DEPARTMENT OF ELECTRICAL ENGINEERING
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LECTURE NOTES

ON

ELECTRICAL ENGINEERING MATERIAL

SEMESTER-3RD

Compiled by

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LECT. IN ELECTRICAL ENGG.

Chapter-1

Introduction

- Material science and engineering plays a vital role in this modern age of science and technology. Various kinds of materials are used in industry, housing, agriculture, transportation, etc. to meet the plant and individual requirements.
- The knowledge of materials and their properties is of great importance for a designengineer
- A design engineer must be familiar with the effects which the manufacturing processes and heat treatment have on the properties of the materials

The engineering materials are mainly classified as

- Metals and their alloys, such as iron, steel, copper, aluminium etc.
- Non-metals such as glass, rubber, plastic etc.

Metals may further be classified as-

- *Ferrous metals-*

The ferrous metals are those which have the iron as their main constituent, such as cast iron, wrought iron etc.

- *Non-ferrous metals.*

The non-ferrous metals are those which have metal other than iron as their main constituent, such as copper, aluminium, brass, tin, zinc etc.

Physical properties

- Physical properties are employed to describe the response of a material to imposed stimuli under conditions in which external forces are not concerned.
- Physical properties include .

a) Dimensions,
b) Appearance,
c) Colour,

d) Density,
e) Melting point,
f) Porosity,
g) structure, etc.

Dimensions

Dimensions of a material implies it's size(length, breadth, width, diameter, etc.) andshape(square, circular, channel, angle section, etc.)

Appearance

- Metals themselves have got different appearances e.g., aluminium is a silvery white metal whereas copper appears brownish red.
- Appearance include lusture, colour and finish of a material.
- Lusture is the ability of a material to reflect light when finely polished. It is the brightness of a surface.

Colour

- The colour of the material is very helpful in identification of a metal. The colour of a metal depends upon the wavelength of the light that the material can absorb.

Density

- The density is the weight of unit volume of a material expressed in metric units.
- Density depends to some extent on the

a) Purity of material
b) Pour volume
c) Treatment, the material has received.

- Density helps differentiating between light and heavy metals even if they have same shape and any outer protective coating.

Melting point

- Melting point of a material is that temperature at which the solid metals change into molten state.
- One metal can be distinguished from the other on the basis of its melting point.

Porosity

- A metal is said to be porous if it has pores within it.
- Pores can absorb lubricant as in a sintered self-lubricating bearing.
- It is the ratio of total **pore volume** to **bulk volume**

Structure

- It means geometric relationships of material components.
- It also implies the arrangement of internal components of matter(*electron structure*, *crystal structure, and micro structure*)

Chemical properties

- A study of chemical properties of materials is necessary because *most of engineering materials when they come in contact with other substances with which they can react, tend to suffer from chemical deterioration.*
- The chemical properties describe the combining tendencies, corrosion characterstics, reactivity, solubilities, etc.of a substance.
- Some of the chemical properties are

  1. corrosion resistance

  2. chemical composition

  3. acidity or alkalinity

Corrosion

- It is the deterioration of a material by chemical reaction with its environment.
- Corrosion degrades material properties and reduces economic value of the material.
- Corrosion attacks metals as well as non-metals. Corrosion of concrete by sulphates in soilsis a common problem

Performance requirement

The material of which a part is composed must be capable of embodying or performing a part's function without failure for example – a component part to be used in a furnace must be of that material which canwithstand high temperatures.

While it is not always possible to assign quantitative values to these functional requirements, they must be related as precisely as possible to specified values of mostclosely applicable mechanical, physical, electrical or thermal properties.

Material's Reliability

Reliability is the degree of probability that a product, and the material of which it is made, will remain stable enough to function in service for the intended life of the product withoutfailure.

A material if it corrodes under certain conditions, then, it is neither stable nor reliable forthose conditions.

Safety

A material must safely perform its function, otherwise, the failure of the product made out of it may be catastrophic in air-planes and high pressure systems. As another example, materials that gives off spark when struck are safety hazards in a coal mine.

Classification of material:

The material are classified into following types

1. **Conducting material** –The material in which electric current flow easily . Example: copper , brass etc.2
2. **Insulating material -** The material in which electric current cannot flow .Example: wood glass .
3. **Semiconducting material** – The material whose property lies between insulating and conducting material. Example : silicon ,gallium .

Classification of material on the basis of atomic theory

- conducting material.
- insulating material.
- Semiconducting material.

Conducting material:

The materials which conduct electricity due to free electrons when an electric potential difference isapplied across them are known as conducting materials.

Gold, silver, copper, aluminum are the examples of conducting materials.

Insulating material:

The material which does not allow the electricity to pass through them is known as an electrical insulatingmaterial.

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glass wool, polystyrene, plastic, wood fiber, and plant fiber are the example of insulating material.

Semiconducting material.

The material whose property is lies between insulating and conducting material. examples of semiconductors are **silicon, germanium, gallium arsenide**

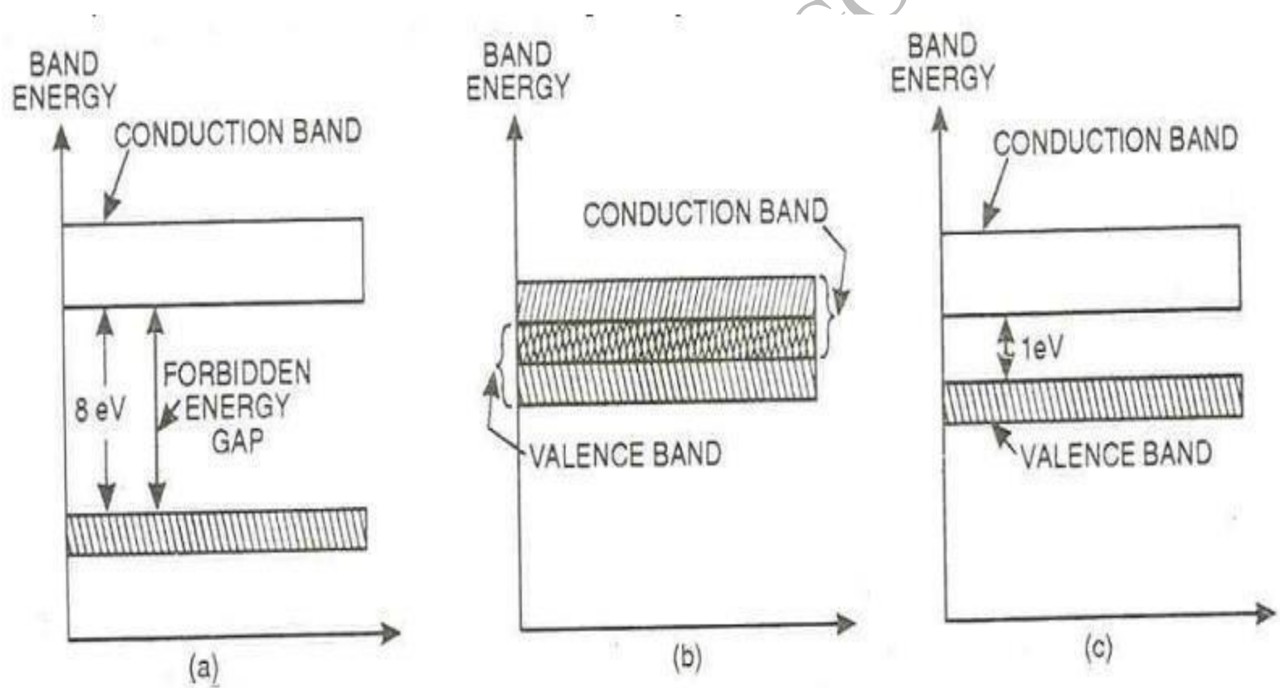
Energy band theory

The range of energies possessed by the electrons of the same orbit of different atoms in a solid is knownas energy band

Types of energy bands.

