iron based superconductors

In all crystal structures, FeAs layer is same and Fe atoms are arranged in square lattice, while FeAs form tetragonal and orthogonal structure which depending on temperature and type. Most of Iron pnictides and chalcogenides become superconductors only when doped with electrons and holes.

- ***1111 family***

  After discovery of high- temperature superconductor $LaFeAsO_{1-x}F_x$, T_c rapidly increased by exchanging La with other rare earth ions of smaller atoms radii in LnFeAsO and this family of LnFeAsO came to know as 1111family. The $LaFeAsO_{1-x}F_x$ was the most remarkable compound that show high superconducting transition ~ 26 K until now are: $SmFeAsO_{1-x}F_x$ (T_c~ 43 K) [25], $CeFeAsO_{1-x}F_x$ (T_c ~ 41 K) $NdFeAsO_{1-x}F_x$ (T_c ~ 51 K) and $PrFeAsO_{1x}F_x$ (T_c ~ 52 K) [28].

- ***122 family***

  The first member of this family was $Ba_{0.6}K_{0.2}Fe_2As_2$ with T_c ~ 38 K and than discovery was followed out reports of similar compounds: Strontium (T_c ~ 37 K) Calcium (T_c ~ 20 K) and Europium (T_c ~ 32 K) .

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Sefat et al doped the electrons in $Ba_2Fe_2As_2$ by the partial replacement of Fe with Co with $T_c \sim 22$ K.

- ***111 family***

X. C. Wang et al discovered the new superconductor LiFeAs and T_c up to 18 K was found in these compounds.

- ***11 family***

PbO- type αFeSe compound with $T_c \sim 8$ K by F. C. Hsu et al was the first member of this family. After many studies it is observed that a clean superconducting phase exists only in those samples which prepared with intentional Se deficiency.

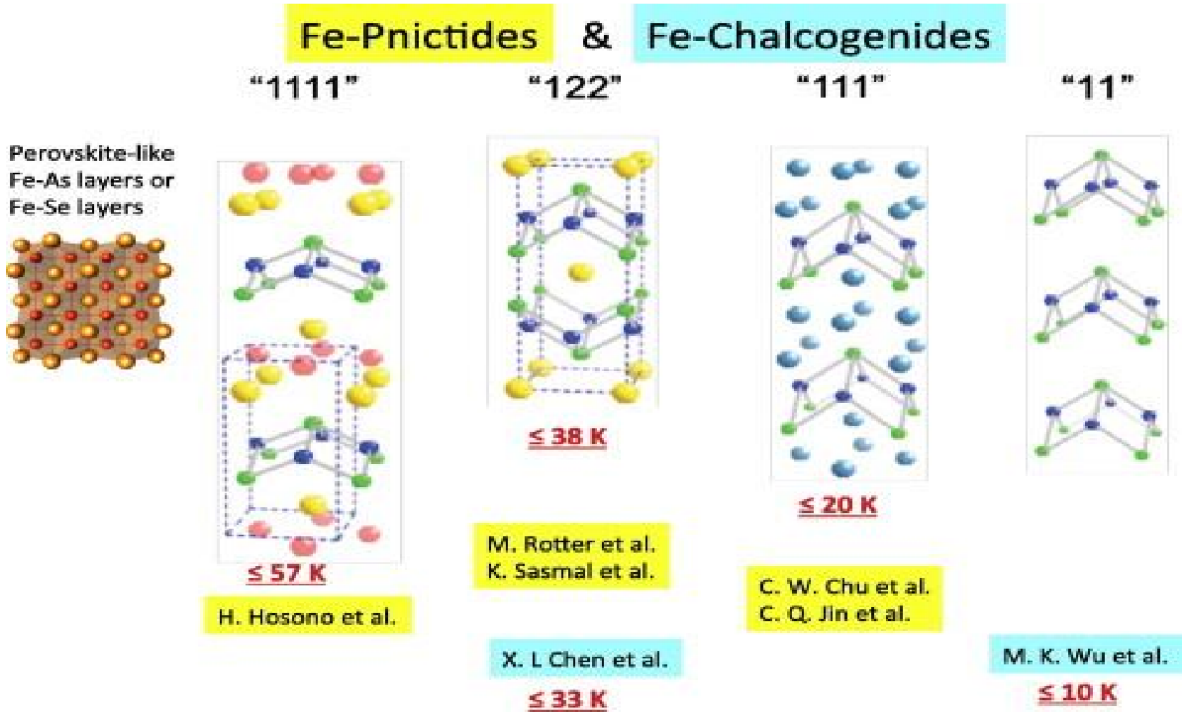

Figure 1.7: Crystal Structure of Fe- pnictides and chalcogenides families [24]

