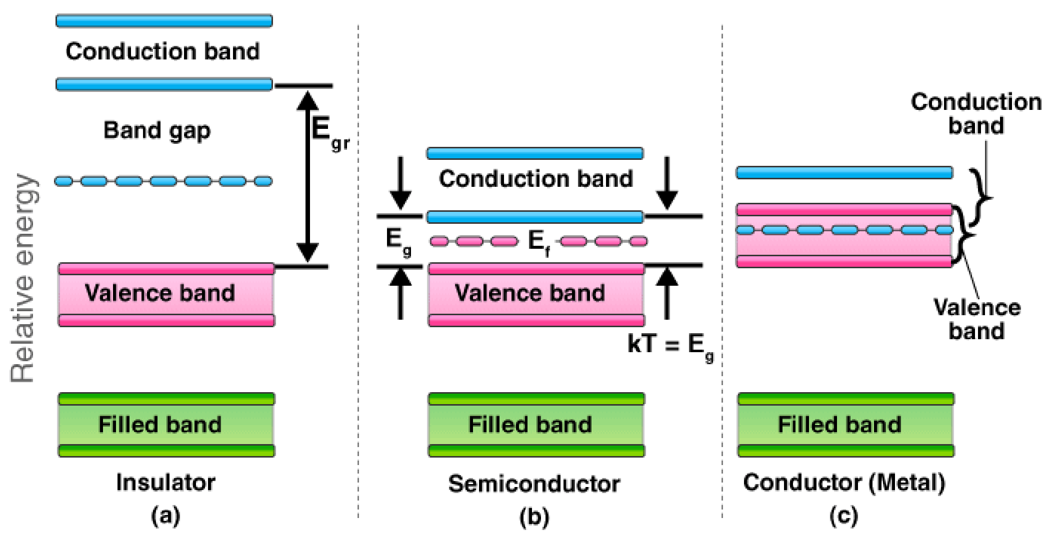
SEMICONDUCTORS: A solid is a semiconductor, if its electrical conductivity is in between those of insulators and conductors. The requirements of a material so act as a semiconductor are Almost filled valence band (according to band theory of solids)Almost empty conduction band and a narrow energy gap or forbidden gap (E_g) in between valence band and conduction band. It requires ~1ev to move electron from valence band to conduction band. Ex: Si, Ge etc.

Band diagrams in solids

Valence Band: The electrons in the outermost shell are known as valence electrons. These valence electrons contain a series of energy levels and form an energy band known as the valence band. The valence band has the highest occupied energy.

Conduction Band: The valence electrons are not tightly held to the nucleus due to which a few of these valence electrons leave the outermost orbit even at room temperature and become free electrons. The free electrons conduct current in conductors and are therefore known as conduction electrons. The conduction band is one that contains conduction electrons and has the lowest occupied energy levels.

Forbidden Energy Gap: The gap between the valence band and the conduction band is referred to as the forbidden gap. If the forbidden energy gap is greater, then the valence band electrons are tightly bound or firmly attached to the nucleus. We require some amount of external energy that is equal to the forbidden energy gap. The figure below shows the conduction band, valence band and the forbidden energy gap.



Semiconductor devices (p-n junction diode as rectifier and transistors): A semiconductor device like a p-n junction diode acts as a rectifier by allowing current to flow easily in one direction (forward bias) while significantly resisting current flow in the opposite direction (reverse bias), effectively converting alternating current (AC) into direct current (DC) by only allowing one half of the AC wave to pass through; transistors, on the other hand, are more complex semiconductor devices with three terminals that can amplify or switch electrical signals based on the voltage applied to their control terminal.

p-n junction diodes as rectifiers**:** principle:

A p-n junction diode is formed by joining p-type (positively doped) and n-type (negatively doped) semiconductor materials, creating a depletion region at the junction which acts as a barrier to current flow in one direction.

Forward bias: When a positive voltage is applied to the p-type side and a negative voltage to the n-type side, the depletion region narrows, allowing current to flow easily.

Reverse bias: When the polarity is reversed, the depletion region widens, significantly hindering current flow.