- Valence band
- Conduction band
- Forbidden energy band

Classification of materials on the basis of energy band:



Insulators-

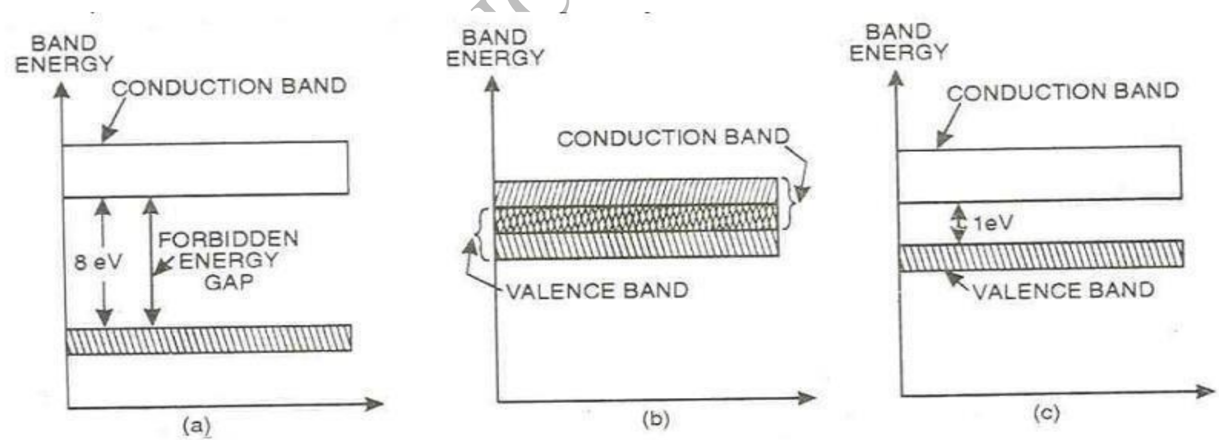
insulators are those materials in which we cannot pass the electric current easily. The valence band of these substances is full whereas the conduction band is completely empty. The forbidden energy gap between valence band and conduction band is very large (8ev) as shown in the fig (a). Therefore a large amount of energy, i.e. a very high electric field is required to push the valence electrons to the conduction band.

Conductors:-

conductors are those materials which offers least resistance to electric current. The valence band of these substances overlaps the conduction band as shown in fig (b). Due to this overlapping, a large number of free electrons are available for conduction. This is the reason, why a slight potential difference applied across them causes a heavy flow of current through them.

Semiconductors:

Semiconductors are those materials whose resistivity lies between conductors and insulators . The valence band of these substances is almost filled, but the conduction band is almost empty. The forbidden energy gap between valence and conduction band is very small (1ev) as shown in fig (c). Therefore comparatively a smaller electric field is required to push the valence electrons to the conduction band.



CONDUCTING MATERIAL

CONDUCTOR – conductor are those material which permit the flow of energy.

ELECTRICAL PROPERTY –

1. Resistivity must be low.
2. Conductivity must be good.
3. Temp. Co-efficient of resistance must be low.

MEC HANICAL PROPERTY

1. Resistance to corrosion.
2. Ductility.
3. It should withstand stress and strain .

ECONOMICAL FACTOR

1. Low in cost.
2. Easy available.
3. Easy to manufacture.

RESISTANCE: The property of material by which it opposes the flow of electric current through it is called resistance.

RESISTANCE DEPEND UPON VARIOUS FACTOR

1. It directly proportional to length of conductor.
2. It inversely proportional to area of conductor.
3. It depends upon the nature of material.
4. It depends upon temp. R=p l\A The unit of resistance is OHM .

SPECIFIC RESISTANCE OR RESISTIVITY

The resistance offered by 1 meter length of conductor of the material having an area of one square meter . R=p L\A L =1m , A = 1m square p=find p=RA\L= ohm * 1\1= ohm meter THE unit of specific resistance is ohm meter .

FACTOR EFFECTING RESISTIVITY

- Temperature
- Alloying
- Mechanical stressing

EFFECT OF TEMPERATURE – Resistivity of material depend upon temp. changes . The resistance of all pure metal increase with increase in temp

EFFECT OF ALLOYING –

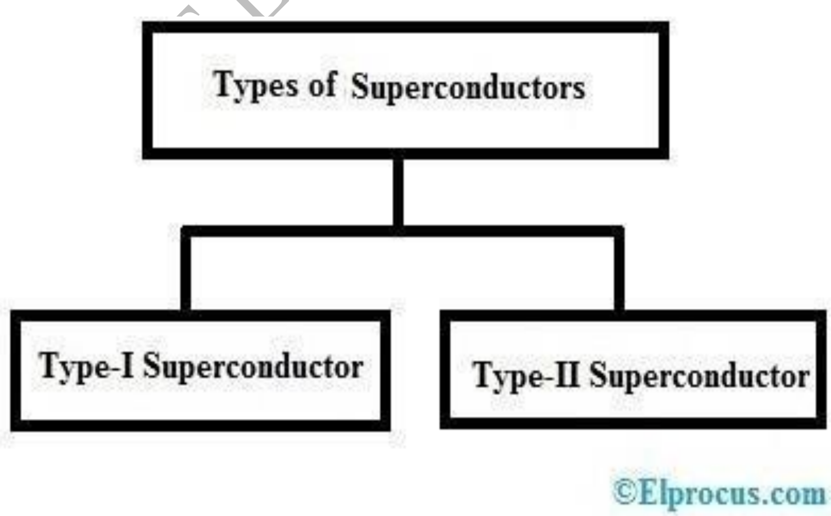
Alloying is a process of adding of impurities in the metals and non metals in small amount. By alloying we can change alloying and mechanical strength of conductor.

EFFECT OF MECHANICAL STREESING When material is subjected to mechanical stresses its resistivity changes due to mechanical distortion on crystal structure of material. The main limitation of mechanical stressing is reduction in the conductivity of material.

SUPERCONDUCTOR -Superconductor are those material which shows zero resistance at a particular temp. The temp. at which this occurs is called super conducting transition temperature . Transition temp. of few metal is given below –

Types of Superconductors

Superconductors are classified into two types namely type-I & type-II.



Type-I Superconductor

This kind of superconductor includes basic conductive parts and these are utilized in different fields from electrical cabling to microchips on the computer. These types of superconductors lose their superconductivity very simply when it is placed in the magnetic field at the critical magnetic field (Hc). After that, it will become like a conductor. These types of semiconductors are also named as soft superconductors due to the reason of loss of superconductivity. These superconductors obey the Meissner effect completely. The superconductor examples are Zinc and Aluminum.

Type-II Superconductor

This kind of superconductor will lose their superconductivity slowly but not simply as it is arranged within the exterior magnetic field. When we observe the graphical representation between magnetization vs. the magnetic field, when the second type semiconductor is placed within a magnetic field, then it will lose its superconductivity slowly.

