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LECTURE NOTES

ON

Electrical Engineering Material

(Electrical 3rd Semester)

Prepared By

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Diploma 2nd Year
Electrical Engineering

ELECTRICAL ENGINEERING MATERIAL

V

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ELECTRICAL ENGINEERING MATERIAL

First Edition

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Strictly for the Syllabus for Diploma 2nd Year, Electrical Engineering

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Chapter

CONDUCTING MATERIALS

1.1 Introduction

It is those substances in which electric current pass through easily. Example: Silver, iron, cu, gold, Al, human body, earth, salt. In terms of energy band the valence and conduction bands overlap each other due to this overlapping; a slight potential difference.

1.1.1 Classification of Electrical Materials

Materials used in the electrical engineering field are classified basing on their properties and applications.

a. Conductor Materials
b. Semiconductor Materials
c. Insulating Materials
d. Dielectric material
e. Magnetic Materials
f. Special purpose Material

1.1.2 Classification of Materials Based on Atomic Structure

The materials such as gold, silver, copper and aluminum which can neither be broken into other substances nor be created are called "elements". The smallest particles into which an element can be divided having the identity of the element are called "atoms". These particles cannot be divided further. The atom although extremely small, has a complex internal structure of its own. This resembles the miniature solar system. An atom consists of the central core called nucleus, with electrons revolving around it as well as spinning around themselves. The nucleus contains protons and neutrons. Each proton possesses as much positive charge as an electron possesses negative charge (1.6×10^{-19}C).

Conductor Materials the number of protons inside the nucleus is equal to the number of electrons revolving around it. This number is called atomic number of the element. The neutron does not possess any charge. Therefore, the atom is electrically neutral. The mass of a proton or a neutron is 1.672×10^{-27}kg. Which is 1850 times more than that of an electron? The mass of an electron is 9.107×10^{-31} kg. The electron's diameter is three times that of a proton. The weight of protons and neutrons together is called atomic weight of the element. The electrons are held in the atom by attractive force between protons and electrons which carry opposite charges. The electrons revolve in successive orbits or shells. The orbits should be visualized to be in different planes and not as they appear to be in the figure. The number of electrons that each shell can accommodate is given by $\mathbf{2n^2}$ where n is the number of the shells counting from the innermost shell. The innermost shell (i.e. the first shell) can accommodate 2 electrons, the second shell 8, the third 18 and so on. The outermost shell in no case will contain more than 8 electrons in the first shell, 8 in the second, 8 in the third and 1 in the fourth even though the third shell can accommodate 18 electrons according to the formula. Within the shell there are sub-shells which are classified as: s, p, d, f, g, s and p and so on. There are energy levels again in this sub – shells. The sub-shell s has one energy level, p has three levels, d has five levels and so on. Not more than two electrons occupy the same energy level, one spinning in one direction and the other in the opposite direction. Thus the sub-shell

S can accommodate 1 x 2 = 2 electrons

P can accommodate 3 x 2 = 6 electrons

D can accommodate 5 x 2 = 10 electrons

F can accommodate 7 x 2 = 14 electrons

G can accommodate 9 x 2 = 18 electrons and so on.

According to Pauli Exclusion Principle, the state of any electron is defined by four Quantum numbers:

a. The shell number 1, 2, 3, etc. of K, L, M, N, etc.

b. The sub-shell number s, p, d, f, g etc.

c. The orbit number in sub-shell 1s, 2s, 3s, etc., and

d. The electron spins Quantum number +1/2 and -1/2

The electrons nearer to nucleus are more firmly held than those farther from it. The energy required to pull out one electron from the first orbit is more than the energy required to pull out one electron from the second orbit and so on. That is, electrons possess a definite amount of energy, called quantum, depending upon the orbit. Hence, orbits are referred to as energy levels. The valence of an element is determined by the number of electrons it can receive or give away from its outermost sub-shell to another element in a reaction. The elements having 3 or less valence electrons give away these electrons but elements having 5 or more valence electrons; do receive such electrons to make the total as 8, for stability. The valence electrons are very loosely held and contribute to the properties of the element. If the valence orbit contains 8 electrons, then the atom is complete and stable; if it contains less than 8, the atom is unstable and very easily gives out or receives valence electrons from the neighbor to complete its valence orbit.

1.2 Resistivity

Resistivity or specific resistance of a material may be defined as: “Resistance offered between the opposite faces of a meter cube of that material.”

The unit of resistivity is ohm meter (Ω-m).

According to law of resistance. The resistance of a material is directly proportional to length of the conductor. And inversely proportional to area of cross-section of the conductor.

$R \propto L$

$R \propto 1/A$

So, $R \propto L/A$

Or $R = \rho L/A$ (where ρ is known as resistivity of material)

Therefore

$\rho = A R/L$

When R= Resistance in Ohms (Ω)

L= Length in m

A= Area of cross section in m^2

ρ = resistivity or Specific resistance in Ω-m

1.3 Temperature Coefficient of Resistance

Based on temperature effect, electrical materials can be classified into two groups:

- **Positive temperature coefficient** means that the resistance of some of the metals and alloys increases when their temperature is raised.ie ($T \propto R$).

- **Negative temperature coefficient** means that the resistance of some of the materials, i.e., carbon and insulators and electrolytes, decreases when their temperature is raised. ie ($T \propto 1/R$).

1.4 Properties of Conductors

A. Electrical Properties

1. The conductivity must be good.
2. Electrical energy displayed in the form of heat must be low.
3. Resistivity must be low.
4. Temperature resistance ratio must be low.

B. Mechanical Properties

1. Ductility: It has that property of a material which allows it to be drawn into a wire.
2. Solder ability: The joint should have minimum contact resistance.
3. Resistance to corrosion: Should not get rusted when used in outdoors.
4. Withstand stress and strain.
5. Easy to fabricate.

