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High-Temperature Superconductivity is the Quantum Leap in Electronics

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Abstract: ***The discovery of high-temperature superconductivity in 1986, is greatly influenced in the field of electronics. Superconductors and superconducting materials conduct electricity without resistance and can transport electrons with no resistance, and hence release no heat, sound, or other energy forms. Compared to traditional materials superconducting materials open up possibilities for new technological applications in the field of electronics. The present paper considers to what extent there is a need for HTS in up-to-date engineering and estimates their potential and evaluates future applications in electronics.***

Keywords: superconducting devices, SQUIDs, high-speed electronics, high temperature superconductors

1. Introduction

In Electrical and Electronics engineering, a conductor is a material that allows the flow of charge or allows the current flow due to the presence of free electron or ions otherwise known as electrical current. Conductor Examples**:** Copper, Gold, Silver, Aluminum etc. Material is a group made up of one type of elements or more and classification of it in the periodic table is arranged according to the ability of the material and efficiency in the delivery of electricity. Metals are generally hard, high melting and boiling point, malleable, good conductors of heat and electricity. Electrical conductivity of a material is the ability to carry an electrical current which requires the presence of charged particles.

According to Ohm’s law the voltage (V) set up across a solution is proportional to the flowing current (I):

$$V = R \times I \qquad \text{---------- (1)}$$

Where R is Resistance (ohm, Ω), V the Voltage (volt, V) and I the Current (ampere, A) .

The resistance (R) is a constant of proportionality. The resistivity ρ is defined as the resistance per unit length per unit area of scross-section and rises linearly with temperature as

$$\rho_T = \rho_0 \; +T \qquad \text{----(2)}$$

Therefore, the temperature dependence of thermal conductivity is defined by the temperature dependences of carrier concentration and mobility of Carrier concentration .The resistivity and conductivity of a material are inversely proportional:

$$Conductivity = \frac{1}{resistivity} \qquad \text{-------------(3)}$$

In a conductor, the valence band and conduction bands are overlapped. A small applied electric field causes electrons to contribute electric current in conductors. The resistivity of conductors increases with increases in temperature so they have the positive temperature coefficient resistivity.

A semiconductor is a type of conductor which has moderate the electrical conductivity and are usually crystalline solids that have applications in various fields such as the production of diodes, transistors, integrated circuits, etc. For Semiconductor, the temperature coefficient of resistivity is negative. Due to exchange of electrons semiconductors arrange as lattice structure. When temperature increased bonds in material are broken and free electrons are generated. At the location at which the electron was placed, "hole" is created. The energy states in semiconductors are group together in bands. An energy gap is found between these bands which contains no states that an electron can occupy. This is called forbidden energy gap. (Fig: 1)

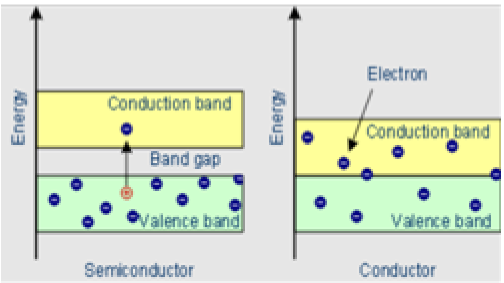

Figure 1: Energy levels in conductor and semiconductor

There are elemental semiconductor materials include silicon (Si), germanium (Ge), tin (Sn), selenium (Se), and tellurium (Te). However, pure silicon is the most common semiconductor as; it is the most important element for the production of integrated circuits in electronic industry.

Superconductors play an important role in today electronics technology. A **superconductor** is a material that resistance is zero when cooled down to a certain temperature call the **critical temperature**, they suddenly become perfect conductors. That is, a current in a superconductor can keep flowing without any decay, forever.

Superconductivity is the phenomenon that occurs in certain materials when cooled to very low temperatures close to absolute zero, where superconductors allow the passage of electricity through without resistance [1, 2].

Superconductivity was discovered in 1911 in the Leiden laboratory of Heike Kimberling Ones, a Dutch physicist, who noticed that the resistivity of Hg metal vanished abruptly at about 4K [3].(Fig. 2)

From then Superconductors have been studied intensively for the promise of technological applications which would be possible if a superconductor material can conducts at room temperature.

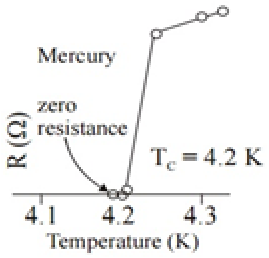

Figure 2: First superconductivity found in mercury

A high-temperature superconducting material has zero electrical resistance at the temperature of liquid nitrogen, so it can reduce the power losses in electrical equipment. The transition temperature (Tc) of high-Tc superconductors can be found by their layered crystal structure, bond lengths, valence properties of the ions, and Coulomb coupling between electronic bands.