APPLICATION OF SUPER CONDUCTOR

- Electrical machines
- Transmission and distribution line
- Electromagnet
- Computers

CLASSIFICATION OF CONDUCTING MATERIAL:

- Low resistivity material
- High resistivity material

LOW RESITIVITY MATERIAL

1. Low resistance temp. Coefficient
2. Sufficient mechanical
3. Ductility
4. Resistance to corrosion

5. Density

APPLICATON OF LOW RESITIVITY MATERIAL -It is used in house wiring, as conductor for transmission and distribution, motor and transformer.

HIGH RESITIVITY MATERIAL

1. High resistivity
2. Low temp. Co-efficient
3. High melting point
4. High ductile
5. Corrosion resistance
6. High mechanical strength

APPLICATION – These are used for making heating element, electric bulb, electric iron etc.

PROPERTIES AND APPLICATION OF LOW RESISTIVITY MATERIAL

• **SILVER**– silver is at top in all conductor material. It is high electrical conductivity & corrosion resistance.

PROPERTY –

1. It is high ductile & malleable.
2. It has highest electrical and thermal conductivity.
3. Its melting point 960 C
4. Its density is 10.5 g /cc.
5. Low surface contact resistance

APPLICATION – it is used to making contact of relay, thermal overload devices.

GOLD

Gold is a precious and costly metal. It is having good conductivity. Gold is having highest malleability and ductility among all metals. Due to high cost, its practical use is limited to precious instruments used for research.

PROPERTIES –

1. It is high ductile and malleable.
2. It offers high resistance of corrosion.
3. Its melting point is 1063 C.
4. Its boiling point is 2970 C .

APPLICATION – It is used for making contacts of highly sensitivity devices .Due to its high cost its use is limited.

COPPER

The extensively used, high conductivity material as conductor for electrical machines or equipment is copper. Malleability, weld ability and solder ability are most important properties of copper. Copper in pure form is having good conductivity. But the conductivity of standard grade copper is reduced due presence of impurities.

PROPERTIES –

1. It is radish in color.
2. It is ductile and malleable in nature.
3. It is low contact resistance.
4. Its melting point is 1083 C.
5. Its boiling point is 2320 C.
6. Its density is 8.9 g /cc.
7. Its tensile strength is 8.15 tones/cm square.

APPLICATION – It is used for making electrical wires, cables , winding of transformer and machine .

TYPES OF COPPER

- Hard drawn copper
- Annealed copper

DIFFERENCE BETWEEN HARD DRAWN COPPER AND ANNEALED COPPER

Hard drawn copper	Annealed copper
1. It is made by drawing copper into conductor in cold condition.	1. It is made by increasing temp. of hard drawn copper to a specific value then cool at room temp.
2. It is very hard	2. It is comparatively soft .
3. Its tensile strength is 8.15 tones/cm square	3. Its tensile strength is 4.5 tones/cm square.
4 It is less flexible.	4. It is more flexible.
5. It is used for making commutator segments.	5. It is used for making winding in transformer.

ALUMINIUM-

Aluminum is an element which is a silver-white, light weight, soft, non-magnetic and ductile metal. Aluminum is the third most abundant element. It is widely available in India & most commonly used material Its conductivity is next to copper.

PROPERTIES –

1. It is silver white color.
2. It is ductile and malleable.
3. It offers high resistance to corrosion.
4. Its specific gravity is 2.7 .
5. Its melting point is 655 C .
6. Its boiling point is 1800 C .
7. It is softer then copper.

APPLICATION – It is used in flexible electric wires , overhead transmission , electronics kit , household items .

LOW RESITIVITY COPPER ALLOYS

The following properties are required in **high resistivity or low conductivity conducting material**–

- High resistivity.
- High melting point.
- High mechanical strength.
- High ductility, so that can be drawn in the form of wire easily.
- High corrosion resistance mean free from oxidation.
- Low cost.
- Long life or durable.
- High flexibility.

BRASS – it is an alloy of copper and zinc containing 60% of copper and 40% zinc.

PROPERTIES –

1. It is high tensile strength .
2. It is lower conductivity than copper .
3. It can attain any shape if pressed .

4. It can be easily drawn into wires .

5. Its melting point is about 890 C .

6. Its specific gravity is 3.3 .

APPLICATION – It is used as a current carrying material on plug point , socket outlets , switches , lamp holders .

BRONZE

Its color is radish yellow in color and it is alloy of copper and tin . It contain 84% copper and 8 to 16% OF tin.

PROPERTIES –

1. It is found in two types i.e. cadmium bronze and silicon bronze.

2. It has good conductivity but less than copper

3. It is free from corrosion .

APPLICATION – It is used for conducting commutator or segments .

PLATINUM

Platinum is among the most stable metals with high resistivity .

PROPERTIES –

1. It is a grayish white metals .

2. It is malleable and ductile .

3. Its melting point is 1775 C .

4. Its specific gravity is 21.4 g/cc .

5. It is high tensile strength .

APPLICATION –

1. It is used as heating element in ovens .

2. It is used in thermocouple.

3. It is used as grid for vacuum tubes

MERCURY

Mercury is silvery white metal .

PROPERTIES – 1. Its specific gravity is 13.55 g/cc .

2. It remain in liquid state at room temperature

3. Its boiling point is 358 C .

4. it is highly poisonous metal .

5. It is heavy white silver metal .

6. oxidation takes place beyond 300 C in contact with air .

APPLICATION – It is used in thermometers , fluorescent tubes , mercury arc rectifier .

LEAD

It is bluish gray colored metal

. **PROPERTIES** –

1. It is a hard and soft metal with high specific gravity.

2. It is high malleable.

3. Lead is corrosion resistant metal.

APPLICATION – It is used in lead acid battery, soldering wires, cable sheathes , protective glass in computers .

Tungsten

- It's Very hard metal.
- Its Resistivity is twice to aluminum.
- It has high tensile strength.
- It can be drawn in the form of very thin wire.
- It oxidize very quickly in the presence of oxygen.
- It can be used up to 2000^{o}C in the atmosphere of inert gases (Nitrogen, Argon etc.) without oxidation.

Properties of Tungsten

- Specific weight : 20 gm/cm^3
- Resistivity : 5.28 μΩ -cm
- Temperature coefficient of resistance : 0.005 / ^{o}C
- Melting point : 3410^{o}C
- Boiling point : 5900^{o}C
- Thermal coefficient of expansion: 4.44 × 10^{-9} / ^{o}C

Uses of Tungsten

1. Used as filament for incandescent lamp.
2. As electrode in X- ray tubes.
3. The great hardness, high melting and boiling points make it suitable for use as electrical contact material in certain applications. It is having high resistance for destructive forces produces during operation of electrical contacts.

Carbon

Carbon in widely used in electrical engineering. Electrical carbon materials are manufactured from graphite and other forms of carbon.

Properties of Carbon

- Resistivity : 1000 – 7000 μΩ – cm
- Temperature coefficient of resistance : – 0.0002 to – 0.0008 /^{o}C
- Melting point : 3500^{o}C
- Specific gravity : 2.1gm /cm^3

Uses of Carbon

Carbon is having following applications in electrical Engineering

1. Used for making pressure sensitive resistors, which are used in automatic voltage regulators.
2. Used for manufacturing the carbon brushes, which are used in DC machines. These carbon brushes improve the commutation as well as reduce the wear and tear.
3. For making filament of incandescent lamp.
4. For making electrical contacts.
5. For making resistors.

6. For making battery cell elements.
7. Carbon electrodes for electric furnaces.
8. Arc lighting and welding electrodes.
9. Component for vacuum valves and tubes.
10. For makings parts for telecommunication equipment.

What is Bundled Conductor?