C. Economical Factors

1. Low Cost
2. Easily Available

1.5 Characteristics of a Good Conductor Material

The conductor materials should have low resistivity so that the desired of a conductor material depends on the following factors:

1. Resistivity of the materials.
2. Temperature coefficient of resistance
3. Resistance against corrosion
4. Oxidation characteristics
5. Ease of soldering and welding
6. Ductility
7. Mechanical Strength
8. Flexibility and abundance
9. Durability and low cost

1.6 Low Resistivity Material

Low resistivity material possessing very low value of resistivity. These are used for such applications where power loss and voltage drop should be low, these are used in house wiring as conductor for supplying power to various conductors and these are also used in electrical machines as windings to carry electric current.

- Low temperature co-efficient
- High mechanical strength
- Long service life
- Low cost and easily available in market

Example: Copper, Silver, Gold, Aluminum, Steel, etc.

Low Resistivity Materials and their Applications

1.6.1 Copper

Properties:

1. Pure copper is one of the best conductors of electricity and its conductivity is highly sensitive to impurities.
2. It is reddish-brown in colour.
3. It is malleable and ductile.
4. It can be welded at red heat.
5. It is highly resistant to corrosion.
6. Melting point is 108^{4}0C.
7. Specific gravity of copper is 8.9.
8. Electrical resistivity is 1.682 micro ohm cm.
9. Its tensile strength varies from 3 to 4.7 tones/cm^2
10. It forms important alloys like bronze and gun-metal.

Copper is a chemical element with symbol Cu (from Latin: cuprum) and atomic number 29. It is a soft, malleable, and ductile metal with very high thermal and electrical conductivity. A freshly exposed surface of pure copper has a reddish-orange color. Uses: Wires, cables, windings of generators and transformers, overhead conductors, busbar etc. because it is such a good conductor of electricity, copper is mostly used in electrical generators and motors, for electrical wiring, and in electronic goods, such as radio and TV sets. Copper also conducts heat well, so it is used in motor vehicle radiators, air-conditioners and home heating systems. The average home contains 400 pounds of copper that is used for electrical wiring, pipes and appliances.

Figure 1.1 copper wires

Hard drawn (cold-drawn) copper. Conductor it is mechanically strong with tensile strength of 40 Kg/mm^2.

It is obtained by drawing cold copper bars into conductor length. It is used for overhead line conductors and bus bars.

Copper is so important is that it can be made into alloys. That means it can be combined with other metals to make new copper alloys, like brass and bronze. These are harder, stronger and more corrosion resistant than pure copper.

Annealed Copper (Soft Copper) Conductor. It is mechanically weak, tensile strength 20 Kg/mm^2, it is easily shaped into any form.

Low-resistivity Hard Copper. It is used in power cables, windings and coils as an insulated conductor. It has high flexibility and high conductivity.

1.6.2 Silver

It is best known electrical conductor.

Properties:

1. It is very costly.
2. It is not affected by weather changes.
3. It is highly ductile and malleable.
4. Its resistivity is 165 micro ohm cm.
5. A soft, white, lustrous.
6. It exhibits the highest electrical conductivity

Applications:

Used in special contact, high rupturing capacity fuses, radio frequency conducting bodies, leads in valves and instruments. Silver is used in making of solder, jewellery; Silver chloride is used as glasses

Figure 1.2 tin soldering silver wires

Figure 1.3 Silver contact wires

1.6.3 Aluminum

Properties:

1. Pure aluminum has silvery colour and lustre. It offers high resistance to corrosion. Its electrical conductivity is next to that of copper.
2. It is ductile and malleable.
3. Its electrical resistivity is 2.669 micro ohms cm at 20^0C.
4. It is good conductor of heat and electricity.
5. Its specific gravity is 2.7.
6. Its melting point is 658^0C.
7. It forms useful alloys with iron, copper, zinc and other metals.
8. It cannot be soldered or welded easily.
9. It is cheaper than copper.
10. It is lighter in weight.
11. It is second in conductivity.
12. At higher voltages, it causes lower coronal loss.
13. As the melting point of the conductor is low, the short-circuit current will damage it.
14. Welding of aluminum is much more difficult than that of any other material

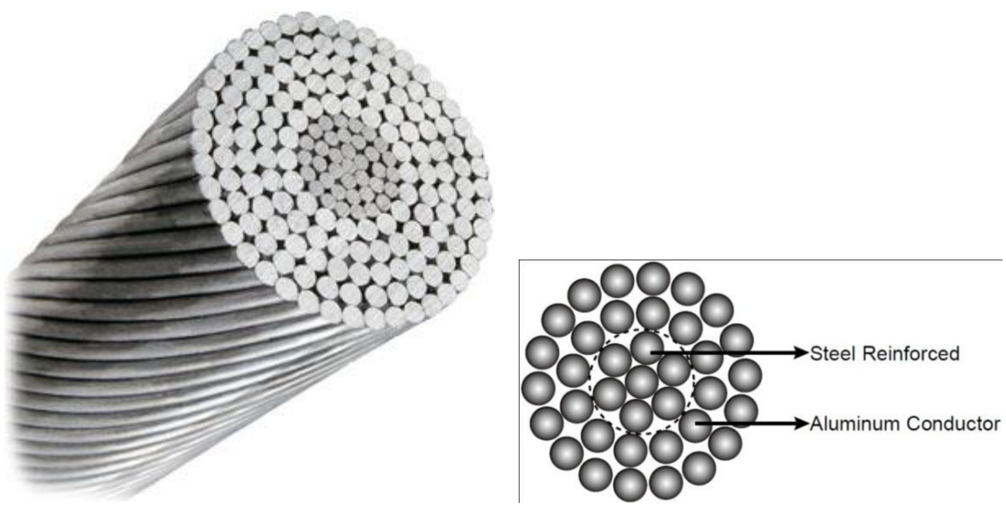

Figure 1.4 ACSR Conductors

Applications:

Overhead transmission line conductor, busbars, and ACSR conductors. Well suited for cold climate. Aluminum is used for aircraft, trains, overhead power cables, saucepans and cooking foil.