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COMPARATIVE STUDY OF CUPRATE PEROVSKITE AND IRONBASED SUPERCONDUCTORS

Iron based superconductors are the first non-cuprate materials exhibiting superconductivity at relatively high temperatures upon hole and electron doping antiferromagnetic parent compounds. From the outset, differences and similarities were apparent between the new superconductor and established exemplars of high T_c superconductivity, the cuprates. Cuprates and iron based superconductors are similar in occurrence of unusual normal state properties which are outside the framework of Fermi liquid theory. The tetragonal- to-orthorhombic phase transition study in the multiband FeAs superconductors hints to a similarity with cuprates in the emergence of the superconducting phase as super stripes and lattice charge instability which can be changed by external fields. Though they share some similarities, there are enough properties which make iron pnictides different. For the cuprates all the spin structure in the ab plane are simple collinear antiferromagnets, while in FeSCs iron spins order only the crystal distorts, with the spin parallel in one direction and antiparallel in the order. In both classes of materials, high temperature superconductivity arises from strong attractive interaction between carriers generated by local structural and chemical changes associated with valency changes, Cu^{2+} to Cu^{3+} in cuprates and Fe^{2+} to Fe^{+} in the pnictides, and from the accompanying changes in the local spin order. At low temperature both groups exhibit spectral weight suppression, but the suppression in FeSCs is doping dependent. The correlation found between the lattice and critical temperature for cuprates matches well with FeSCs. Both show lattice contraction and T_c enhancement with fluorine doping. But the superconductivity induced in FeAs layers is insensitive to randomness unlike that in the CuO_4 planes of high T_c cuprates.

The pressure effect on T_c enhancement in iron oxypnictides is more prominent than in cuprate LaFeAsO and the parent compounds of other subsequently discovered Fe based superconductors all belong to the class of poor conductors known as semimetals; the cuprates parents are insulators. Iron- based superconductors have very high upper critical fields and exhibits multiband features along with an unconventional paring symmetry similar to the cuprate perovskites. But the symmetry of order parameter in Fe based superconductors are suggested as s- wave by several groups while it is d- wave in the cuprates. The iron- containing plane is not having a planar geometry because pnictogen (Pn) or chalcogen (Ch) atoms protrude above and below the plane. Due to large size of Pn

and Ch atoms as compared to Fe atoms, they pack themselves in edge- sharing tetrahedral. But in a cuprate superconductor, the size difference between the copper and oxygen atom is small so cuprate leads to corner-sharing octahedral packing. Due to the tetrahedral configuration, the Fe atoms in Fe based superconductor are closer to each other than the Cu atoms are in a cuprate superconductors. Both Fe and Cu occupy the same row of the periodic table. Their valence electrons occupy 3d orbital. But because of the Fe atoms closer packing, all five Fe 3d orbital contribute charge carriers. In cuprates, only Cu 3d orbital contributes. The Fe based superconductors and cuprates are different in another respect: chemical substitution. In the 1111 family, dopants can be inserted at any of four ionic positions, even into the iron layer. But the chemical manipulation of copper layer in the cuprates proved severely detrimental to their superconductivity.

APPLICATIONS OF HIGH T_c SUPERCONDUCTORS

Due to some characteristics of superconductivity i.e. the zero resistance, Meissner effect and Josephson Effect, this can be exploited for applications of these materials. Soon after Kamerlingh Onnes discovered superconductivity, scientists began dreaming up practical applications for this strangeness phenomenon. There are many more application of superconductors but out of these, here we are presenting very few.