Bundled conductor to those conductors which form from two or more stranded conductors, bundled together to get more current carrying capacity.

- It uses two or more stranded conductors per phase. It also, increase the current carrying capacity of the system, a bundle conductor also contributes various facilities to the electrical transmission system.
- A bundled conductor reduces the reactance of the electric transmission line.
- It also reduces voltage gradient, corona loss, radio interference, surge impedance of the transmission lines.

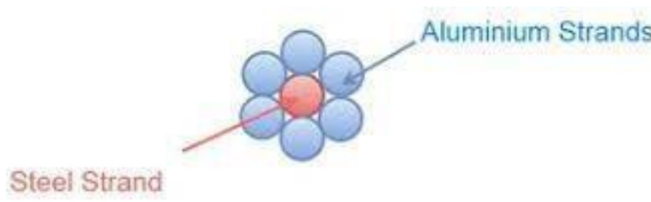
  By making bundle conductor, the geometric mean radius (GMR) of the conductor increased.
- As the self GMR of the conductor increases, the inductance of the conductor decreases. Theoretically, there is an optimum sub-conductor spacing in bundle conductor that will give minimum voltage gradient on the surface of bundle conductor.
- The optimum spacing between sub-conductors for reducing voltage gradient is eight to ten times of the diameter of the conductor.
- It is a conductor made up of two or more sub conductor per phase in close proximity and is used as one phase conductor . For voltage more than 220KV ,it is preferable to use more than one conductor per phase which i9s known as bundle conductor .
- **PROPERTY** –
- 1. Reduce corona loss.
- 2. Reduce reactance.
- 3. Reduce surge impedance.
- 4. It reduce radio interference.

APPLICATION It is used for transmission purpose as it helps in obtaining better voltage regulation and efficiency by reducing the inductance and skin effect present in the power lines .

Stranded Conductor

- The stranded conductor usually has a central wire which is surrounded by the layers of wires. These layers consist of 6, 12, 18, …. wires successively. Thus the total strands are 7, 13, 19. .... Such a stranded conductor with 37 strands.

- A stranded conductor is consists of several thin wires of small cross sectional area called strands



Stranded Conductor

As shown in figure above, at the center of stranded conductor, a steel conductor is used , which provide the high tensile strength to conductor. In the outer layers of stranded conductor, we use aluminum conductors, which provide the conductivity to stranded conductor.

Basic, reason of using stranded conductor is to make the conductor flexible. If we use a single solid conductor. It does not have sufficient flexibility and it is difficult to coil a solid conductor. Hence, it becomes difficult to transport a single solid conductor of long length over the distance. To eliminate this drawback, conductor is formed by using several thin wires of small cross section. These thin wires are called strands. By making the conductor stranded, it becomes flexible. Which makes stranded conductor suitable to be coiled easily to transport it over long distance?

Chapter 3

SEMICONDUCTING MATERIAL

Semi conducting material – Those are the material which posses the conductivity higher then insulator and less than conductor. These are used for manufacture of active component in electronics industries.

Crystal structure of semiconductor

• In crystal structure the atoms are bonded together in a cohesive bond .The semiconductor has 4 electron in there outer most orbit . To fill the outermost orbit , each atom requires four more electron by sharing one electron each from the four adjacent atoms and hence form a crystal

COVALENT BOND

The type of bonding in which bonds are formed by sharing the valance electrons are called covalent bond

TYPE OF SEMICONDUCTOR

• INTRINSIC SEMICONDUCTOR

• EXTRINSIC SEMICONDUCTOR

INTRINSIC SEMICONDUCTOR – These semiconductor are in the purest form i.e. an extremely pure semiconductor is called intrinsic semiconductor.

EXTRINSIC SEMICONDUCTOR – A doped semiconductor is called extrinsic semiconductor .

Doping

The process by which an impurity is added to a semiconductor is known as **Doping**. The amount and type of impurity which is to be added to the material have to be closely controlled during the preparation of extrinsic semiconductor.

DIFFERENCE BETWEEN INTRINSIC AND EXTRINSIC SEMICONDUCTOR

INTRINSIC semiconductor	EXTRINSIC semiconductor
These materials do not contain any impurities.	These materials contain added impurities
Conduction take place by thermally or optically excited electrons.	Conduction take place by the movement of free electron.
Conductivity takes place at higher temp.	Conductivity takes place at normal temp.
It exhibits poor conductivity.	It possesses comparatively better conductivity than intrinsic semiconductor.
The band gap between conduction and valence band is small.	The energy gap is higher than intrinsic semiconductor.
Equal amount of electron and holes are present in conduction and valence band.	The majority presence of electrons and holes depends on the type of extrinsic semiconductor.
EX- Si, Ge etc.	**EX-** GaAs, GaP etc.

EXTRINSIC SEMI-CONDUCTOR

It is of two types

- P-type Semi-conductor
- N-type Semi-conductor

P-type Semiconductor:

In a p-type semiconductor, trivalent impurity from the III group elements is added as the impurity. Trivalent impurities like Aluminum, Indium and Gallium are added to the intrinsic semiconductor. The trivalent impurities added provide extra holes known as the acceptor atom. The majority carriers in a p-type semiconductor are holes.

N-type Semiconductor:

In an n-type semiconductor, pentavalent impurity from the V group is added to the pure semiconductor. Examples of pentavalent impurities are Arsenic, Antimony, Bismuth etc. The pentavalent impurities provide extra electrons and are termed as donor atoms. Electrons are the majority charge carriers in n-type semiconductors.

Difference between N-type semiconductors and P-type semiconductor

N-type Semiconductor	P-type Semiconductor
Impurities such as Arsenic, Antimony, Phosphorous and Bismuth (elements having five valence electrons) are added in N-type semiconductors.	Impurities such as Aluminium, Gallium and Indium (elements having three valence electrons) are added in P-type semiconductors.
Impurities are added in N-type semiconductors in order to increase the number of electrons (also known as Donor atom).	Impurities are added in P-type semiconductors in order to increase the number of holes (also known as Acceptor atom).
In a N-type semiconductor, the majority of charge carriers are free electrons whereas the holes are in minority	In a P-type semiconductor, the majority of charge carriers are holes whereas the free electrons are in minority.
In the case of N-type semiconductor, the majority of charge carriers move from low potential to high potential.	In the case of a P-type semiconductor, the majority of charge carriers move from high potential to low potential.

INSULATING MATERIAL

The material which cannot allow passing electric current.

CHARCTERSTIC OF GOOD INSULATING MATERIAL

1. It should have high resistance.
2. The leakage current through the material should be minimum.
3. It should have good heat dissipation capability.
4. It should have high mechanical strength to withstand vibrations.
5. It should have small dielectric loss.
6. It should also have small thermal expansion to prevent mechanical strength .
7. It should be non ignitable .
8. It should be resistant to oils , liquids , gas fumes .

SELECTION OF INSULATING MATERIAL

Properties of the material

. • Ease of shaping.

• Material availability.

• Cost factor.