Aluminum Conductor with Steel Reinforcement (ACSR). An aluminum conductor having a central force of galvanized steel wires is used for high-voltage transmission purposes. Reinforcement is done to increase the tensile strength of aluminum conductor. The ACSR conductor has a larger diameter than any other type of conductor of same resistance

There are four major types of overhead conductors used for electrical transmission and distribution.

- AAC - All Aluminum Conductors.
- AAAC - All Aluminum Alloy Conductors.
- ACSR - Aluminum Conductor Steel Reinforced.
- ACAR - Aluminum Conductor Aluminum-Alloy Reinforced.

1.6.4 Steel

Steel contains iron with a small percentage of carbon added to it. Iron itself is not strong but when carbon is added to it, it assumes very good mechanical properties. The tensile strength of steel is higher than that of iron. The resistivity of steel is 8-9 times higher than that of copper. Hence, steel is not generally used as conductor material. Galvanized steel wires are used as overhead telephone wires and as earth wires. Aluminum conductors are steel-reinforced to increase their tensile strength.

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Applications:

Steel is used in overhead telephone wire.

Type of Steel	Iron Alloyed With	Typical Use
low carbon steel	about 0.25 per cent carbon	car body panels
high carbon steel	up to 2.5 per cent carbon	cutting tools
stainless steel	chromium and nickel	cutlery and sinks

Gold

Gold is a good conductor of heat and electricity

Its melting point is 1,064 °C

it is a bright, slightly reddish yellow, dense, soft, malleable, and ductile metal

Applications

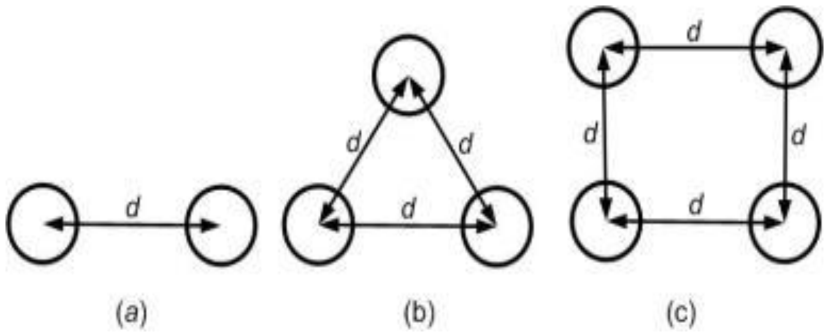
It is also used in electronics circuit manufacturing, gold powder and gold sheet is used for soldering a semiconductor, it is used for making a ring

1.7 Bundled Conductors & Underground Cables

A bundle conductor is a conductor made up of two or more sub-conductors; bundled conductor is exclusively used in EHVAC line. It is used for more than 220kv, which helps to reduce the corona effect.

The effective diameter of bundled conductor is high, The bundled conductor consists of a two or more parallel conductor sub conductor at a spacing of several diameter these group of conductor forms a phase conductor, thus effective diameter of bundled conductor is much larger than that of normal conductor

Bundled conductor lines will have higher capacitance and lower inductance than ordinary lines they will have higher Surge Impedance Loading ($Z= (L/C)^{1/2}$). Higher Surge Impedance Loading (SIL) will have higher maximum power transfer ability.



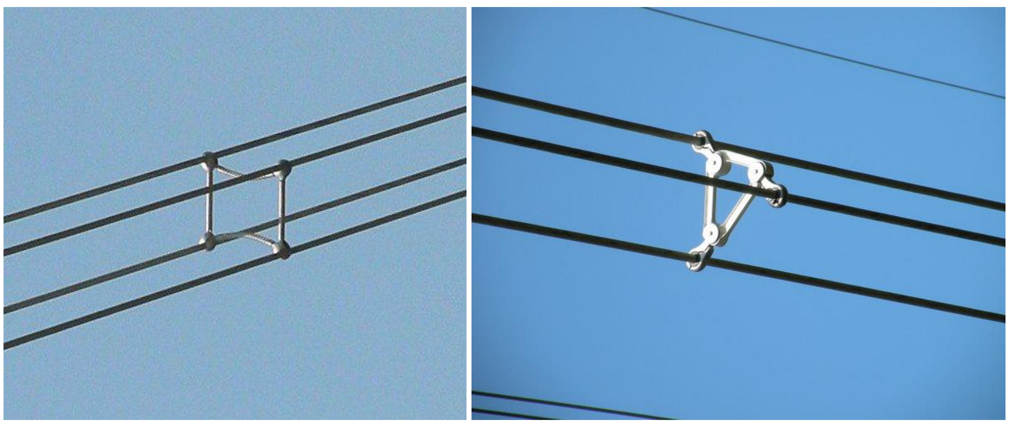


Figure 1.5 Shows that bundled conductor configuration

1.8 Standard Conductors

These kinds of conductors are defined as standard because you can find them on international normative (EN50182, ASTM B231, B399, B232). Stranded wire is composed of a number of small wires bundled or wrapped together to form a larger conductor. Stranded wire is more flexible than solid wire of the same total cross-sectional area. Standard conductor is very much popular in power system for transmission and distributed line. It is used to reduce the skin effect

1.9 Conductor Materials for Overhead Lines

Electrical and Mechanical Properties:

The function of overhead lines is to transmit electrical energy. The important properties which the line conductors must have are:

1. High electrical conductivity.
2. High tensile strength.

3. Low density.
4. Low cost.

Bundling of conductor increases the electrical and mechanical properties in comparison to the solid conductors. It is called as stranding. The number of strands in cables are 7,19, 37, 61, 91, 127 or 169 as these conductors give the cylindrical formation.

Copper conductor used for transmission is hard-drawn copper.

Properties:

1. It has the best conductivity.
2. It has high current density.
3. The metal is quite homogeneous.
4. It has low specific resistance.
5. It is durable and has high scrap value.