Rectification applications: This property is used in circuits to convert AC to DC, with different configurations like half-wave and full-wave rectifiers depending on how the diodes are connected.

Transistors: Structure: A transistor typically consists of three regions: emitter, base, and collector, which are formed by multiple p-n junctions arranged in specific configurations (like NPN or PNP).

Amplification principle: By controlling the small current flowing through the base region, a much larger current can be controlled in the collector circuit, enabling amplification of signals.

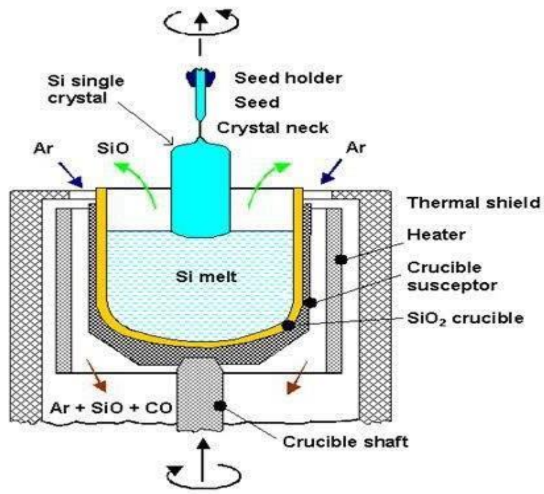
Switching function: Transistors can also be used as switches by turning on or off the current flow through the collector depending on the voltage applied to the base.

Conductors: Gold, Aluminum, Silver, Copper, all these metals allow an electric current to flow through them. There is no forbidden gap between the valence band and conduction band which results in the overlapping of both the bands. The number of free electrons available at room temperature is large.

Insulators: Glass and wood are examples of the insulator. These substances do not allow electricity to pass through them. They have high resistivity and very low conductivity. The energy gap in the insulator is very high up to 7eV. The material cannot conduct because the movement of the electrons from the valence band to the conduction band is not possible.

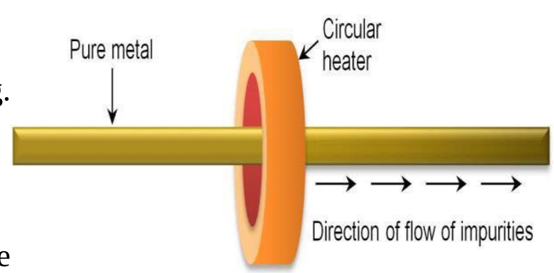
Semiconductors: Germanium and Silicon are the most preferable material whose electrical properties lie in between semiconductors and insulators. The energy band diagram of semiconductors is shown where the conduction band is empty and the valence band is completely filled but the forbidden gap between the two bands is very small that is about 1eV. For Germanium, the forbidden gap is 0.72eV and for Silicon, it is 1.1eV. Thus, semiconductor requires small conductivity.

Preparation of single crystalline semiconductor using Czochralski process



The Czochralski process is a method of crystal growth used to obtain single crystals of semiconductors (e.g.), metals (e.g. palladium, platinum, silver, gold), salts and many oxide crystals (LaAlO3,). The process begins when the chamber is heated to approximately 1500 degrees Celsius melting the silicon. When the silicon is fully melted, a small seed crystal mounted on the end of a rotating shaft is slowly lowered until it just dips below the surface of themolten silicon. The shaft rotates counter clockwise and the crucible rotates clockwise. The rotating rod is then drawn upwards very slowly about 25 mm per hour when making large cylindrical ingots. This process is normally performed in an inert atmosphere, such as argon, and in an inert chamber, such as quartz.