GENERAL PROPERTY OF INSULATING MATERIAL

• Electrical property

• Thermal property

. • Mechanical property & physical property

• Chemical property

• Visual properties

ELECTRICAL PROPERTY

• Resistivity (insulation resistance)

• Dielectric strength

• Dielectric loss

• Dielectric constant

THERMAL PROPERTY

• Heat resistance

• Thermal resistance and thermal conductivity

MECHANICAL & PHYSICAL PROPERTY –

- Tensile strength
- Compressive strength
- Brittleness
- Porosity
- Density

CHEMICAL PROPERTY –

- Chemical resistance
- Hygroscopicity
- Solubility
- Radiation resistance
- Moisture permeability

VISIUAL PROPERTY –

- Appearance
- Colour
- Crystalline

CLASSIFICATION OF INSULATING MATERIAL -

According to substance and material it is classified as

(a) Solids: mica, asbestos, ceramic, glass

(b)Liquids: mineral oil, synthetic varnishes etc

(c) Gases: air, hydrogen, argon etc

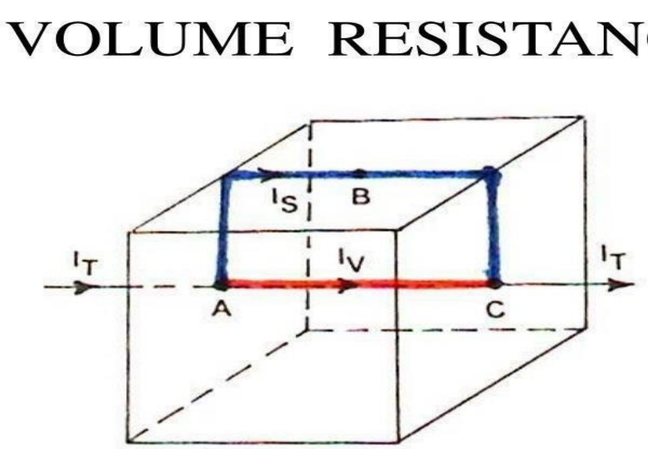
ELECTRICAL PROPERTIES OF INSULATING MATERIALS

Insulation resistance: Insulation resistance is defined as the resistance to current leakage through and over the surface of the insulation material surrounding a conductor.

Types of insulation resistance-

- VOLUME insulation resistance-
- SURFACE insulation resistance-

VOLUME insulation resistance-The resistance offered to current Iv which flow through the material is called volume resistance, as from A-C, shown in fig below.



SURFACE INSULATION RESISTANCE-

The resistance offered to current which flows over the surface of insulating material is called SURFACE insulation resistance. As from A-B and then from B-C as shown in above fig.

DI-ELECTRIC STRENGTH: It is the maximum voltage which when applied to an insulating material without destructing its insulating properties is known as di-electric strength. Every electrical apparatus is designed to operate within a defined range of voltage.

DIELECTRIC CONSTANT

The dielectric constant of a substance is the ratio of the permittivity of the substance to the permittivity of the free space.

Mathematically dielectric constant is:

$k = \epsilon 0/\epsilon$

here,

- κ is the dielectric constant
- ϵ is the permittivity of the substance
- $\epsilon 0$ is the permittivity of the free space

HEAT RESISTANCE

This is general property of insulating material to withstand temperature variation within desirable limits, without damaging its other important properties.

If an insulator has favorable properties at ambient temperature but, if it is not able to retain these, it is not a good insulator.

CLASSIFICATION ON THE BASIS OF OPERATING TEMPERATURE:

Heat generated due to I^2R losses and di electric losses will be dissipated through the insulator itself. How effective this flow of heat takes place depends upon the thermal conductivity of the insulator. An insulator with better thermal conductivity will not allow temperature rise because of effective heat transfer through it to the atmosphere.

CHEMICAL PROPERTY –

- solubility
- chemical resistance
- weather ability

Solubility: In certain application insulation can be applied only after it is dissolved in some solvents. In such cases the insulating material should be solube in certain appropriate solvent. If the insulating material is soluble in water then moisture in the atmosphere will always be able to remove the applied insulation and cause break down.

CHEMICAL RESISTANCE:

Presence of gases, water, acids, alkalies and salt affects different insulators differently. Chemically a material is a better insulator if it resist chemical action.

WEATHERABILITY:

Insulators come in contact with atmosphere both during manufacture or operation. The contact of insulation with atmosphere is often so complete that even the less chemically aggressive atmosphere can prove a threat to the smooth running of apparatus.

HYGROSCOPICITY:

The property of insulating material by virtue of which it absorbs moisture. The insulating material should be non-hygroscopic. The absorption of moisture reduces the resistivity of the insulator.

Mechanical property:

Mechanical strength

Porosity

Density

Brittleness

Mechanical strength:

The insulating material should have high mechanical strength to bear the mechanical stresses and strain during operation. Temperature and humidity are the main factor which reduces the mechanical strength of insulating materials**.**

POROSITY:

A material having very small holes in it is called a porous material. Insulator absorbs moisture. If it is porous which reduces its resistivity as will as mechanical strength. Porous material are impregnated with varnish or resin to fill their pores which makes them non-pores thus better insulating material.

BRITTLENESS: The insulating material should not be brittle. Otherwise insulator may fracture easily due to stress.

GLASS

It is normally transparent , brittle and hard. It is insoluble in water and the usual organic solvents.

Glass find its use in electrical industry because of its low dielectric loss, slow aging and good mechanical strength.

Glass has its limitations because it is not easy to manufacture and is dense and heavy.

fuse bodies, insulators.

Capacitor.

Radio and television tubes

Laminated boards.

Lamps/ Fluorescent Tubes

COTTON

Cotton is natural fibrous material obtained from plants. It is used as insulator only after impregnation with oils or varnishes, which reduce its hygroscopicity.

PROPERTIES

Operating Temperature: Upto115 ºC

Highly Hygroscopic(up to 70%)

APPLICATIONS

Small Coils

Windings of small and medium Sized motors, generators and transformers.

EPOXY GLASS

Insulating material manufactured by bonding multiple layers of glass fiber impregnated with epoxy resins is called epoxy glass.

PROPERTIES

Dielectric constant: 5

Resistivity: 10^{14} ohm-m

Dielectric Strength: 0.4 kV/mm

Non-Hygroscopic

High chemical Resistance

Dielectric Material

What Is Dielectric Material?

A dielectric material is defined as the non-metallic material with specific resistance high, temperature coefficient of resistance negative and with large insulation resistance. The other way of defining dielectric material is that it is non-conducting material which stores electrical charges.

Properties of Dielectric Material:

Following are the exhibited by the dielectric materials:

- The energy gap in the dielectric materials is very large.
- The temperature coefficient of resistance is negative and the insulation resistance is high.
- The dielectric materials have high resistivity.
- The attraction between the electrons and the parent nucleus is very strong.
- The electrical conductivity of these materials is very low as there are no free electrons to carry current.

Dielectric vs. Insulators

Dielectric	Insulators
Material that can develop an electric field with minimal loss of energy is known as a dielectric.	A substance that has low conductivity and that which obstructs the flow of current is known as an insulator.
Weakly bonded as compared to the insulators	Covalently bonded
Stores charges	Obstructs charges
Their application lies in power cables, capacitors and more	They are used in the high voltage system and conducting wires

Application of Dielectric Properties:

- Dielectrics are used as a capacitor for storing energy.
- The dielectric material in a transformer is used as an insulator and as a cooling agent.
- To enhance the performance of a semiconductor device, high permittivity dielectric materials are used.
- Electric is a processed dielectric material that acts as an electrostatic equivalent to magnets.

Dielectric constant: (The dielectric constant of a material is defined as the ratio of the permittivity of the o). It can also defined as the ratio of the) to the permittivity of free space (medium (capacitance with dielectric (Cd) and with air (CA) between the plates.