- Powerful new superconducting magnets could be made much smaller than a resistive magnet, because the windings could carry large currents with no energy loss.
- Generators wound with superconductors could generate the same amount of electricity with smaller equipment and less energy. Once the electricity was generated it could be distributed through superconducting wires.
- Some applications of high temperature superconductors include; medical imaging systems, superconducting quantum interference devices (SQUIDS), analog signal processing devices, infrared sensors, magnetic shielding devices, and microwave devices, power transmission, superconducting magnets in generators, energy storage devices, particle accelerators, levitated vehicle

transportation, rotating machinery, and magnetic separators will become more practical.

- The ability of superconductors to conduct electricity with zero resistance can be exploited in the use of electrical transmission lines.

The field of electronics holds great promise for practical applications of superconductors. The use of new superconductive films may result in more densely packed chips which could transmit information more rapidly by several orders of magnitude. Superconducting electronics have been achieved impressive accomplishments in the field of digital electronics. Logic delays of 13 picoseconds and switching times of 9 picoseconds has experimentally demonstrated.

- By using superconducting magnets, the prototype levitated trains have been constructed in Japan.
- Superconducting magnets are already crucial components of several technologies like in MRI. Magnetic resonance imaging (MRI) is playing an ever increasing role in diagnostic medicine.

REVIEW OF LITERATURES

The brief reviews concerning the research work incorporate in this thesis. Firstly, electronic structure of cuprates perovskite superconductors is discerned and then followed by review of Fe based superconductors.

. *Electronic structure of superconductors*

Literature review pertaining to Cuprate perovskites

The existence of superconductivity in Pr123 have propounded by Y. Nishihara et al They carried out a systematic study to understand the mechanism of superconductivity on doping with Pr and Ce in the various cuprate systems and reported the valence state of Pr & Ce, which is very important. N. Pavlenko et al have studied the electronic structure of interfaces between $YBa_2Cu_3O_6$ and $SrTiO_3$ using local spin density approximation (LSDA) with infer-atomic coulomb repulsion (LSDA+U). They found a metallic state in cuprate-titanate heterostructures with the hole carriers concentration in the CuO_2 layers and in the first interface TiO_2 or SrO planes. L. Braicovich et al [39] have probed the collective magnetic modes of La_2CuO_4 and under doped $La_{2-x}Sr_xCuO_4$ (LSCO) momentum resolved resonant inelastic x-ray scattering (RIXS) at the Cu L_3 edge. In conclusion they reported that

high–energy branch in the excitation spectrum of an under doped high T_c superconductor, coexisting with a less-dispersive branch at lower energy is a strong evidence that LSCO sample is in a dynamically inhomogeneous state, possibly a stripe liquid with spin dynamics up to 400Me. N. L. Saini et al [40] have investigated the instantaneous in plane Cu- O bond distribution in the $Bi_2Sr_2Ca_2O_{8+\delta}$ (Bi2212) superconductor by high K- resolutions Cu K edge extended X- ray absorption fine structure (EXAFS). These measurements have done along the two orthogonal Cu-OCu bonds of the CuO_2 square plane. They concluded an anisotropic Cu-O distribution in the two directions and gave further information on the local atomic displacements in the lattice- charge stripes. D. Castro et al have proposed the highest critical temperature can be achieved in the compounds for which the interaction between apical oxygen (s) and the CuO_2 plane is the weakest. Cu L_3 edge resonant inelastic X- ray scattering (RIXS) and resonant x- ray photoemission spectroscopy (RXPS) of $La_{2-x}Sr_xCuO_4$ have studied by G. Ghiringhelli et al They found the dd excitations of both doped and undoped sites in LSCO. RIXS found to be much more sensitive to the hole doping level than resonant photoemissions. The RXPS Raman feature has suppressed at the doped sites leading to a diminished sensitivity to the doping. The different final states of RIXS and RXPS act as intermediate state selectors. The nonlocal core hole screening plays a crucial role in the intermediate state determining the onset of the non- Raman features in the RIXDS and RXPS spectra. They concluded that with increasing hole doping, the nonlocal core hole screening becomes more effective, because it has a lower onset. This picture has an impact on the interpretation of the L_3 x- ray absorption spectra in Cuprates. A. Bianconi et al have measured the linearly polarized Cu K- edge X-ray absorption near edge structure (XANES) of $Bi_2Sr_2CaCu_2O_{8+\delta}$ (Bi:2:2:1:2) and spectra interpreted by the multiple- scattering approach in real space. They identified the physical origin of peaks A_1 and A_2 on the rising absorption edge. Above the main K- XANES peak a satellite peak at 7 eV in both polarization have shown to be a multielectron shake- up excitation, and it have enhanced going into the insulating phase. In terms of the one- electron approximation, the interpretation of the XANES of $Bi_2Sr_2CaCu_2O_{8+\delta}$ indicates that the high- energy bands beyond the Cu $3dx^2\text{-}y^2$ band do not show electron correlation effects. Using XAS over a wide range of hole concentrations A. K. Ariffin et al have studied the angular dependence of main and satellite peak at the Cu- L_{III} edge of Pb- Bi2201. The