Purification of single crystalline semiconductor using zone refining process

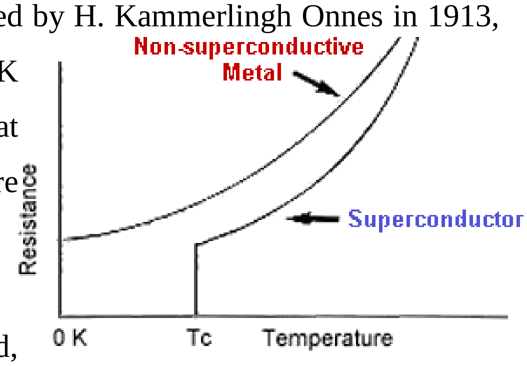


Zone refining refers to the method of purifying a crystal wherein a thin region of the crystal undergoes melting. The principle of zone refining is that the impurities in an ingot or ore of metal are more soluble in the melt state when compared to the corresponding solid state of the impurities. In the zone refining process, a circular mobile heater is fixed at one end of the metal rod which is made up of the impure metal. Now, the circular mobile heater is moved slowly across the metal rod. The metallic impurities melt at the temporary position of this heater. The melt containing the impurities moves forward along with the heater through the entirety of the metal rod. The pure metal is left to solidify as the heater moves along the rod, as the heatermoves forward, the concentration of the impurities in the melt increases. This is because the impurities are more soluble in their corresponding melt state. Finally, the impurities are accumulated at one end of the metal rod. The process described above is repeated many times in the same direction. The end of the rod in which the impurities have now accumulated in is cut off, leaving behind the pure metal.

SUPERCONDUCTORS:

Introduction: Ordinary metals conduct electricity and their specific conductivity is around 10^6 ohm^{-1} cm^{-1}. It has been found that for a number of metals and alloys, the electrical resistance disappears abruptly and completely at temperature a few degrees above absolute zero (0 degrees Kelvin, -273 degrees Celsius). Materials should be super conducting, when they offer no resistance to the passage of electricity.

The temperature at which electrical resistance is zero is called the critical temperature (T_c) or Transition temperature. This phenomenon was first observed by H. Kammerlingh Onnes in 1913, superconductors having a critical temperature T_c above 77K are particularly interesting and known as superconductors at high temperature, that property known as high temperature super conductivity.

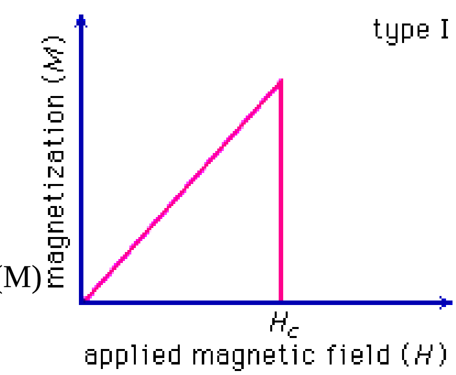


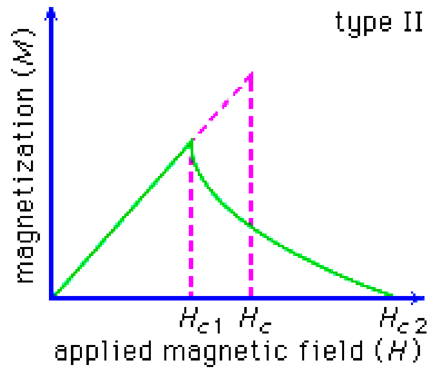
Type I and Type II superconductors

Depending upon their behavior in an external magnetic field, superconductors are divided into two types:

a) Type I superconductors and b) Type II superconductors

Type I superconductors: Type I superconductors are those superconductors which lose their superconductivity very easily or abruptly when placed in the external magnetic field. As you can see from the graph of intensity of magnetization (M) versus applied magnetic field (H), when theType I superconductor is placed in the magnetic field, it suddenly or easily loses its superconductivity at critical magnetic field (Hc). After Hc, the Type I superconductor will become conductor. Type I superconductors are also known as soft superconductors because of this reason that is they lose their superconductivity easily. Type I superconductors perfectly obey Meissner effect.