Superconductor is a macroscopic quantum state in which the interior of the material remains free of electric and magnetic fields. Semiconductors can conduct electrical currents under special circumstances and an essential component in many of the electronic circuits used in everyday items including mobile phones, digital cameras, televisions, and computers.

Conductors, Semiconductors and Superconductors: A Comparison

	Conductors	Semiconductor	Superconductor
1	It is an object or material which allows the flow of charge when a voltage is applied	An object or material which has a conductivity between insulator and a conductor	An object or material that has zero electrical resistance & expels magnetic fields
2	The resistivity of Normal conductors have some resistance that depends on its length, width, and material.	The resistivity of semiconductor is finite	The resistivity of a superconductor is zero below critical temperature.
3	Electrical *conductivity* of a *conductor* is the reciprocal of resistivity of the material.	semiconductors have an electrical conductivity between a conductor and an insulator	Superconductors have an electrical conductivity higher than that of the conductor.
4	A perfect conductor show perfect diamagnetism Characteristics	Semiconductor do not show perfect diamagnetism	Superconductors show perfect diamagnetism
5	Due to resistance, the conductor consumes energy in the form of heat	Due to small resistance, the semiconductor also consumes energy in the form of heat.	There is no energy loss or consumption in superconductors
6	The current in a conductor die out when the power source is removed	*Current* conduction in a *semiconductor* occurs due to mobile or "free" electrons (emitter) and replaced by new ones being provided by a *battery/power source*.	The current in superconductor keeps flowing even after the power source is removed
7	The magnetic field lines of force can pass within the conductor	The magnetic field lines of force can also pass within the semiconductor	The magnetic field lines of force can not pass within the superconductor as it expels the magnetic field from the inside.
8	A conductor cannot store energy due to its resistance. It dissipates energy.	A semiconductor cannot store energy due to some resistance present in it.	A superconductor can store energy as it does no dissipate energy .
9	Conductors can operate at normal range/ room temperatures.	Semiconductors can operate in normal range of temperatures.	Superconductivity in conductors can achieve when it is supercooled down below 5 K.
10	In conductors, the energy gap between valence band and conduction band is overlaps.	The energy gap of a superconductor is of the order of a few eV.	The energy gap of superconductors is of the order of 10^{-4} eV.
11	In conductors, the valence band overlaps with the conduction band, so the conduction band may be populated by electrons.	The band gap of a semiconductor is between 0.25 and 2.5 eV	The band gap of a superconductor is above 2.5 eV.
12	The conductors are made into wires for conduction of electrical current	The semiconductors can be made into wires/ devices for conduction of electrical current	The superconductors have specific application due to its very low temperature but it will revolutionize in near future once its temperature is maintained efficiently.
13	Example of some conductor materials are iron , copper, gold, aluminium, etc.	Example of semiconductor materials are Silicon, germanium, selenium, tellurium, gallium arsenide, etc.	Example of superconductor materials are Aluminium, niobium, magnesium, diboride, etc.

2. Development of Superconducting Materials

In 1911, H. Onnes first discovered superconductivity, which is the result of liquefaction of gaseous helium that time, superconductors were simple metels such as mercury, lead, and bismuth etc, [4,5]. Since this initial discovery, many more elements have been discovered. In 1912, element Pb was found as a superconductor at 7 K and niobium (Nb) at 9.3 K has the highest *Tc* among the element. And, some other elements are found in superconducting form as carbon (C) in the form of nanotubes, chromium (Cr) as thin films and platinum (Pt) as a compacted powder. Matthias et al. discovered that the compound niobium-germanium (Nb3Ge), sometimes known as binary alloys, has a Tc of 23.2 K, which was the highest of any materials at that time. Until the mid-1980s, all known superconductors operated at temperatures much below liquid nitrogen's boiling point (about 77 K). In 1979, superconductivity was discovered in the magnetic substance CeCu2Si2 as the first example of a new class of superconductor materials known as "heavy fermion" superconductors, in which magnetism is responsible for the creation of Cooper pairs. In the late 1980's, the discovery of so-called 'high temperature' superconductors by Bednorz and Muller in 1986. Their findings were awarded the Nobel Prize in Physics by the Royal Swedish Academy of Sciences. Using liquid nitrogen instead of liquid helium to attain superconducting Tc is easy because the 77 Kelvin temperature of liquid nitrogen is far easier to attain and maintain than the cooled 4.2 Kelvin of liquid helium. Most importantly, nitrogen constitutes 78% of the air we breathe but liquid helium has a few limited resources, so relatively much cheaper. Until 1986, The maximum temperature of a superconductor could achieve was 23 K. As a result, any usage of superconductors became extremely expensive.