hole content for single crystals cannot be determined directly by the same method which is used for polycrystalline materials due to the modulation of the relative intensity and the geometrical factor. They found the linear relation for Bi-2201 and Bi(Pb)-2201 of hole content p La- concentration is universal. Using a bulk- sensitive total- fluorescence- yield technique, high- resolution O k- edge and Cu $L_{2,3}$ edge X- ray absorption near- edge spectra for the series of $(Tl_{0.5}\,Pb_{0.5})\,Sr_2\,(Ca_{1-x}Y_x)\,Cu_2O_7$ compounds (x= 0-0.9) have measured by J. M. Chen et al .The pre-edge peak at ~ 528.3eV near the O 1s edge is mainly due to the core-level excitation of O 1s electrons to O 2p holes located in the CuO2 planes. The intensity of this pre- edge peak increases linearly with the Ca doping for $0 \leq x \leq 0.5$.This gives information about the effect of chemical substitution of Ca^{2+} for Y^{3+} . The substitution of Ca^{2+} induced the hole states in the CuO_2 planes near the Fermi level. The generation of holes in the O 2p orbitals within the CuO_2 planes plays an important role to control the transition temperature. High energy shoulders at 933.1 and 952.9 eV in the Cu L- edge absorption spectra indicated the transition from the Cu $(2p_{3/2,1/2})\ 3d^9$ L ground state to the Cu($2p_{3/2,\ 1/2}$)$^{-1}$ $3d^{10}$ L excited state, where L is O 2p ligand hole. The normalized intensity of these defect states showed the proportional relationship with the Ca concentration. With the help of XANES study, it has been concluded that the transition from superconductors to semiconductors of $(Tl_{0.5}\,Pb_{0.5})\,Sr_2\,(Ca_{1-x}Y_x)\,Cu_2O_7$ as increase of the Y content and decrease of the hole content from the CuO_2 planes. The linearly polarized Cu L_3-edge x- ray- absorption near- edge structure (XANES) of $Bi_2Sr_2CaCu_2O_{8+\delta}$ has measured by A. Bianconi et al . The spectra has been interpreted by the full multiple- scattering in real space and interpretation of XANES of In terms of a one- electron approximation revel the high energy bands beyond the Cu 3d x^2-y^2 band does not evidence electron correlation effects. They identified the physical origin of the peaks C_1 and C_2 in the continuum. The oscillator strength for the 2p→s channel is negligible. The Z+1 approximation describing the fully relaxed final- state potential and it is valid also for the 2p → 3d transitions in the nearly filled band limit. The coulomb interaction in the final state is found to be 5.5 eV between the Cu 2p core hole and the excited Cu 3d electron forming a bound state below the continuum threshold. The integral of the polarized spectra give the relative weight of the Cu 3d z^2 unoccupied states. With the help of measurements of intensities of the O K edge pre peak and the Cu L_{III} white line from an I_2 intercalated BSCCO (2212) single crystal, the