1.10 High Resistivity Material

High resistivity material possessing very high value of resistivity

- Low temperature co-efficient
- High mechanical strength
- Long service life
- Low cost and easily available in market
- High melting point to withstand high temperature

Example: Tungsten, Carbon, Platinum, Mercury

High Resistivity Materials and their Applications:

1.10.1 Tungsten

Properties:

1. It is grayish in colour when in metallic form.
2. It has a very high melting point (3300^0C)
3. It is a very hard metal and does not become brittle at high temperature.
4. It can be drawn into very thin wires for making filaments.
5. Its resistivity is about twice that of aluminum.
6. In its thinnest form, it has very high tensile strength.
7. It oxidizes very quickly in the presence of oxygen even at a temperature of a few hundred degrees centigrade.
8. In the atmosphere of an inert gas like nitrogen or argon, or in vacuum, it will reliably work up to 2000^0C.

Figure 1.6 tungsten used as filament in bulbs.

Applications:

It is used as filaments of electric lamps and as a heater in electron tubes. It is also used in thermionic valves, radars. Grids of electronic valves, sparking and contact points.

1.10.2 Carbon

Carbon is mostly available as graphite which contains about 90% of carbon. Amorphous carbon is found in the form of coal, coke, charcoal, petroleum, etc.

Carbon is very high resistivity material, generally carbon are manufacture from graphite.

Electrical carbon is obtained by grinding the raw carbon materials, mixing with binding agents, moulding and baking it.

Figure 1.8 graphite pieces

Properties:

1. Carbon has very high resistivity (about 4600 micro ohm cm).
2. It has negative temperature coefficient of resistance.
3. It has a pressure-sensitive resistance material and has low surface friction.
4. The current density is 55 to 65 A/cm^2
5. This oxidizes at about 300^0C and is very weak.
6. It has very good abrasive resistance.
7. It withstands arcing and maintains its properties at high temperature.

Applications:

Carbon is used brushes of electrical machine, battery and welding.

1.10.3 Platinum

Properties:

1. It is a grayish-white metal.
2. It is non-corroding.
3. It is resistant to most chemicals.
4. It can be drawn into thin wires and strips.
5. Its melting point is 1775^0C.
6. Its resistivity is 10.5 micro ohm cm.
7. It is not oxidized even at high temperature.

Applications:

1. It is used as heating element in laboratory ovens and furnaces.
2. It is used as electrical contact material and as a material for grids in special-purpose vacuum tubes.
3. Platinum-rhodium thermocouple is used for measurement of temperatures up to 1600^0C.

1.10.4 Mercury

Properties:

1. It is good conductor of heat and electricity.
2. It is a heavy silver-white metal.
3. It is the only metal which is liquid at room temperature.
4. Its electrical resistivity is 95.8 micro ohm cm.
5. Oxidation takes place if heated beyond 300^0C in contact with air or oxygen.
6. It expands and contracts in regular degrees when temperature changes.

Figure 1.9 Mercury vapour lamps

Applications:

Mercury vapour lamps, mercury arc rectifiers, gas filled tubes; for making and breaking contacts; used in valves, tubes, liquid switch.

1.11 Cable

Electrical and Mechanical Properties of Cables:

Cables are most useful for low-voltage distribution in thickly populated areas. The advantages of cables are: The cable transmission is not subjected to supply interruption caused by lightning or thunderstorms, birds and other severe weather conditions. It reduces the accidents caused by breaking of the conductors.

Required Properties of Cables:

1. High insulation resistance.
2. Moisture and water percolated due to rain or other causes should not come in contact with conductor.
3. Low discharge current.
4. Resistant to chemical action due to chemical content in earth or damages due to insects.
5. As there is not much opportunity for heat dissipation from conductor, the insulator must be capable of withstanding, without any change in qualities, the temperature within the cable.
6. It must be flexible, light and occupy less space.
7. Available in right quantity and at low rate. Materials Used for Manufacturing Cables are Paper (impregnated, vulcanized bitumen, rubber, compressed air, petroleum jelly, metal sheath (lead or lead alloy), galvanized steel or tapes for armoring and jute.

Figure 1.10 shows those electrical cables

1.12 Superconductor

Historically, the first superconductor to be discovered was mercury- discovered by Kimberling Ones in 1911. The best conductors like silver, copper and gold are not superconductors.

Superconductivity depends on:

a) Electron-proton interaction, and

b) Critical temperature.

They are some metal and chemical compounds whose resistivity is zero when these temperatures is near 0^0Kelvin and this stage such metal is called super conductivity.

The transition from normal conductivity to superconductivity takes place almost suddenly. It occurs very narrow range of temperature. Super conductor is two types:

1) Soft Conductor

2) Hard Conductor.

A large number of metals and alloys are superconductors, with critical temperatures T_c ranging from less 1K to 18K. Even some heavily doped semiconductors have been found to be superconductors.

Type I superconductors are those superconductors which looses their superconductivity very easily or abruptly when placed in the external magnetic field. Type I superconductors are also known as **soft superconductors** because of this reason that is they looses their superconductivity easily

Type II superconductors are those superconductors which looses their superconductivity gradually but not easily or abruptly when placed in the external magnetic field. Type II superconductors are also known as hard **superconductors**

Applications:

1. Superconductors can be used for the production of strong magnetic fields. Magnetic inductions in the order of 10 Wb/m^2, far above the largest value obtainable with iron-core electromagnets, have been obtained in superconducting Solenoids.
2. Superconductors are based on the effect of an applied magnetic field on the transition between normal and superconducting states. e.g. at a constant temperature below T_c, changes back and forth from normal to superconducting behavior can be affected by varying the external magnetic field, which thereby can control the current in a circuit connected to the superconductor. Thus, amplifiers, oscillators, control systems, and especially the logic and information storage functions of a large-scale computer can be provided by the controlling magnetic field exercises on superconductivity.
3. Super conducting material is used for power cable will enable transmission of power over a long distance using a diameter of few centimeter without any power loss.