Capacitance: The property of a conductor or system of conductor that describes its ability to store electric charge. C = q / V = A ε / d where C is capacitance of capacitor q is charge on the capacitor plate V is potential difference between plates A is area of capacitor plate ε is permittivity of medium d is distance between capacitor plates

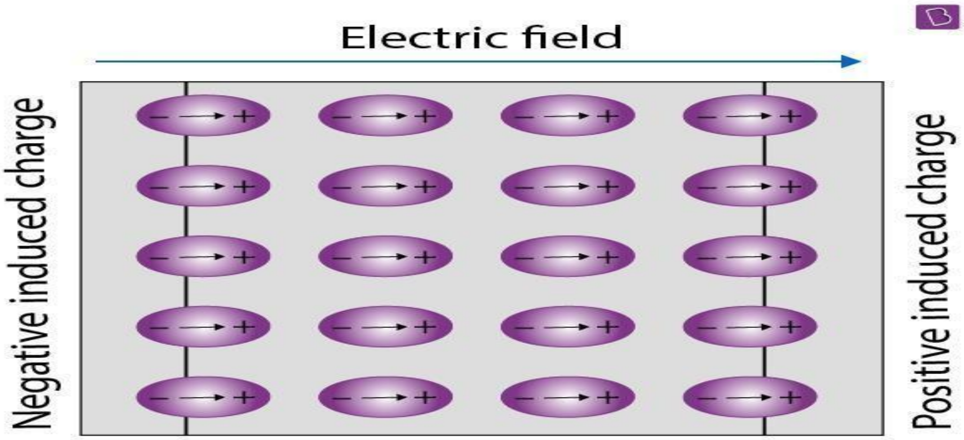
Units: Farad

Di-electric loss:

- The dielectric material separated with two electrodes is stressed when subjected to a potential.
- When the potential is reversed the stress is also reversed the change of stress involved changes of molecular arrangement within the di-electric there's energy loss with each reversal. This is because the molecules have to overcome a certain amount of internal friction in the process of alignment; as a result energy is released in the form of heat in di-electric.
- The loss appearing in the form heat due to reversal of electric stress is known as Di-electric loss.

Dielectric Polarization:

A dielectric may be made up of polar or non-polar molecules. But the net effect of an external field is almost the same, i.e., the external field will compel the molecules to align their dipole moments along its own direction.



Let us consider a dielectric slab in an electric field which is acting in the direction shown in the figure. The arrangement of charges within the molecules of the dielectric in the electric field is as shown in the figure. The positive charges move in the direction of the field and the negative charges in the opposite direction. In other words, the electric dipoles align themselves with the direction of the field. In this state, the entire dielectric and its molecules are said to be polarized.

The alignment of the dipole moments of the permanent or induced dipoles with the direction of the applied electric field is called polarization.

Within the two extremely thin surface layers indicated by shaded regions, there is an excess negative charge in one layer and an excess equal positive charge in the other layer.

The induced charges on the surfaces of the dielectric are due to these layers. These charges are not free but each is bound to a molecule lying in or near the surface. That is why these charges are called bound charges or fictitious charges. Within the remaining dielectric, the net charge per unit volume remains zero. Thus, although the dielectric is polarized, yet as a whole, it remains electrically neutral.

Obviously, the positive induced surface charge must be equal in magnitude to the negative induced surface charge. Thus, in polarization, the internal state of the slab is characterized not by an excess charge but by the relative displacement of the charges within it.

Polarization can thus also be thought of as a phenomenon in which an alignment of positive and negative charges takes place within the dielectric resulting in no net increase in the charge of the dielectric.

Magnetic Material

Magnetic Field: The magnetic field is an imaginary line of force around a magnet which enables other ferromagnetic materials to get repelled or attracted towards it.The magnetic field lines are formed due to various reasons like orbital movement of electrons, current flowing in a conductor etc.

Magnetic Flux Density(B)

When a substance is subjected to the magnetic field H, then the density of magnetic field lines that pass through the substance per square meter is known as **Magnetic Flux Density**. It is given by

$B = \mu \times H$ (Tesla or weber /m^2)

Where μ is called the **Permeability** and is defined as the degree to which a substance gets magnetized.The value of permeability in vacuum is given by

m = 4px 10^{-7}(H/m)

Classification of Magnets

Depending on the above explained properties of magnets, magnets can be classified as:

- Diamagnetic
- Para-magnetic
- Ferro-magnetic

Diamagnetic Substance

Diamagnetic Substances are repelled by magnets due to the fact that they produce negative magnetization. **The net magnetic moment is zero in diamagnetic substance** because when an external field is applied to a diamagnetic substance then the magnetic moment of electrons is aligned to the opposite direction of the applied field. Every element in the periodic table possess the property of diamagnetism, but few elements like Cu, Al_2O_3, Si, Zn have stronger diamagnetic property.

Paramagnetic Substance

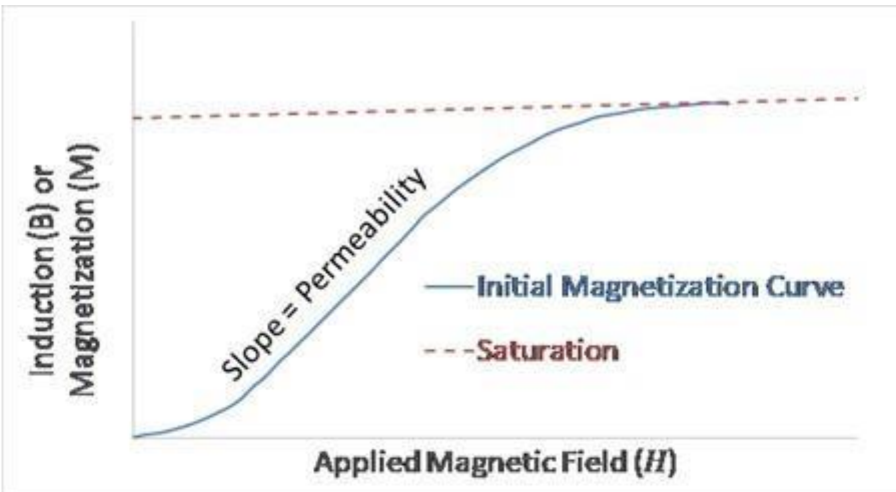
In Paramagnetic material, there exists a little magnetic moment since the net magnetic moment is not cancelled out completely. The magnetic moments in paramagnetic material are randomly aligned and when they are subjected to an external magnetic field, these magnetic moments align themselves in the direction of the applied magnetic field H.

Example of paramagnetic materials include Al, Cr, Mo,Ti,Zr.

Ferromagnetic Substance

Unlike diamagnets or paramagnets, those materials which tend to remain magnetized even when the magnetic field is removed exhibits ferromagnetism. **This phenomenon is also known as Hysteresis** and the plot between variations of magnetism with magnetic field is called **Hysteresis Loop**. However at one point or temperature the ferromagnetic materials tend to lose its magnetic properties. This temperature or point is known as **Curie point or Curie temperature**.

Magnetization Curve:



- When a magnetic material is placed into a magnetic field $(\vec{H})$, it's magnetic dipoles will align to create a response magnetization $(\vec{M})$ which will combine with the applied field to generate a magnetic induction $(\vec{B})$. If the response were linear, it would be an easy calculation. However, the response is nonlinear, resulting in hysteresis curves when the applied magnetic field is cycled.

- The magnetization curve of a magnetic material is as descriptive of a material's magnetic properties as its stress-strain curve is descriptive of its mechanical properties. Just as key tensile properties can be found on a stress-strain curve, key magnetic properties can also be found on the magnetization curve.