The discovery of a barium-doped lanthanum copper oxide (La2-xBaxCuO4), also known as Bednorz and Muller molecules (LBCO), that became superconducting at 35 K gave rise to a new class of high-temperature superconductors, some of which were superconducting above the boiling temperature of nitrogen (77 K) [6]. Because this substance is an insulator at room temperature, the discovery was extremely surprising. They were later awarded the Nobel Prize in Physics for "their significant contribution to the discovery of superconductivity in ceramic materials."Because of this breakthrough, scientists began to study more than 50 high-temperature superconductors, almost all of which contain the copper oxide layer known today. Wu and Chu found that the maximum Tc value of YaBaCuO was 90 K, and later Maeda et al. discovered the first superconducting transition temperature of 100 K in the BiSrCaCuO compound (BSCO).

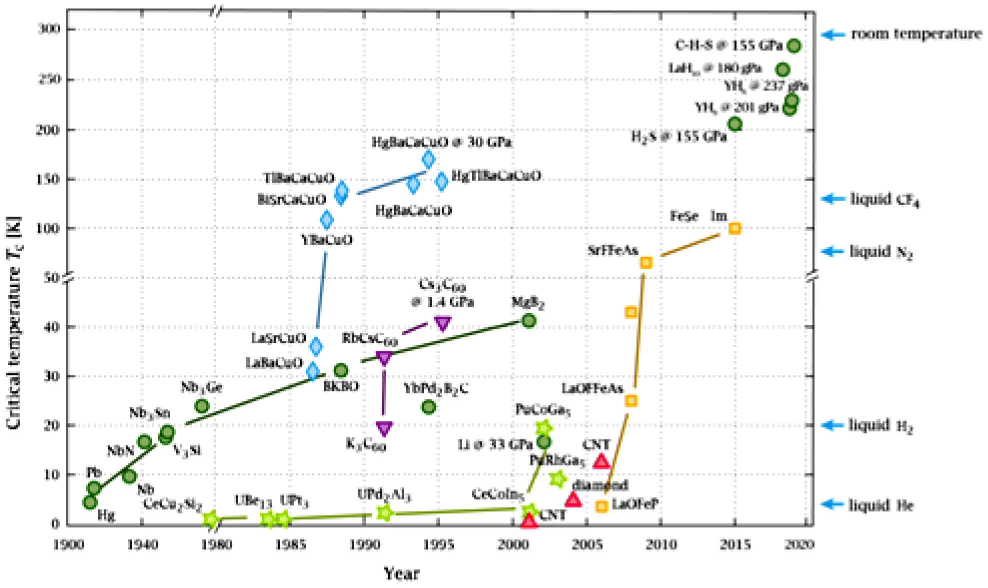

Figure 3: Tc vs. year of discovery of some important superconductors (ref-13)

When employing such compounds (BSCO), the maximum Tc obtained is 130 K at atmospheric pressure HgBaSrCaCuO and 164 K at a high external pressure of 30 GPa [7]. High temperature superconductors are the name given to these materials (HTSC). In alkali-doped C60 and organic polymers, several forms of low-temperature superconductivity have been reported. The maximum value of Tc 40 K was then discovered in the metals (K, Rb, and Cs). The MgB2 group, which is the first type I superconducting compound among intermetallic compounds with a Tc greater than 30 K, set a new record temperature of 40 K in 2001 [8].In 2006, the last superconductor "family" discovered was "Pnictids", which was first discovered by a group of Japanese researchers. Hideo Hosono et al. developed a new superconductor LaFePO based on ferromagnetic metallic iron (Fe) and Tc ~ 3K [9]. Since then, the maximum Tc of the compound LaFeAsO1-xFx was observed in 2008, reaching 26 K. Then, more than 70 new superconductors with the highest Tc up to 55 K were observed in Sm-based FeAs superconductors, which emphasized the importance of iron-based superconductors relative to other known high-temperature superconductors. As mentioned above, cuprate and iron-based have contributed to the development of high-temperature superconductors. [34]

In this regard, the discovery of these types of superconductors leads to the realization of a *Tc* approaching room temperature. In 2012, Yoshikazu Mizuguchi was discovered novel layered structured superconductors which is similar to those of the Cu-oxide and Fe-based superconductors. The characteristic structure of superconducting BiS2 layers form a new superconducting family "BiS2-based superconductors"[10,11]. So far, many superconductors have been discovered in this family, and the highest record of *Tc* is found 11 K in LaO0.5F0.5BiS2 [12]. In addition, the discovery of the Bi-oxide superconductor B1-xKxBiO3 with a *Tc* of ~30 K were found [13, 14]. Figure 1 clearly shows some important superconductors and their discovery year.