1.13 Low Resistivity Copper Alloy

We have notice earlier that copper becomes mechanically hard when it is drawn however hardening of copper is also combination of other metal brass, bronze, beryllium copper alloys

1.13.1 Brass

When copper is alloyed with zinc called brass. The proportions of zinc and copper can vary to create different types of brass alloys with varying mechanical and electrical properties, it has lower conductivity then copper .it is wieldable.

Application:

It is used in manufacture of switches, lamp holder etc.

1.13.2 Bronze

Bronze it is an alloy consisting primarily of copper, commonly with about 12% tin and often with the addition of other metals (such as aluminum, manganese, nickel or zinc) and sometimes non-metals or metalloids such as arsenic, phosphorus or silicon. Brass is an alloy of copper and zinc. Bronze is a metal alloy consisting primarily of copper, usually with tin as the main additive, but sometimes with other elements such as phosphorus, manganese, aluminum, or silicon. Higher malleability than zinc or copper

Applications:

Switch Blade, Sliding Contact.

1.13.3 Beryllium Copper Alloy

The copper alloy containing a beryllium is called as a beryllium copper alloy. It has high mechanical strength. It has high mechanical strength. It is used for making current carrying spring, brush holder, sliding contact. It has many specialized applications in tools for hazardous environments, musical instruments, precision measurement devices, bullets, and aerospace. Beryllium alloys present a toxic inhalation hazard during manufacture.

Applications:

Kneif and Switch Blade.

MODEL QUESTIONS

1. What is the difference between low resistivity material and high resistivity material?
2. What is superconductor?
3. Write the properties and application of low resistivity material?
4. Write the properties and application of low resistivity material?
5. What does u mean by resistivity?

2

Chapter

SEMICONDUCTING MATERIALS

2.1 Introduction

"A semiconductor material is one whose conductivity lies between that of a conductor and an insulator." The two most commonly used semiconductor materials are germanium and silicon, Atom is the smallest practical which consists of proton electron and neutron.

Conductor:

It is those substances in which electric current pass through easily.

Example: Silver, iron, cu, gold, Al, human body, earth, salt.

- Forbidden energy gap =0ev.
- Positive temperature coefficient (T α R) if temperature increases then resistance increases and if resistance increases then temperature increases.
- In terms of energy band as the valence and conduction bands overlap each other due to this overlapping; a slight potential difference across a conductor causes the free electrons to constitute electric current.

Semi-conductor:

It is those substances in which are lies in between Conductor and Insulator.

Example: Si, Ge

- Forbidden energy gap =1ev
- Negative temperature coefficient so (T α 1/R) if temperature increases then resistance decreases and if resistance increases then temperature decrease.
- In terms of energy band, the valence band is almost filled and conduction band is almost empty.

Insulator:

It is those substances in which electric current cannot pass through easily.

- Example: Glass, wood, dry, air, mica, sulphur, wax, oil.
- Forbidden energy gap > 8ev or 15ev.
- Zero temperature coefficient (T=0).
- In terms of energy band, the valence band is full while the conduction band is empty Proton +, Electron- , Neutron +_

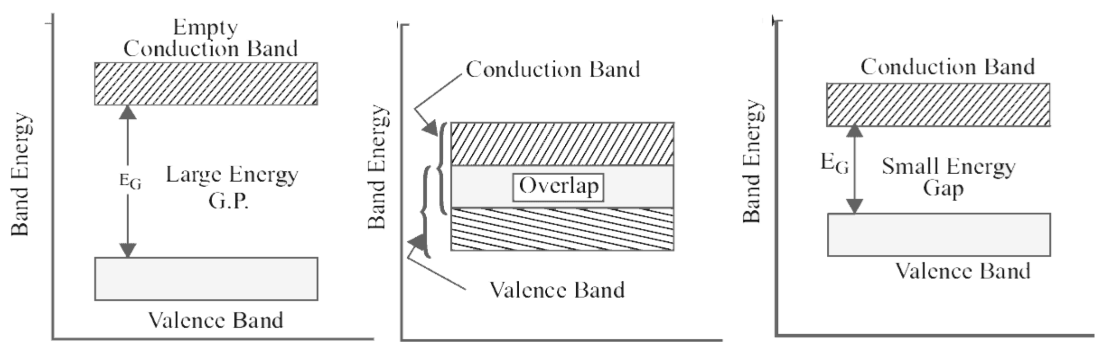


Figure 2.1 Energy band diagrams of insulator, conductor and semi-conductor

2.2 Simplified Si and Ge Atoms

The electrical characteristics of a semiconductor fall between those of a conductor and an insulator. A semiconductor has 4 electrons in its valence ring (outmost orbit). A good insulator has 8 electrons in its valence ring. The best conductor has one electron in the valence ring. The two most widely used semiconductors are silicon (Si) and germanium (Ge). Their atoms structure is shown in below figure 2.2.

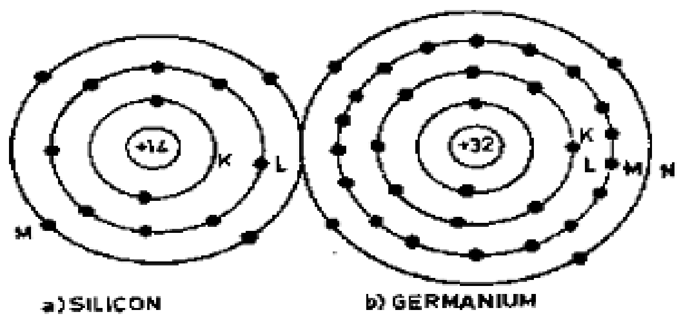


Figure 2.2 Shows that atoms structure of Si and Ge

The electrical characteristics of a semiconductor fall between those of a conductor and an insulator. A semiconductor has 4 electrons in its valence ring (outmost orbit). A good insulator has 8 electrons in its valence ring. The best conductor has one electron in the valence ring. The two most widely used semiconductors are silicon (Si) and germanium (Ge).