Type II superconductors: Type II superconductors are those superconductors which lose their superconductivity gradually but not easily or abruptly when placed in the external magnetic field. As you can see from the graph of intensity of magnetization (M) versus applied magnetic field (H), when the Type II superconductor is placed in the magnetic field, it gradually loses its superconductivity. Type II superconductors start to lose their superconductivity at lower critical magnetic field (Hc1) and completely lose their superconductivity at upper critical magnetic field (Hc2). The state between the lower critical magnetic field (Hc1) and upper critical magnetic field (Hc2) is known as vortex state or intermediate state. After Hc2, the Type II superconductor will become conductor. Type II superconductors are also known as hard superconductors because of this reason that is they lose their superconductivity gradually but not easily. Type II superconductors obey Meissner effect but not completely.

Properties of superconductors:

1. A superconductor is characterized by zero electrical resistivity. Once the current is started to flow, it will continue without if the applied voltage is removed.
2. Meissner effect: An important property of the superconducting phase is the repulsion of all the magnetic flux lines from the bulk of superconductor. It is called Meissner effect.

- When a specimen (non-superconducting) is placed in a magnetic field, the magnetic lines pass through it (fig. a).

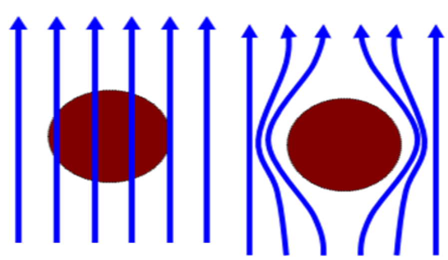


Fig. (a) $T>T_c$ Fig. (b) $T<T_c$

- Now if the temperature is decreased below Tc (transition temp.), it expels all the magnetic flux lines from inside of the specimen (fig. b) since diamagnetic materials have negative magnetic susceptibility, the specimen becomes an ideal diamagnetic in superconducting state.
- If a specimen of superconductor is placed in a strong magnetic field, the specimen loses its property of superconductivity and becomes normal material.

3. We know that the entropy is a measure of the disorder of a system, the entropy decreases on

cooling below its T_c. hence decrease in entropy between the normal state and superconducting state shows that superconductor more order than the Normal state.

4. They possess grater resistivity than the other elements at room temperatures.
5. The transition temperature for different isotopes of superconductive element decreases with atomic masses of isotope.
6. On adding impurity to a super conducting element, the critical temperature is lowered.
7. Superconductivity is more concerned with the conduction of electrons than the atom of element itself.
8. In superconducting state, all electromagnetic effects disappear.
9. During transition, neither thermal expansion nor elastic properties change.

Applications of superconductors:

The phenomenon of superconductivity has many practical applications such as:

1. Superconducting magnets capable of generating high fields with low power consumptions are being employed in scientific tests and research equipment.
2. They are also used for MRI (magnetic resonance imaging) in the medical field as a diamagnetic tool. On the basis of production of cross-sectional images, any abnormal in body tissues and organs can be detected.
3. Electrical power transition through superconducting cables-power loss is extremely low and equipment operates at low voltage
4. Superconducting magnets are employed for operating friction less, high speed, levitating trains.
5. Superconductors can be used to perform logic and storage functions in computers.
6. These can be used in manufacture of electrical generators and transformers in exceptionally small sizes having efficiency of 99.99%.
7. Superconductors serve as gas sensors because their electrical resistivity sharply changes on contact with certain gases.
8. Super conductors are also used in harnessing the various forms of nuclear energies.

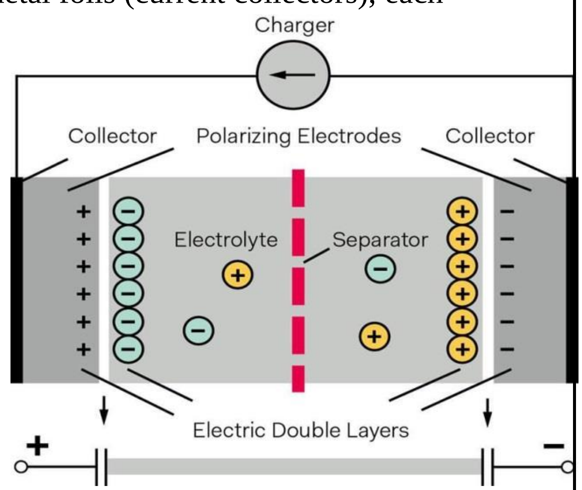
SUPER CAPACITORS:

Introduction: A capacitor is pair of two conductors of any shape, which are separated through a small distance or in close proximity and have equal and opposite charge. In other words, a capacitor is a device that stores electric energy. A super capacitor is also a capacitor but its capacitance value is much higher than other capacitors.