Recently, by applying a pressure of about 90 GPa to another superconducting material sulphur hydride, a Tc of 80 K was discovered. The magnetic susceptibility measurement confirmed that Tc was 203 K after cooling in a magnetic field. [15,16]. Hydrogen sulfide (H2S) was first discovered in 2014 and 2015, and then confirmed as a high-temperature superconductor with a transition temperature of 80 K under pressure (about 150 GPa). [17,18,19] In 2019, it was also discovered that lanthanum hydride (LaH10) became a superconductor at 250 K and pressure (about 150 gigapascals) [19,20] .With cooling and a modest electric charge, the Massachusetts Institute of Technology's Physics department reported superconductivity in bilayer graphene with one layer twisted at an angle of roughly 1.1 degrees in 2018. The experimental results have a lower correlation with classical. The superconducting effect is the result of electrons spinning in vortices between graphene layers called skyrmions. As a unit, they create the necessary framework conditions for superconductivity. [21]

A room-temperature superconductor consisting of hydrogen, carbon, and sulphur was described in an article published in Nature in 2020 under pressures of roughly 270 gigapascals. [22] This is the highest temperature at which superconductivity has been seen in any material. [19]. The new superconductors continue to attract people's interest. Many governments, corporations, and universities are putting enormous quantities of money into research and development.

Superconductivity Phenomenon/ Theory of Superconductivity

A state of metals below a certain critical temperature is known as superconductivity. [23]. Heavily doped semiconductor (as Ge or Si) can become superconductor. Superconductors depend on the motion of highly correlated pairs of electrons which are formed in special circumstance, when two electrons each interact strongly with a lattice and with each other. In the 1950s, Leon N. Cooper together with John Bardeen and J. Robert Schrieffer found an explanation of the superconductivity phenomenon called the BCS theory **received the Nobel Prize in 1972**, states that

When an electron travels in the lattice, the surrounding ions may shift their position slightly. Such temporary distortions of the lattice called phonons in solid state and create small regions of positive charge, which in turn attract other electrons. Pairs of electrons can behave as fermions and must obey the Pauli Exclusion Principle. The electron pairs have a slightly lower energy gap on the order of 0.001 eV. [24]

A model of Cooper pair attraction (fig. 4)

The BCS theory explains the attractive force between electrons through the medium. If one electron in the crystal attracts neighboring positive ions, a nearby second electron will be pulled in by these positive charges. This means that an attractive interaction throughout the medium is generated between electrons and all such paired electrons form a condensate that moves as a single entity and overcomes the Columbic interaction.

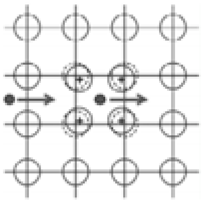

Figure 4: The generation of a cooper pair of electrons in a crystal

An electron when interact with the lattice, two possibilities may occur, either the electron "emits" a phonon or "absorbs" one. The electron interacts with the lattice and "emits" a phonon absorbed by the lattice. But another electron will immediately absorb this phonon and leave the lattice in its original state. This is the main feature called the Cooper pair (Figure 5).

Superconductivity is the physics of Cooper pairs. The Cooper pair is the bound state of two electrons. Electrons usually repel each other in a vacuum, but they may also attract each other under certain circumstances and form Cooper pairs. The electrons in normal conditions have spin taking the value of -1/2 or +1/2. But under certain conditions (below Tc), they form a pair. Electrons with opposite values of the spin but same momentum are attracted to each other and form a pair called cooper pair which has zero spin and twice the electron charge.

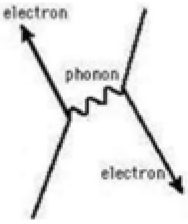

Figure 5: Formation of Cooper pair

In a Cooper Pair, these two half integer spins combine to form an integer spin, indicating that the Cooper Pair is a Boson. Cooper pairs can exist in the same quantum state and move without causing energy loss or electrical resistance without interacting with the lattice. The idea that there must be a band gap separating the charge carriers from the condition of normal conduction was one of the first steps toward a theory of superconductivity. The fact that Bosons can occupy a state has a significant effect on the density of states.

According to Band Theory, normal metal electrons fill energy states in an increasing density of state up to the Fermi level, but the bosonic nature of Cooper Pairs in superconductors allows them to occupy lower states than before the material reached its superconducting transition temperature. As a result, superconductors have an energy gap (Band gap) below the Fermi level. Due to this the resistance is **exactly** zero. Because the material may lose superconductivity if thermal energy could move charge carriers over the gap, the critical temperature for superconductivity must be a measure of the band gap. For elements, metals, and simple alloys, the BCS theory described superconductivity at temperatures near to absolute zero. At higher temperatures, however, this concept is unable to properly explain superconductivity.