2.3 Inter atomic bonds

Covalent bond: it is a chemical bond. It is also called molecular bond. It involves the sharing of electron pairs between atoms. These electron pairs are known as shared pairs or bonding pairs, and the stable balance of attractive and repulsive forces between atoms, when they share electrons, is known as covalent bonding.

(ii) Carbon **and** oxygen combine to form carbon dioxide (CO_2)

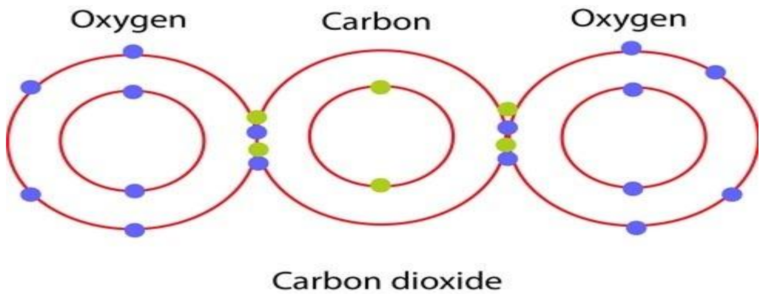


Figure 2.3 covalent bond formation of CO_2

Covalent bonds are formed between non-metal atoms. Each of the atoms involved in bonding contribute one-two, three or more electrons to form the shared pair.

Ionic bond: Ionic bonding is a type of chemical bonding that involves the electrostatic attraction between oppositely charged ions, and is the primary interaction occurring in ionic compounds

For example, when sodium (Na) and chlorine (Cl) are combined, the sodium atoms each lose an electron, forming cations (Na^+), and the chlorine atoms each gain an electron to form anions (Cl^-)

$$Na + Cl \rightarrow Na^+ + Cl^- \rightarrow NaCl$$

Metallic bond: Metallic bonding is the force of attraction between valence electrons and the metal atoms. It is the sharing of many detached electrons between many positive ions.

Semiconductor is two types 1) Intrinsic type semi-conductor 2) Extrinsic type semi-conductor.

2.4 Intrinsic Conductor

- It is a pure form of semiconductor.
- Here number of electrons is equal to number of holes.
- Its conductivity is low, Examples: Si, Ge.
- It is also called as an Undopped semiconductor.
- If its temperature is brought down to 0^0K this intrinsic material are as a good insulator and very little amount of current will flow through it.

2.5 Extrinsic Semiconductor

- It is impure form of semiconductor.
- Here number of electron is not equal to number of holes.
- Its conductivity is more, Examples: P-type N-type.
- Extrinsic semiconductor is two types 1) P-type semi-conductor 2) N-type semiconductor.

2.5 Difference between Si and Ge Semiconductor

Si	Ge
It is cheaper	It is costly
High Peak inverse voltage	Less Peak inverse voltage
It has high Knee voltage -0.7	It has less knee voltage-0.3

2.6 Difference between P-Type and N-Type Semi-conductor

P-Type Semiconductor	N-Type Semiconductor
p-type semiconductor is prepared by addition of trivalent impurities	n-type of semiconductor is prepared by addition of pentavalent impurities
To obey octet rule accept one electron from another atom	To obey octet rule donate one electron to another atom
p-type semiconductor majority charge carrier is hole and minority charge carrier is electron	n-type semiconductor majority charge carrier is electron and minority charge carrier is hole
it is also called accepter type semi conductor	it is also called donner type semi conductor

2.7 N-type Material

When a pentavalent impurity is added to an intrinsic material such as silicon or germanium, only four of its valence electrons lock into the covalent bond formation of atom structure. The fifth valence electron of the impurity atom is free to wander through the crystal. Shows the addition of an atom of arsenic as an impurity. The impurity atom becomes ionized and has a positive charge when its fifth electron moves away. The positive impurity ion is not free but is firmly held in the crystal structure. The pentavalent atom donates an extra electron and is called a donor impurity. A material doped with a donor impurity has excess of electrons in its structure. It is called N-type material. The net charge of N-type material is still natural since the total number of electrons is equal to the total number of protons. Arsenics impurity atom provides a fifth electron that cannot enter a covalent bond structure.

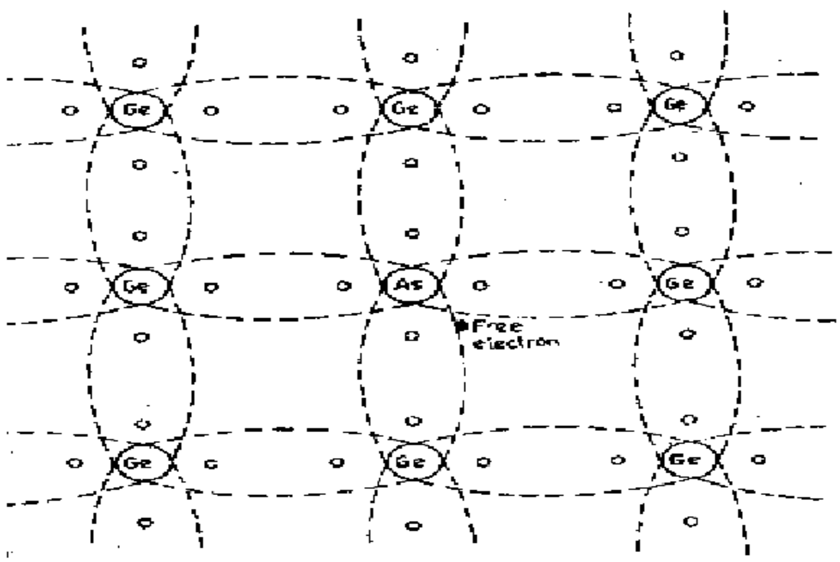


Figure 2.4 Arsenic impurity atom provides a fifth electron

2.8 P-type Materials

When a trivalent impurity is added to the intrinsic material, the two lock into a crystal structure. The impurity has three valence electrons. There is a hole in the covalent bond structure created by the lack of an electron. The hole represents an incomplete covalent bond and exhibits a positive charge. In order to complete the bond and from a stable 8-electron structure, a valence electron from a nearby atom gains sufficient energy to break loose from its bond and jumps into the hole due to its attraction. Therefore, this type of impurity is called an "acceptor". The electrons available to fill the hole and complete the bond have been release by the nearby atom whose bonds have been broken and hole created. Thus, the process will continue creating a mobility of holes. The impurity atom Arsenic impurity atom provides a fifth electron becomes negatively ionized as accepts an electron. The germanium or silicon atom which releases one electron becomes positively ionized. The net charge of the material is still neutral. The total number of electrons is equal to the total number of protons.