FY and the TY modes of detection has compared by S. G. Saxena et al . They found out the relative intensities in case of the O K-edge is much higher in the FY mode as the TY signal. It tends to get masked by the large contribution from the dirty surface. They also concluded that the relative intensities from the two techniques find out to be quite similar only except in the 75o orientation case. from the TY and FY measurements, the relative intensities for the Cu L_{III} white line do not quite similar as the contamination on the surface mainly as of oxygen and other low Z elements. In a highquality $HgBa_2Ca_2Cu_3O_y$ thick film, the electronic structure have studied by B. R. Sekhar et al near the Cu-O planes in the normal and superconducting states using polarized x-ray absorption in order to get quantitative information on the changes in density and symmetry of the itinerant holes. They observed the Cu L_3-edge absorption spectra, an increase in the density of doping holes along the planes parallel and perpendicular to the Cu-O sheets while going from the normal to the superconducting state. There results shown that the Cu L_3 edge on a Hg- 1223 thick film in the normal and superconducting states have shown a considerable increase in the density of out-of plane doping holes (Cu 3*dz*22*r*2 9 *L*I) and a smaller increase in the in-plane (Cu 3*dx*22*y*2 9 *L*I) density of doping holes and clearly revealed that there are more itinerant holes available for conduction below the superconducting transition. Charging ordering in the system $La_{1.8x}Eu_{0.2}Sr_xCuO_4$ as a function of temperature for x= 0.125 and 0.15 has studied by J. Fink et al using resonant soft x- ray scattering with photon energies near the O K and Cu L_3 edges. Superstructure diffraction intensities calculations indicated that magnetic interactions and structural changes are not the driving force for the formation of strip like phases in two dimensional doped Cuprates. Line shape analysis of the scattered intensity as a function of photon energy gives evidence for a high hole concentration in the stripes. The unoccupied electronic structure of the CuO_2 planes and CuO_3 chains of $Y_{1x}Ca_xBa_2Cu_3O_{7-y}$ single crystals, using polarization-dependent O 1s and Cu 2p near- edge x- ray absorption has studied by M. Merz et al . They found the clear evidence for a prominent role of the apical sites. Hole states in planes and chains are identified and hole counts for the relevant orbitals near the Fermi level are derived for both under- and overdoped samples. Oxygen-deficient as well as oxygen- rich samples shown that the hole introduced by replacing Y^{3+} with Ca^{2+} in the planes. BSCCO single crystal study of the anomalous temperature dependence of itinerant holes, charge

aggregation and pair formation has been carried out by B. Dalela et al using polarized X-ray absorption technique. Using a liquid nitrogen cryostat the total yield measurements made at the Cu L_3 edges varying the temperature from the 80 K to room temperature (300 K).In the normal state, they found the processes of charge aggregation, pair formation and pair breaking repeating themselves at various temperatures. B. Ozkurt has investigated the effect of NiO doping on the phase formation and physical properties of Bi-2212 compounds. From the XRD analysis it has been shown that in all cases Bi-2212 phase is the major one. With increasing Ni doping, the hole carrier concentrations of samples decreases, which cause a degradation of the structural and superconducting properties of the present sample. It has been also concluded that Ni doping of samples decreased the onset critical density and critical transition temperature, in comparison of undoped samples. I. Verma et al have studied the effect of Mn doping on the microstructural and superconducting properties of (Bi, Pb):2223. SEM studies shown the significant affects on formation rate of Bi-2223 phase after MnO_2 addition and increment in the grain size of the sample up to x = 0.2. The effect of Cr addition on the structural and superconducting properties of BSCCO has investigated by G. Yildirim et al . They found that the decrement in grain size and composition of Sr and Cu with Cr doping. They also discussed the possible reasons for the degradation in microstructural and superconducting properties due to Ce addition. X. Wan et al have discussed the electronic structure, lattice dynamics, and electron-phonon interaction of the newly discovered superconductor $LaO_{0.5}F_{0.5}BiS_2$ using density-functional-based calculations. The large phonon softening and strongly anharmonic double- well behavior of the total energy as a function of the in plane S displacements has been predicted by the strong Fermi surface nesting at $(\pi,\pi,0)$. The system was strongly electron- phonon coupled; it has been predicted by large value of electron- phonon constant. A. Subedi et al have presented the results of first-principles calculations of the phonon dispersions and electron- phonon coupling for $BiTi_2Sb_2O$. The calculation of the electron-phonon coupling has been indicated that there is strong coupling to the in-plane and large coupling enough to readily explain the superconductivity. It has been also concluded that phonon dispersions had a weak lattice instability near zone corners which leads to a charge- density wave phase.