- The first thing to note is that there are two types of magnetization curves generated in response to an applied field. **M-H** curves focus on the internal response of the magnetic material, while **B-H** curves focus on the magnetic induction. Therefore, it is important to know what type of curve you are looking at when trying to determine magnetic properties.

- Figure 1 shows schematically what happens when a magnetic field $(\vec{H})$ is applied to a magnetic material. As the field increases in strength, the magnetic moment of the material ($(\vec{M})$ increases as well, as the magnetic dipoles begin to align with the applied magnetic field. That is, the material is becoming **magnetically polarized**. Since M is increasing, the corresponding magnetic induction $(\vec{B})$ increases as well. Eventually, when the magnetic dipoles are fully aligned with the field, (M) can increase no more. This is known as the **saturation magnetization**.
- The slope of the magnetization curve is the **magnetic permeability (μ)** of the material. Note, however, that the initial magnetization is usually not a straight line! This means that the magnetic permeability will vary depending on the magnetic field strength. Often, test labs will therefore report 3 values of permeability. These will be the initial (low slope), intermediate (maximum slope), and the final (lower slope again). Since the longest, linear part of the curve is the maximum slope, this would often be considered to be the default permeability.

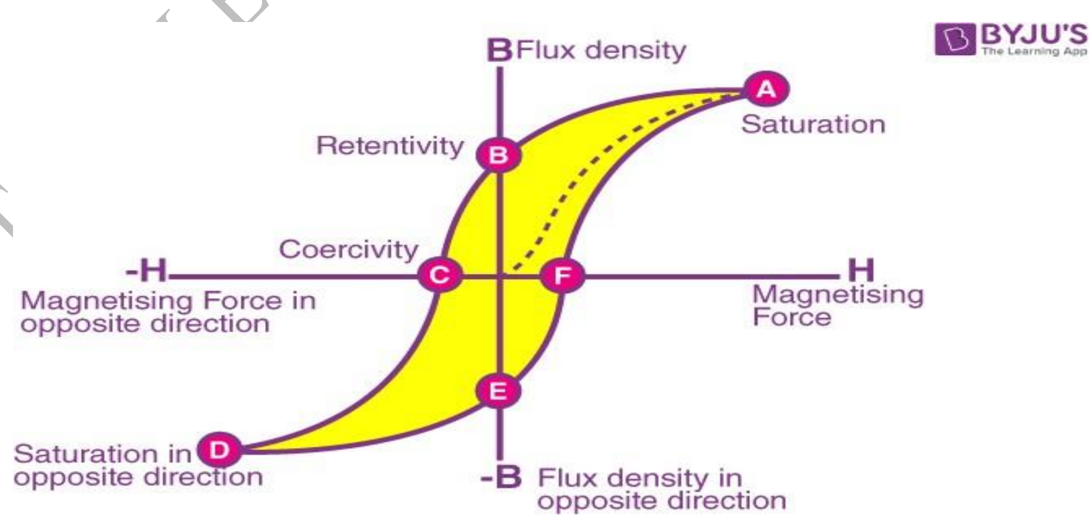
Hysteresis Loop

Hysteresis Loop Definition

A curve, or loop, plotted on B-H coordinates showing how the magnetization of a ferromagnetic material varies when subjected to a periodically reversing magnetic field, is known as Hysteresis Loop.

Hysteresis Loop

The hysteresis loop shows the relationship between the magnetic flux density and the magnetizing field strength. The loop is generated by measuring the magnetic flux coming out from the ferromagnetic substance while changing the external magnetizing field.



Looking at the graph, if B is measured for various values of H and if the results are plotted in graphic forms then the graph will show a hysteresis loop.

- The magnetic flux density (B) is increased when the magnetic field strength(H) is increased from 0 (zero).
- With increasing the magnetic field there is an increase in the value of magnetism and finally reaches point A which is called saturation point where B is constant.
- With a decrease in the value of the magnetic field, there is a decrease in the value of magnetism. But at B and H are equal to zero, substance or material retains some amount of magnetism is called retentivity or residual magnetism.
- When there is a decrease in the magnetic field towards the negative side, magnetism also decreases. At point C the substance is completely demagnetized.
- The force required to remove the retentivity of the material is known as Coercive force (C).
- In the opposite direction, the cycle is continued where the saturation point is D, retentivity point is E and coercive force is F.
- Due to the forward and opposite direction process, the cycle is complete and this cycle is called the hysteresis loop.

Advantages of Hysteresis Loop

1. A smaller region of the hysteresis loop is indicative of less loss of hysteresis.

2. Hysteresis loop provides a substance with the importance of retentivity and coercivity. Therefore the w ay to select the right material to make a permanent magnet is made simpler by the heart of machines.

3. Residual magnetism can be calculated from the B-H graph and it is, therefore, simple to choose material for electromagnets.

Retentively and Coercivity

When a ferromagnetic material is magnetized by applying the external magnetizing field, after magnetization if we remove the external magnetizing field the material will not relax back to its zero magnetization position.

Receptivity

The amount of magnetization present when the external magnetizing field is removed is known as retentivity.

- It is a material's ability to retain a certain amount of magnetic property while an external magnetizing field is removed.
- The value of B at point b in the hysteresis loop.

Coercivity

The amount of reverse(-ve H) external magnetizing field required to completely demagnetize the substance is known as coercivity of substance. The value of H at point c in the hysteresis loop.

Curie point:

The temperature above which a ferromagnetic substance loses its ferromagnetism and becomes paramagnetic.

Eddy Current:

Eddy currents are loops of electrical current induced within conductors by a changing magnetic field in the conductor according to Faraday's law of induction. Eddy currents flow in closed loops within conductors, in planes perpendicular to the magnetic field.

Magneto-striction:

When a ferromagnetic material is magnetized a small amount of change occurs in dimension of the material which causes small extension, reducing the cross section of the crystal.

When the material is subjected to the rapid alternating magnetic field, extension and contraction of the material takes place and this phenomenon is called as Magneto-striction.

All ferromagnetic materials are classified into 2 categories.

- Soft magnetic material
- Hard magnetic material

Soft magnetic material:

- The material which have sharply rising magnetization curve, relatively small and narrow hysteresis loop and small energy loss during cyclic magnetization is known as Soft magnetic material.
- It is used for construction of cores for electro-machines and switch-gear parts
- It should have high permeability
- It is easier for soft magnet material to get saturation as orientation take place easily.

Hard magnetic material:

- The magnetic material which have gradually rising magnetizing curve, large hysteresis loop area and large energy loss during each cycle of magnetization is known as Hard magnetic material
- It is also used for making permanent magnet.
- The desired property required for making permanent magnet are high saturation value, high coercive force and high residual magnetism.
- In hard magnet is difficult to orient the domain as compare to soft magnet material ,therefore it is difficult to magnetized hard magnet

- It is used for the construction of core of transformer , electromagnet of electric motor

Soft Magnet	Hard Magnet
Magnetization and demagnetization is easy	Magnetization and demagnetization is difficult
A soft magnet can be produced by heating and gradual cooling	A hard magnet can be produced by heating and sudden cooling
The hysteresis loop area is small, retentivity and coercivity is also small	The hysteresis loop area is large, retentivity and coercivity is also high
Soft magnets are temporary magnets	Hard magnets are permanent magnets
Examples: Ferrous-nickel alloy, Ferrites Garnets	Examples: Steel, carbon steel, chromium steel, tungsten

Material for special purpose

Fuse?