2.9 Semiconductors Commonly Used

The following materials are commonly used as semiconductors:

(i) Boron	(ii) Carbon	(iii) Silicon	(iv) Germanium
(v) Phosphorus	(vi) Arsenic	(vii) Antinomy	(viii) Sulphur
(ix) Selenium	(x) Tellurium	(xi) Iodine	

Give five examples of semiconductor and its applications:

1. **Silicon:** It is used in processing and manufacturing
2. **Germanium**: It is used in thermal sensitive purpose
3. **Sic:** It is used in LED
4. **Diamond:** It is used for cutting purpose
5. **GaAS**: It is used in high speed device.

2.10 Working and Application of Semiconductors

Semiconductor materials are used in:

1. Rectifiers
2. Temperature-Sensitive Resistors
3. Photoconductive And Photovoltaic Cells
4. Varistors
5. Hall Effect Generators
6. Strain Gauges
7. Transistors

2.10.1 Rectifiers (Which convert's DC to AC)

(a) Germanium and Silicon Rectifiers:

When a P-type material and an N-type material are joined together, they form a junction called P-N junction. When an external voltage is applied across the two material, a flow of current results if the positive and negative terminals of the voltage source are connected respectively to the ends of the P and N material. The voltage applied this way is called "forward-biasing" the P-N junction. If the applied voltage is reversed, that is, the positive of the supply voltage is connected to N side and negative of the supply is connected to the P side, there is no flow of current. This is called "reverse biasing". Thus the P-N junction offers high conductivity when forward biased and no conductivity when reverse biased. Thus, the semiconductor can be used as a rectifier. The modern P-N junction rectifiers use germanium or silicon material.

One terminal is called Anode and another terminal is called Cathode. When P-ype of semiconductor is connected with N-Type of semiconductors it forms a junction. The junction is known as P-N junction, P –type of semiconductor is connected to positive terminal of battery and N-type of semiconductor is connected to negative terminal of battery, P-type f semiconductor majority charge carrier is holes and N-type of semiconductor majority charge carrier is electron., When Diffusion process occur i.e. means inter mixing of holes and electrons (+-) And so that +ve charges are attracted towards N-type of semi-conductor and –ve charges are attracted towards P-type semiconductor so in P-type of semiconductor majority charge carrier is holes and minority charge carrier is electron, similarly N-Type of semi conductor majority charge carrier is electron and minority charge carrier is holes and it forms a thin and narrow depletion layer, when applied voltage current increases and resistance decreases due to depletion layer is small

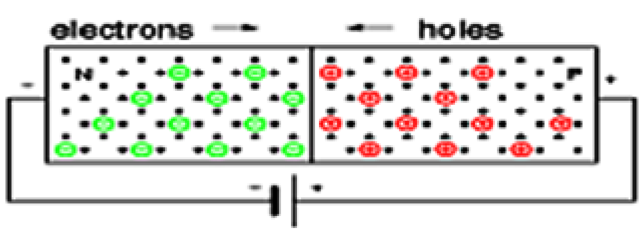


Figure 2.5 Forward biased condition of Germanium and Silicon Rectifiers

P–type of semiconductor is connected to positive terminal of battery and N-type of semiconductor is connected to negative terminal of battery. P-type f semiconductor majority charge carrier is holes .and N-type of semiconductor majority charge carrier is electron. When Diffusion process occur i.e. means inter mixing of holes and electrons (+-) And so that +ve charges are attracted towards N-type of semi-conductor and –ve charges are attracted towards P-type semiconductor so in P-type of semiconductor majority charge carrier is holes and minority charge carrier is electron similarly N-Type of semi conductor majority charge carrier is electron and minority charge carrier is holes and it forms a wider depletion layer. When applied voltage current decreases and resistance increases due to depletion layer is large.

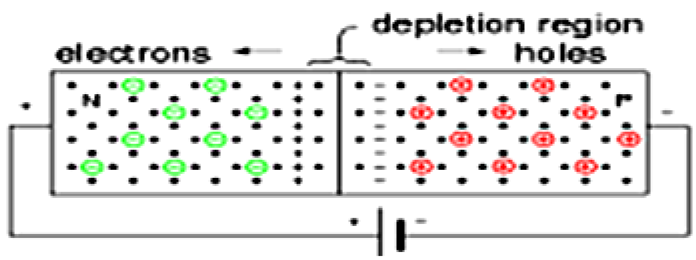
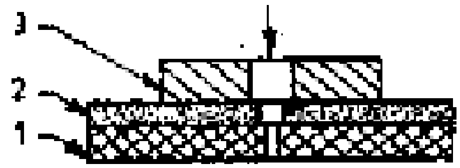


Figure 2.6 Reverse biased condition of Germanium and Silicon Rectifiers

(b) Copper Oxide Rectifier:

The earliest semiconductor to be used was copper oxide. Its application was in copper oxide rectifier. Copper oxide rectifier is a place of 99.98 % pure copper on which a film of cuprous oxide is produced by a special process. From one side of the plate, cuprous oxide is cleaned and electrode is soldered directly to the copper. The second electrode is soldered to cuprous oxide film. When a positive potential is applied to the oxide layer and negative to the copper, it corresponds to forward biasing of a P-N junction. By arranging the copper plate. Elements in stacks, rectifiers for use in many kinds of measuring instruments and circuits can be obtained. These rectifiers have low permissible current density. They are not used for power supply purposes. To have a good contact with copper oxide, a lead plate is pressed against it. The two terminals of the rectifiers are the copper plate and lead plate. The oxide will be in between the plates as shown in figure 2.7. This rectifier will allow the current to flow only from oxide to copper and will not allow flow from copper to oxide. The voltage that may be applied to a single rectifier ranges between 4 and 8 V, so a number of units are connected in series for operating on high voltages. Similarly, parallel connected of the units, increases the current rating of the rectifiers, as the maximum current density in the forward direction is 0.1 to 0.15 A/cm^{2}at an allowable voltage of 8V. The life of copper oxide rectifiers is 12 to 15 years and efficiency is 70%.