Literature review pertaining to iron- based superconductors

The electronic properties of $CaFe_2As_2$ parent compound of a pnictide superconductor studied by using the angle resolved photoemission spectroscopy (ARPES). Fermi surfaces around Γ and X points are cylindrical and quasi-2D, above the transition temperature (T_c). But below Ts the former becomes a 3D ellipsoid, which the latter remains quasi-2D. It is concluded that the low dimensionality plays an important role in understanding the superconducting mechanism in pnictides N. Chen et al have concluded the larger in density of inner orbital coupling corresponding to high Tc. The Density –functional theory (DFT) calculation has been showed the internal chemical pressure originates from the deep inner orbital coupling between As and its near cation A atom. Y. Qi et al have reported the superconductor $LaFe_{1-x}Ir_xAso$ with a maximum Tc about 11.8 K by replacing the Fe with the 5d-transion metal (Ir).By XRD, it has been shown that the material has ZrCuSiAs type structure with a space group P4/nmm. Hall Effect measurement has been revealed that the conduction carries in material is electron like carriers. In conclusion they have reported that superconductivity can be realized not only in FeAs-122 family, but also in FeAs-1111 by replacing the Fe sites with higher d- orbital electrons. F. Han et al have successfully synthesized a series of superconductors $SrFe_{2-x}M_xAs_2$ by substituting the Fe with 4d and 5d transition metals Rh, Ir and Pd in $SrFe_2As_2$.In $SrFe_2As_2$, it found that the normal state resistivity exhibits a roughly linear behavior starting just above T_c all the way up to 300 K at the optimal doping point. This may reflect a novel scattering mechanism in the normal state. The phase diagrams of $SrFe_{2-x}M_xAs_2$ obtained and found to be similar to the case of doping Co and Ni to the Fe sites. However, the suppression to the AF order in doping Ir is much slower and superconductivity suddenly sets in at a high doping(x=0.43).Regarding the close values of the maximum superconducting transition temperature in doping Co, Rh and Ir which locate actually in the same column in the periodic table of elements but have very different masses, they argued that the superconductivity is intimately related to the suppression of the AF order, rather than the electron phonon coupling. By measuring the magnetic field induced broadening of resistive transition curve they determined the upper critical field. It is found that the superconductivity in the entire doped sample is rather robust against the magnetic field. J. Parkash et al have synthesized new members of the La- based oxypnictide series with nominal compositions of $La_{0.9}Yb_{0.1}O_{0.8}F_{0.2}FeAs$, $La_{0.8}Yb_{0.2}O_{0.2}FeAs$ and $La_{0.7}Yb_{0.3}O_{0.8}F_{0.2}FeAs$. These new superconducting oxypnictide has

been obtained by substituting Yb ions in $LaO_{0.8}F_{0.2}FeAs$. The transition temperature of 31.3 K obtained for x= 0.1 composition is highest reported in La based oxypnictide at ambient pressure. From magnetoresistance studies, they obtained an upper critical field of 46T corresponding to a coherence length ~27A^0 in the above composition. G. F. Chen et al concluded that the superconductivity occurs in F- doped sample $LaFeAsO_{0.9}F_{0.1-\delta}$ close to ~26 K. The main magnetic transition appears near 20 K. They found high upper critical field of over 50 T and clear signature of superconducting energy gap opening below Tc. Furthermore, they showed that the new superconductor has electron type conducting carries by the help of the Hall Effect measurement. R. A. Jishi et al have reported the results of electronic structure calculations on LiFeAs and NaFeAs members of a new class of superconducting compounds. The density of the states in the vicinity of the Fermi energy is found to be dominated by contributions from the Fe 3d states. They have been also calculated the Raman and infrared phonon frequencies at the brillouin zone center as well the phonon dispersion curves along high symmetry directions in the brillouin zone. They showed that the iron based superconductors are not of the conventional type because the amount of the electron phonon coupling amount is too small. F. Yndurain has proposed that in the superconducting phase of $LaFeAsO_{1-x}F_x$, the Fe atoms have a finite magnetic moment that fluctuates between two equivalent collinear antiferromagnetic configurations. The presence of this moment enhances dramatically the electron-phonon interaction at least fort the As A_{1g} phonon mode and varies substantially the density of states near the Fermi level. The maximum value of the calculated λ parameter takes place at x= 0.125. It is indicated that electron-phonon interaction, coupled with Fe magnetic moments, must be carefully revised, before ruling out its connection with Fe-based compounds superconductivity. H. Liu et al have found the CeFeAsO exhibits unusual electronic structure that deviates strongly from the band structure calculation. The electron signature of the magnetic/structural transition indicates the dramatic change of the quasiparticle scattering rate. A dispersion kink at ~25 MeV is observed in the parent compound of Fe based superconductor. These results have shown the interplay between charge, spin and lattice in the FeAs based parent compounds. F. Ma et al have concluded the iron based layered LaFeAsO as a parent compound of the Fe-doped superconductors is a quasi-two dimensional antiferromagnetic semimetal, in which the antiferromagnetic spin-