In addition, the electrons in the BCS model must always be more dynamic than phonons: they move faster, so the first electron has passed the replaced ion long before the second arrives; at this distance, their mutual repulsion effect is small. In high-temperature superconductors, the mechanism is very similar to the BCS theory: phonons have almost no effect at high Tc, and their effect is replaced by spin density waves. Known conventional superconductors are strong phonon systems, and all known high-temperature superconductors are systems of strong spin density waves, which are in close proximity to magnetic transitions, such as an antiferromagnet. When an electron moves in a superconductor with a high temperature Tc, its spin generates a spin density wave around it. This spin density wave, in turn, causes adjacent electrons to fall into the spin depression created by the first electron. [35]. Therefore, Cooper pairs are formed again. More spin density waves and Cooper pairs are formed when the system temperature is decreased, giving rise to superconductivity. Note that in high-Tc systems, there is a significant Coulomb repulsion between electrons because these systems are magnetic due to the Coulomb interaction. The Cooper pairs cannot be paired on the same lattice site due to Coulomb repulsion. As a result, electron pairing takes place at nearby lattice sites. The pairing state has a node (zero) at the origin, which is known as d-wave pairing. This means that in HTSC, the Cooper pair's components are no longer electrons or holes, but rather charge carriers. Because of the difficulty of explaining high transition temperatures using the phonon model, many other models have been proposed by the researchers and scientists and further development in the field of superconductivity phenomenon at high temperature is going on.

Structure of superconductors:

In 1986, Bednorz and Muller found that La2CuO4 in which Lanthanum is partially replaced by Barium shows superconductivity around 3°k. The oxide La–Ba–Cu–O is metallic and probably magnetic. Thus it is unlikely material for superconductor. In 1987, several groups reported that compound of the type YBa2Cu3O7 called YBCO become super conducting at 77°k. This compound is also called as '123' (i.e. one atom of Yttrium, two atom of Barium and three atoms of Copper). [25]

For most materials, this critical temperature is incredibly cold and is difficult to achieve it. The critical temperature may be absolute zero to several Kelvin. However, in recent decades, scientists discovered materials that act as superconductors at much higher temperatures, as high as 150 Kelvin (or -123 Celsius). This is still extremely cold, but can be easily achievable for real life applications since we can achieve these temperatures simply by using liquid nitrogen. The unit cell structure of $YBa_2Cu_3O_7$ is based on the perovskite structure. (Fig. 6)

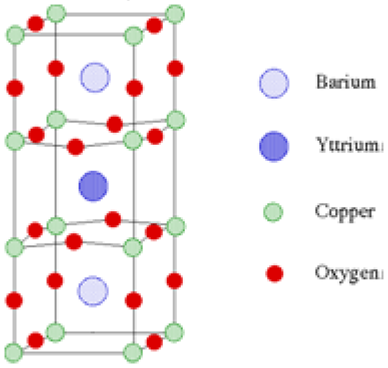

Figure 6: The unit cell structure of YBCO Superconductor

The main feature of the structure give rise to superconductivity is the existence of two-dimensional copper oxide sheets extending infinitely through the material in the ab plane. The 1-2-3 type high temperature superconductor has a structure similar to perovskite. The unit cell consists of three stacked cubic unit cells; it is considered to be orthorhombic rather than cubic, having an almost square base, but rectangular sides.

Specific Features of the Structure of HTSC

High-temperature superconductivity was first found in a ceramic sample. Thin films are most promising objects for practical applications nowadays. High temperature superconductivity in single crystals, ceramics and thin films evidences that the real structure of a sample does not account for this phenomenon. The real structure is responsible for the critical current destroying superconductivity but not the superconductivity effect as such. A common property of all known HTSC is the presence of at least one element with alternating valency. High-temperature superconductivity was discovered in compounds containing copper, bismuth, thallium, iron, etc, thin film elements, however, are pioneers in the practical applications of high-temperature superconducting materials. They are used in magnetometers operating at nitrogen temperatures, which are immensely sensitive and widely used everywhere, from geology to medical equipment. These achievements in the field of high-temperature superconductivity are used in practice already today.

Superconductor Materials Classification

A lot of materials available which can superconduct but excluding mercury, the original superconductors are metals, semiconductors, etc. Broadly a superconductor can be classified as:

Class I: Superconductors with one definite critical temperature. The Meissner effect and resistivity are two factors of superconductor which show amazing changes during its transition to the superconducting state when it is cooled below the critical temperature (Tc).

Class II: Superconductors that have two critical temperatures (Tc1 and Tc2). Above both, Superconductors behave as normal conducting state, while below them, they are completely superconducting. In between, superconducting materials behave as a mix of the two. Class II Superconductor are also characterized by the existence of "Mixed state" in which there is a partial penetration of the magnetic field and partial resistivity found into the superconducting material.

In Mixed state vortex can be originates. The motion of vortices dissipates energy and generates an electric field which in turn results in an effective resistivity of the material. (Fig. 7) A vortex is the negative energy of the interface between superconducting and normal phases.[26] [27]

Based on the value of T_C, a superconductor can be classified as,

High temperature superconductors having the critical temperature greater than 77 K are known as high T_C Superconductors or ceramic or oxide superconductors or P-type superconductors. In it the Superconductors is due to hole states.