It is an electrical safety device which is used to protect components, circuits and from the risk of fire and damage due to over current conditions. Fuse is a thin piece of metal wire which melts and isolates the circuit when an excessive current passed through it and breaks the circuit.

Fuse Wire Materials:

The material used for making fuse element has a low melting point such as tin, lead, or zinc. The material mainly used for fuse element is **tin, lead, silver, copper, zinc, aluminum, and an alloy of lead and tin**. An alloy of lead and tin is used for small current rating fuses.

The material used for fuse elements must have the following properties:

- Low melting point.
- Low ohmic loss.
- High conductivity (or low resistivity)
- Low cost.
- Free from detraction.

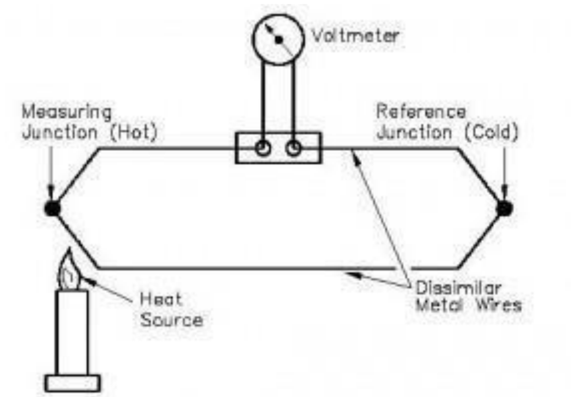
What is a Thermocouple?

The thermocouple can be defined as a kind of temperature sensor that is used to measure the temperature at one specific point in the form of the EMF or an electric current. This sensor comprises two dissimilar metal wires that are connected together at one junction. The temperature can be measured at this junction, and the change in temperature of the metal wire stimulates the voltages.

How Does a Thermocouple Work?

The **thermocouple diagram** is shown in the below picture. This circuit can be built with two different metals, and they are coupled together by generating two junctions. The two metals are surrounded by the connection through welding.

In the above diagram, the junctions are denoted by P & Q, and the temperatures are denoted by T1, & T2. When the temperature of the junction is dissimilar from each other, then the electromagnetic force generates in the circuit.



If the temperate at the junction end turn into equivalent, then the equivalent, as well as reverse electromagnetic force, produces in the circuit, and there is no flow of current through it. Similarly, the temperature at the junction end becomes imbalanced, then the potential variation induces in this circuit.

The magnitude of the electromagnetic force induces in the circuit relies on the sorts of material utilized for thermocouple making. The entire flow of current throughout the circuit is calculated by the measuring tools.

The electromagnetic force induced in the circuit is calculated by the following equation

$$\mathbf{E = a(\Delta\Theta) + b(\Delta\Theta)2}$$

Where ΔΘ is the temperature difference among the hot thermocouple junction end as well as the reference thermocouple junction end, a & b are constants

SOLDERING:

Soldering is a joining process used to join different types of metals together by melting solder. Solder is a metal alloy usually made of tin and leads which is melted using a hot iron. The iron is heated to temperatures above 600 degrees Fahrenheit which then cools to create a strong electrical bond.

Solder is a metal alloy used to create strong permanent bonds; such as copper joining in circuit boards and copper pipe joints. It can also be supplied in two different types and diameters, lead and lead free and also can be between .032” and .062”. Inside the solder core is the flux, a material used to strengthen and improve its mechanical properties.

What Metals are Used?

Filler metals used in soldering were once lead based (lead solder), however, owing to regulations, lead-based solders are increasingly replaced with lead free solders, which may consist of antimony, bismuth, brass, copper, indium, tin or silver.

Types of Soldering:

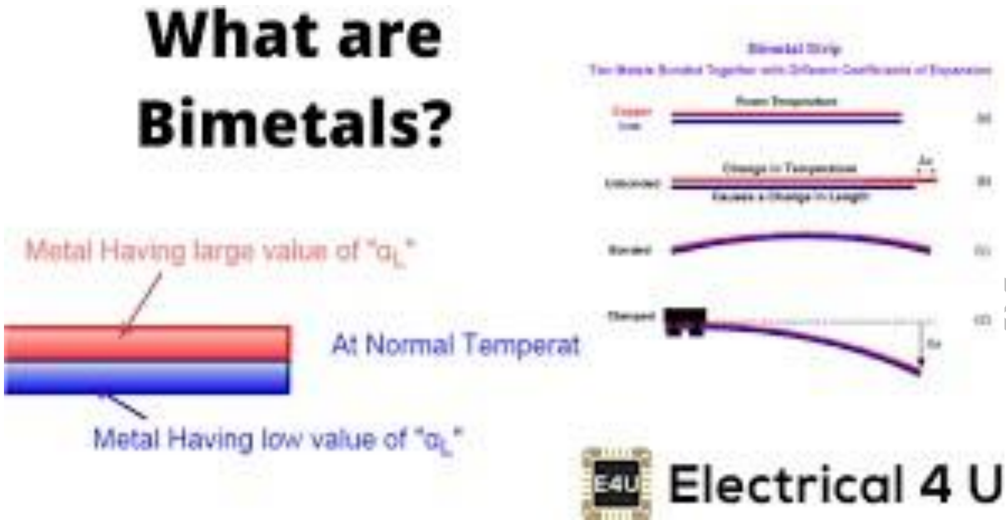
There are three types of soldering which use increasingly higher temperatures, which in turn produce progressively stronger joints:

- **Soft soldering (90 °C - 450 °C) -** This process has the lowest filler metal melting point of all the soldering types at less than around 400°C these filler metals are usually alloys, often containing lead with liquidus temperatures under 350°C. Because of the low temperatures used in soft soldering it thermally stresses components the least but does not make strong joints and is then therefore unsuitable for mechanical load-bearing applications. It is also not suited for high temperature use as this type of solder loses strength and melts.
- **Hard (silver) soldering (>450 °C)** – Brass or silver is the bonding metal used in this process, and requires a blowtorch to achieve the temperatures at which the solder metals.
- **Brazing (>450 °C)** – This type of soldering uses a metal with a much higher melting point than those used in hard and soft soldering. However, similarly to hard soldering, the metal being bonded is heated as opposed to being melted. Once both the materials are heated sufficiently, you can then place the soldering metal between them which melts and acts as a bonding agent.

What is Bimetallic Strip?

A bimetallic strip works on the principle of thermal expansion, which is defined as the change in volume of metal with the change in temperature. The bimetallic strip works on two basic fundamentals of metals.

- The first fundamental is the thermal expansion, which states that the metals expand or contract based on variation in temperature
- The second fundamental is the temperature coefficient, where each metal (having its own temperature coefficient) expands or contracts differently at a constant temperature.



On heating, the expansions in the length of both metal strips are different. Due to which the bimetallic element bends and form an arc in such a way that the metal with higher Coefficient of linear thermal expansion is outer at side of the arc and metal with lower Coefficient of linear thermal expansion is at inner side of the arc . On cooling, bimetal element bends and form an arc in such a way that the metal with lower Coefficient of linear thermal expansion is at outer side of the arc & metal with higher Coefficient of linear thermal expansion is at inner side of the arc . The above phenomenon can used to produce a useful device for detecting and measuring change in temperature.

Commonly Used Combinations for Making Bimetallic Strips

Many combinations of metals with different Coefficient of linear thermal expansion can be used to form the **bimetals**. Some of the commonly used combinations for making bimetallic strips are listed below-

1. Iron, nickel, constantan (high "Coefficient of linear thermal expansion")
2. Alloy of iron and nickel (low "Coefficient of linear thermal expansion")