density wave forms on the Fe-Fe square lattice due to the Fermi surface nesting and after F doping suggesting a new superconducting mechanism mediated by spin fluctuations. R. Jin et al have investigated the electronic, magnetic, and optical properties of two Fe based superconductors and related parent compounds via three powerful techniques: Scanning tunneling microscope (STM), high temperature vibrating sample magnetometry, and optical transmission spectroscopy (OTS). Below the superconducting transition temperature, the STM of polycrystalline $NdFeAsO_{0.86}F_{0.14}$ showed single-gap feature. The quantitative fitting of STM data results in Bardeen-Cooper-schriffer like temperature dependence of the energy gap $\Delta(T)$,with $2\Delta(T)/K_BT_c$~4.3. The tunneling spectra of $BaFe_2As_2$ single crystal reveal no evidence for the opening of a gap below the magnetic/structural transition temperature T_{MS}~140 K. Above T_{MS}, the T-linear dependence of magnetic susceptibility of $BaFe_2As_2$ and $SrFe_2As_2$ may be attributed to their unique electronic structures that have both hole pockets and electron pockets. Y.

Zhang et al have used x-ray photoelectron spectroscopy (XPS) to investigate the band structure features of SmFeAsO and $SmFeAsO_{0.8}F_{0.2}$ and the changes of the band structure by the fluorine substituting for oxygen. A small peak at 0.2 eV below the Fermi level E_F, in the valence band of SmFeAsO, which corresponds to the low-spin state of Fe 3d electrons. The O 1s and Sm 3d core levels shift towards high energy by ~0.55 eV with fluorine doping, but in comparison the Fe 2p and As 3d core levels do not shift significantly. With the fluorine doping, the peak at 0.2 eV disappears, and a broad plateau forms near the Fermi level. Along with band width broadening, the density of state at E_F is slightly suppressed. It is concluded that the superconducting transition temperature Tc is not simple correlated the density of state at E_F in the FeAs-based superconductors. Y. Xia et al have presented the ARPES study of Fermi surface and polarizationresolved band topology of $Fe_{1+x}Te$. The result showed a pair of nearly electron-hole compensated Fermi pockets, an absence of a spin – density wave gap, and strong Fermi velocity renormalization. The observed new hole pocket is consistent with a long rang ordered magneto structural ground state. No signature of Fermi surface nesting instability associated with the antiferromagnetic observed. Finally, they have concluded that the $Fe_{1+x}Te$ series are different from the pnictides and likely harbor a novel mechanism for superconductivity and magnetism. S. Lebegue has reported the calculations on the electronic structure of the