Low temperature superconductors having the critical temperature less than 77 K are known as low T_C Superconductors or elemental superconductors or N-type superconductors. In it the Super conduction is due to cooper pairs.

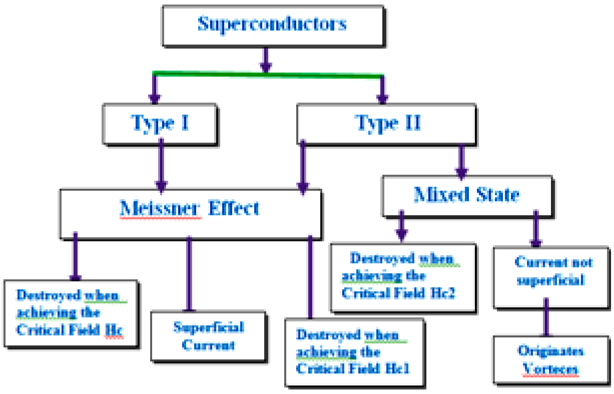

Figure 7: Shows the general classification of superconductors

Superconducting properties

The superconducting materials show some amazing and essential properties for current electronics technology.

Zero Electric Resistance/Infinite Conductivity

The superconductor is the absence of electrical resistance. When the material is cooled below the critical temperature, its resistance will be reduced to zero suddenly. Mercury shows zero resistance below 4k.

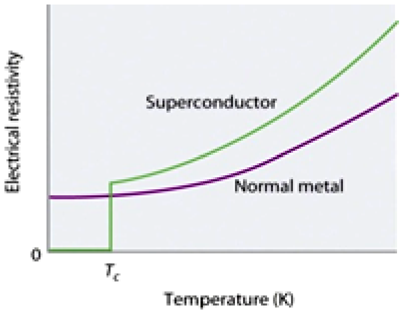

Figure 8: The Temperature Dependence of the Electrical Resistivity of a Normal Metal and a Superconductor

Perfect Conductor of Electricity

A superconductor is a perfect conductor of electricity; it carries direct current with 100% efficiency because no energy is dissipated by resistive heating. Once induced in a superconducting loop, direct current can flow undiminished forever. Superconductors also conduct alternating current, but with some slight dissipation of energy.

Expulsion of Magnetic Field (Meissner Effect)

When a superconductor is cooled below the critical temperature, it doesn't allow the magnetic field to penetrate in it. This occurrence in superconductors is called Meissner effect. (Fig. 9)

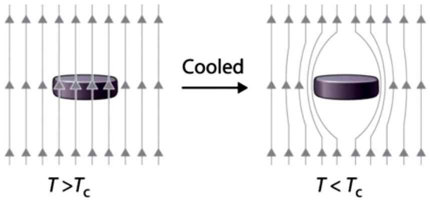

Figure 9: Meaissner Effect

This energy of superconductor material to remove magnetic field comes from the exothermic superconducting transition. When critical temperature increase (T>Tc) the superconductor returns to its initial state, i.e. no magnetic field inside or outside it [28].

Critical temperature/Transition temperature

The temperature below which the material changes from normal conductors to superconductors is called critical temperature or transition temperature.

Critical Magnetic Field

The certain value of the magnetic field below which the material changes from normal conducting state to superconducting state is called the critical magnetic field. The value of the critical magnetic field is inversely proportional to the temperature, i.e., as the critical magnetic field is negative coefficient of temperature.

Josephson Current

If the two superconductors are divided with the help of thin-film in insulating material, then it forms a junction of low resistance to found the electrons with copper pair. Electron can tunnel from one surface of the junction to the other surface and forms current and this current because of the flow of cooper pairs is known as Josephson Current.

Critical Current

When the current supplied through a conductor under the condition of superconducting, then a magnetic field can be developed. If the current flow increases beyond a certain rate then the magnetic field can be enhanced, which is equivalent to the critical value of the conductor at which this returns to its usual condition? The flow of current value is known as the critical current.

Persistent currents

If a superconductor ring is arranged in a magnetic field above its critical temperature, with multiply connected topology and a current is setup in it, then after removing magnetic field the flow of current can be induced within the ring because of its self-inductance. From Lenz law, the induced current opposes the change within flux that flows through the ring. When the ring is placed in a superconducting condition, then the flow of current will be induced to continue the flow of current is named as the persistent current.