Super capacitor

Super capacitor is an electrochemical capacitor that has high energy density and better performance efficiency as compared to the common capacitor, the reason why it has the prefix 'super 'attached to it. It stores and releases energy by reversible desorption and adsorption of ions at the electrode-electrolyte interface. Conventional capacitors have low energy density with wider cell voltage and higher specific power. On the other hand, super capacitors have high capacitance over a lower limit of cell voltage.

Construction: Super capacitors are constructed with two metal foils (current collectors), each coated with an electrode material such as activated carbon, which serve as the power connection between the electrode material and the external terminals of the capacitor. Specifically to the electrode material is a very large surface area. The electrodes are kept apart by an ion-permeable membrane (separator) used as an insulator to protect the electrodes against short circuits. The cell is then impregnated with a liquid or viscous electrolyte of organic or aqueous type. Theelectrolyte, an ionic conductor, enters the pores of the electrodes and serves as the conductive connection between the electrodes across the separator. When a voltage is supplied across the super capacitor's plates, one of the plates develops a positive charge, while the other plate develops a negative charge. This attracts the negatively charged ions in the electrolyte to the positively charged plate and the positively charged ions to the negatively charged plate. On the inner surface of both plates, a thin coating of ions is deposited. This results in the production of an electrostatic double layer, which is similar to connecting two capacitors in series. Each charge possesses high capacitance as the distance between both the resultant capacitors is very thin



and the area of electrodes is high.

Classification of Super capacitors

Super capacitors are also referred to as gold capacitors, power capacitors, ultra-capacitors or super condensers. On the basis of their charge storage mechanism, these are classified into three types:

1. Electrostatic double-layer capacitors
2. Pseudo capacitors
3. Hybrid capacitors

Electrostatic Double-Layer Capacitor (EDLC)

This type of capacitor works on the charge storage mechanism where a charge is physically stored on the surface of the electrodes without causing any irreversible chemical reactions via theformation of an electrical double layer. Usually, carbon-based electrodes are used in super capacitors which are separated by a dielectric substance that acts as an insulator and possesses electrical properties that eventually affect the performance of the super capacitor. Charges are electrostatically stored in super capacitors. An electric field is generated at each electrolyte as soon as the voltage is applied across the terminal which leads to the polarization of the electrolyte. As a result of which ions diffuse through the dielectric to the porous electrodes of opposite charges. In such a way, the formation of an electric double layer takes place at each electrode. This results in the increased surface area of each electrode and decreased distance between the electrodes.

Pseudo Capacitors

Pseudo capacitors are also referred to as electrochemical pseudo-capacitors. These capacitors make use of metal oxide or conducting polymer electrodes with a high amount of electrochemical pseudo capacitance. These types of components store electrical energy by electron charge transfer between electrode and electrolyte. This can be done by a reduction-oxidation reaction commonly known as a redox reaction. These devices use electrodes made up of redox-active materials such as metal oxides (MnO_2) and conducting polymers (polyanilines, polypyrroles, and polythiophenes). These electrodes store charge through reversible faradaic reaction mechanisms.

Hybrid Capacitors

These capacitors have adopted both the mechanisms of EDLC and pseudo capacitors. Hybrid capacitors are composed of electrodes with different characteristics based on chemical as well as electrical mechanisms. As a result, one electrode exhibits electrostatic capacitance and the other provides electrochemical capacitance.

Applications of Super capacitors

Super capacitors are used in the following

1. Consumer electronics
2. Power generation and distribution
3. Voltage stabilization
4. Energy harvesting
5. Batteries
6. Medical
7. Military
8. Transport
9. Aviation
10. Cars
11. Rail
12. Buses
13. Motor racing
14. Hybrid electric vehicles