superconducting material LaOFeP. It has been found that the interlayer chemical bonding present a significant part of covelency, which is completely ionic. Four sheets of the Fermi surface have a significant two-dimensional character. The electronic structure of $Ba_2Ti_2Fe_2As_4O$, superconductor has investigated by H. Jiang et al using first-principles calculations based on local density approximations. The conducting Ti_2As_2O and Fe_2As_2 layers has the multiple Fermi surface sheets originating from Ti-3d and Fe-3d states respectively. Compared with $BaFe_2As_2$ compound, there are sizeable changes in the related Fermi surface sheets. This change indicates the significant electron transfer (about 0.12e) from Ti to Fe, which suppresses the stripe-like antiferromagnetism at the Fe sites and simultaneously induces superconductivity. An additional Neel-type antiferromagnetic instability at the Ti sites is relatively robust against the electron transfer, who accounts for the anomaly at 125 K in the superconducting $Ba_2Ti_2Fe_2As_4O$ is suggested by them through their calculations. A study of Fermi surface topology and low-energy electronic structure for the recently discovered iron-based superconductor $Ca_{10}(Pt_3As_8)(Fe_2As_2)_5$ (the 10-3-8 phase, with T_c ~ 8 K), via angle-resolved photoemission spectroscopy (ARPES) has presented by M. Neupane et al . Despite its triclinic crystal structure, ARPES results indicate a fourfold symmetric band structure with the absence of Dirac-cone-like Fermi dots which found around the Brillouin zone corners in other iron-based superconductors. If the potential from the √5 superlattice arising from the PtAs layers is very weak, and the triclinic band structure can be unfolded onto the tetragonal Brillouin zone, then first principles calculations agree with experimental data. It has been concluded that the Ca-Fe-Pt-As superconductors are ideal systems for the study of interlayer hopping in the iron-based superconductors. A strongly temperature dependent spin-fluctuation spectrum in the normal conducting state, which develops a prominent low-energy resonance feature when entering the superconducting state is revealed by Magnetic inelastic neutron scattering studies of ironbased superconductors. Scanning tunneling spectroscopy (STS) and angle resolved photoemission spectroscopy (ARPES) studies gave the fingerprints of fluctuation modes through their interactions with electronic quasiparticles and also discussed the quasiparticle scattering rate and the superconducting order parameter. They reproduced the quasiparticle dispersions which obtained from momentum distribution curves as well as energy distribution curves and also discussed the relevance of the coupling

between electronic excitations and spin fluctuations for the superconducting mechanism [73]. V. Baledent el at [74] have determined the Fe electronic properties in the Co-doped pnictides $BaFe_2As_2$ superconductors by hard x-ray absorption spectroscopy at the Fe *K* edge in the high-resolution, partial fluorescence yield mode. It is found that the absorption spectra are remarkably stable through the temperature-induced phase transitions but on the other hand pressure leads to slight energy shift of the main edge but not of the pre-edge. The effect due to pressure is ascribed to the lattice compression and band widening which confirmed by multiple scattering simulations. The results of Fe electronic structure suggested that both doping and pressure are equivalent ways to destabilize the magnetic phase to the advantage of superconductivity. T. Yildirim have discovered structural and dynamical properties of $LaOBiS_2$ with electron doping and presented state- of-the- art first- principles calculations. Their results also suggested that the BiS_2 thin films on various substrates may show unusual properties due to epitaxial strain at the interface. A new materials ($Ba_{1-x}K_xBiO_3$) with similar structures but with a BiO_2 plane has smaller mass of the oxygen atom, which gives higher phonon energies, and also higher T_c ~ 31 K. Their results indicated that the BiS_2-based layered systems with strongly coupled electron-phonon superconductivity are very rich in physics, involving nearly ferroelectric soft phonons and CDW phases. S. Ideta et al have determined angle-resolved photoemission spectroscopy studies of $Ba(Fe_{1-x}Ni_x)_2As_2$ (Ni-122) and $Ba(Fe_{1-x}Cu_x)_2As_2$ (Cu-122), and compared the results with $Ba(Fe_{1-x}Co_x)_2As_2$ (Co-122). From the above study, it is found that Ni 3d-derived features are formed below the Fe 3d band and that Cu 3d-derived ones further below it. The hole and electron Fermi surface (FS) volumes are increased and decreased with substitution, respectively, qualitatively consistent with the rigid-band model. However, the total extra electron number estimated from the FS volumes is found to decrease in going from Co-, Ni-, to Cu-122 for a fixed nominal extra electron number. They estimated that the Neel temperature T_N and the critical temperature T_c maximum are determined by the FS volumes rather than the nominal extra electron concentration or the substituted atom concentration. N. Xu et al have investigated angle-resolved photoemission spectroscopy of the Fermi surface and electronic band structure of $BaCo_2As_2$ and revealed that same compound can be used as an approximation to the bare unoccupied band structure of the related $BaFe_{2-x}Co_xAs_2$ and $Ba_{1-x}K_xFe_2As_2$ compounds. However, their experimental results indicated

that electronic correlations are much less important in $BaCo_2As_2$ than in the ferropnictides, in agreement with dynamical-mean-field-theory calculations. Their results also suggested that this effect is due to the increased filling of the electronic 3d shell in the presence of Hund‟s exchange coupling.

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