Superconducting Ring

The zero resistance offered by superconducting circuits leads to unique consequences. In a superconducting short-circuit, it is possible to maintain large currents indefinitely with zero applied voltage. Rings of superconducting material have been experimentally proven to sustain continuous current for years with no applied voltage.(Fig. 10)

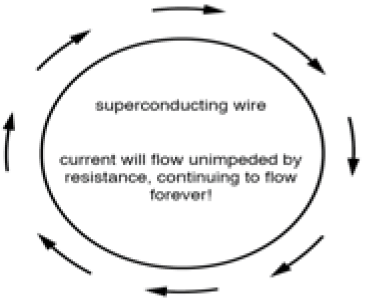

Figure 10: Superconductoing Ring

Vortex State

In a vortex state, Type II superconductors usually have normal cores surrounded by superconducting regions. This permits magnetic fields to pass through. The normal cores get more closely packed as their critical temperatures approach, eventually overlapping as the superconducting state is lost [29].
(Fig .11)

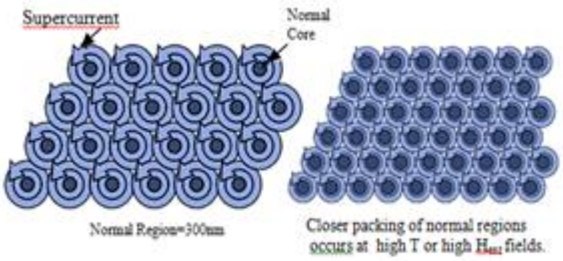

Figure 11: Vortex state for superconductors

Magnetic fields begin to penetrate through normal material cores surrounded by superconducting current vortices at the lower of the two essential magnetic fields in a Type II superconductor. Magnetic fields can penetrate while maintaining zero electric resistivity routes through the material as long as these vortices are immobile (pinned).While the Meissner effect has been modified to allow magnetic fields in the normal core, the superconducting regions still exclude magnetic fields.
With the increase of temperature and the external magnetic field, normal regions are packed together more closely. When the current flows, the vortices feel a force and when they move they lose the supreconducting state [30].

Coherence length

The coherence is a measure of the volume where the coherent state takes place and it is a measure of the extension of a Cooper pair. Bigger the coherence length, the weaker the binding between the two electrons that constitute the Cooper pair. So it relates inversely to the superconducting gap and to critical temperature. Actually, it is given by $\xi0 = hvF\ \pi\Delta0 = hvF\ 2\pi Tc$
where $h \equiv 2\pi\}$ and vF is the Fermi velocity.

Energy Gap

Energy Gap in Superconductors is a Function of Temperature. A superconductor depends strongly upon the superconductor's internal magnetic field. Superconductor energy gap is occupied with the energy of the external magnetic field, the normal metal conducting bands that became inaccessible at the superconductor, normal conductor phase transition are once again available for conduction, and the superconductor quenches.

Origins of the superconductor energy gap arising from loss of dissipative electron scattering and development of coherent electron lattice order at the superconductor phase transition lie in the laws of thermodynamics, which cannot be casually neglected.

Perfect diamagnetism: A superconductor expels a weak magnetic field nearly completely from its interior (screening currents flow to compensate the field within a surface layer of a few 100 or 1000 A, and the field at the sample surface drops to zero over this layer) [31].

Major Characteristics of Superconductivity

1) No resistance, permanent current i.e., Zero resistance makes permanent current possible.
2) Strong magnetic field without power consumption means increase of a critical current generate a strong magnetic field without power consumption.
3) Magnetic shielding (Meissner effect) means if the strength of an external magnetic field is below a critical level, the density of magnetic flux in a superconductor is zero (Meissner effect)-Magnetic shielding.
4) Superconducting magnet (SCM) means In second class superconductors that can exist above a critical magnetic level, the density of magnetic flux is not zero- Birth of a superconducting magnet (SCM).
5) A quantum computer using fluxoid means Digitization of magnetic flux in class II superconductors may enable the development of a quantum computer that requires no power consumption and generates no heat.
6) An advanced semiconductor with Josephson junction device mea by application of the Josephson effect, in which current flows within the insulator inserted between two superconductors (electron tunneling), we may enable the development of an advanced semiconductor.[32]

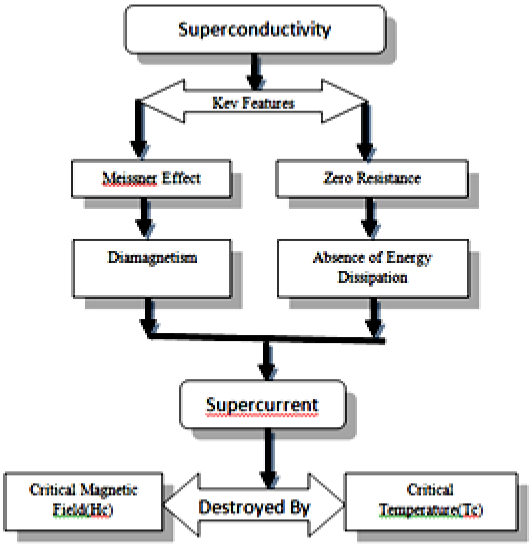

Figure 12: Diagram of the main characteristics of SC

Conditions Required for a Material to Exhibit Superconducting Behaviour

- The material must be cooled below a characteristic temperature, known as its superconducting transition or

critical temperature (T_c).
- The current passing through a given cross-section of the material must be below a characteristic level known as the critical current density (J_c).
- The magnetic field to which the material is exposed must be below a characteristic value known as the critical magnetic field (H_c).

These conditions are interdependent, and define the environmental operating conditions for the superconductor. (Fig.13)

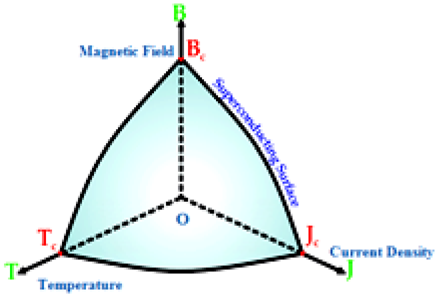

Figure 13: The condition required for a material to exhait superconductivity

Applications of superconductors in Electronics

1) Electrical energy can be transported and stored in wires without resistance loads.
2) Superconductors electromagnets can produce large magnetic fields and used in magnetism for making High field magnet, NMR, medical diagnostic equipment, refining instruments by magnetic separation, magnetic shielding, in energy related devices for producing magnetic fusion and magneto-hydrodynamics devices, energy storage and electrical power transmission instruments, in transportation for making high speed trains, ship drive system, in electronics for making bolometer, electromagnetic shielding, in computers and information technology for making semiconductor devices superconductor hybrid, active super conducting element, voltage standard, Opto-electronics instruments etc.
3) Superconductor components do not produce Joule heating, so smaller electronic circuits can be produced.
4) Superconductor components can be used in Josephson junction such as digital computers in detectors for high frequency electromagnetic radiation
5) Superconductor wire can be used for low current applications such as LASER ablation, election beam evaporators.
6) Superconductor materials can be used in SQUID (Superconducting Quantum Interference Devices). SQUID device generally used in non-intrusive medical diagnostics on the brain as it is incredibly sensitive to small magnetic fields and can detect the magnetic fields from the heart (10^{-10}Tesla) and even the brain (10^{-13}Tesla).[33]
7) Superconductor can be used in memory or storage elements.
8) Superconducting wires provide significant advantages because they conduct electricity with little or no resistance and associated energy loss and can transmit much larger amounts of electricity
9) They are like transistors but are capable of switching 100 times faster also they are capable of detecting minute magnetic fields.
10) Heat is an enemy of IC but using superconductor wire in electrical circuit no heat is generated. So, circuit can be packed close together which reduce time for electrical signal to travel from one area of circuit to another.

3. Conclusions and Discussion

Semiconductors may be the active parts of transistors, integrated circuits, sensors, and LEDs in coming future as semiconductor work nowadays. These superconductor materials will be the heart of future electronics industry. We will use electronic products making with superconducting materials (e.g., modern TV sets, computers, illumination elements, and of course as mobile phones). But these materials produce heat and loss electrical energy, so a new material is need in the electronics industry. Superconductor is a type of electrical conductor that fulfils all these needs. The basic facts which make Superconductivity the best for electronics industry are, resistivity goes to zero below the critical temperature Tc and superconductors expel flux (the Meissner effect) and act as perfect diamagnets.

One potential application of superconductor is transportation of electrical energy without loss means no energy is wasted. Through further development and significant advancement the hope is that we will one day be able to use superconductors to create vehicles that use magnetism and levitation to propel themselves forward. In near future, using superconductor we can create more advanced energy storage devices.

Superconductivity is delivering electricity without losing energy by the formation of so-called Cooper pairs. Superconductivity can be explained by the **BCS theory**, which says that electrons are able to travel through a solid in the form of pairs called cooper pairs, with no resistance. Scientists are developing and applying nanotechnology to the next level of research on semiconductors to a new field of research focusing on manipulating photons instead of electrons. Unfortunately, today's technology cannot create superconductivity at room temperature. Also, the production of a supercool superconducting compound is still expensive and complex. There are many developments and research going on in the area of Superconductivity to produce tailor-made materials in which superconductivity occurs even at normal ambient temperature.

Above all, superconductors are the quantum leap in the field of electronics because it has special and Unique Properties such as, it has Zero resistance to direct current, has extremely high current carrying density, has extremely low resistance at high frequencies ,has extremely low signal dispersion, has high sensitivity to magnetic field, has the capability of exclusion of externally applied magnetic field, has capacity of rapid single flux quantum transfer, has capacity to reach close to speed of light signal transmission, which make it more valuable and Globally acceptable from any other electronics used materials.

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