1-Copper; 2-Copper Oxide; 3-Lead Plate

Figure 2.7 Copper Oxide Rectifiers

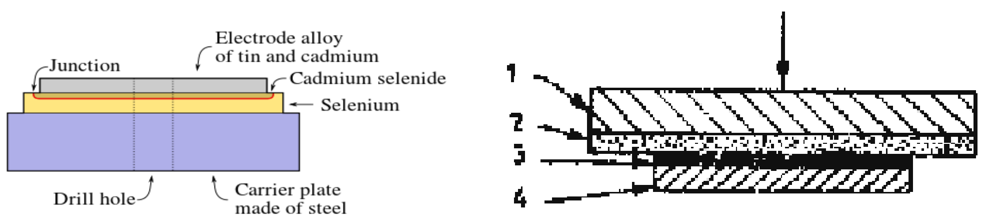
Applications:

These types of rectifiers are mostly used for meters, battery cell charging, X-ray works, measuring instruments, railway signaling, telecommunication systems, etc.

(c) Selenium Rectifiers:

In this type, a film of 0.5 mm. thickness is deposited on one side of the metallic back plate (iron or aluminum). By means of chemical treatment, a film of "blocking" or "barrier" layer is formed between selenium and counter electrodes.

The rectification is from back plate to selenium. The rectifier construction is as shown in A single unit can sustain 6 V. The normal current density is about 0.04 A per cm^{2}for full wave rectification. The power efficiency is 50 to 75 %. The units can be combined in series or in parallel, similar to that of copper oxide rectifiers to work at desired voltage or for the required current capacity.



1-Metalic Back Plate; 2-Selenium Layer; 3-Barrier Layer; 4-Counter Electrode

Figure 2.8 Selenium Rectifier

Applications:

This type of rectifiers are widely used for battery charging, telegraph and telephone circuits, control circuits, railway signaling, meters, electroplating and other works.

Such rectifiers are available in capacities of up to 50 to 100 KW.

2.10.2 Temperature-sensitive Elements (Thermistors)

If the temperature of a semiconductor material is increased, that causes a decrease in its resistance. This property is used in temperature sensitive elements which are called as "thermistors". Thermistors are non linear device.

Thermistor is a negative temperature device ie NTC (T α 1/R) if temperature increases then resistance decreases.

The termistors are thermally sensitive material (resistors). They are made from oxides of certain metals such as copper, manganese, cobalt, iron and zinc.

Advantages of Thermistor:

- It is a small size and low cost
- Fast response over a narrow temperature
- Its weight is also less

Applications of Thermistors:

Thermistors find application in temperature measurements and control. They sense temperature variations and convert these variations into an electrical signal which is then used to control heating devices.

Thermistors are also used for measurement of radio frequency power, voltage regulation.

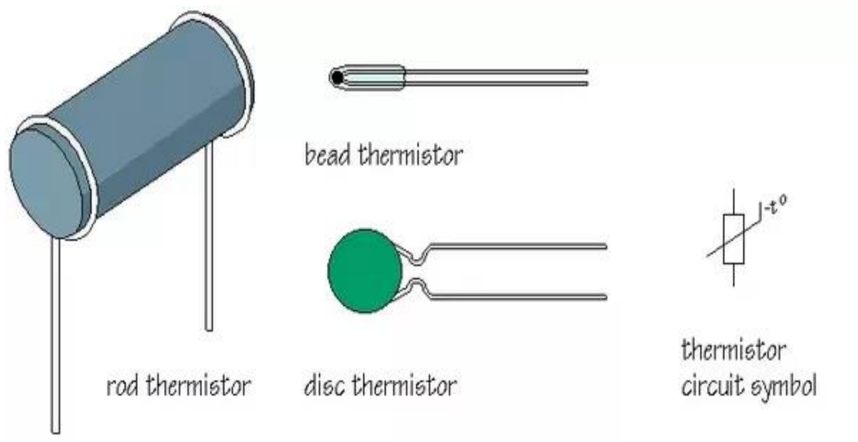


Figure 2.9 Different Types of Thermistor

2.10.3 Photoconductive Cells& Photovoltaic Cells

(a) Photoconductive Cells

Photo conductive cell is a two terminal semiconductor device .it is also called as photo resistive cell. The resistance of semiconductor materials is low under light and increases in darkness. Photoconductive cells can be used in applications which require the control of a certain function or event according to the colour or intensity of light.

Applications:

They are used in burglar alarms, flame detectors and control for street lights.

It is used in sensor switch

It is also used in smoke detector

(b) Photovoltaic Cells

- It is also called as PV Cell
- It is also called photo voltaic cell
- It converts light in to electrical energy

What is Solar Energy?

It is the combination of light and heat is produced by sun is known as a solar energy .so there are lot of application in solar cell

- Photovoltaic cells are devices that develop and emf when illuminated. They convert light energy into electrical energy.
- Solar cell is developed in the form of slice of single crystal silicon
- Typical size of solar cell is 2ommx20mmx300mm
- The overall efficiency of solar cell is about 10 to 20%

Applications:

The applications of photovoltaic cells are in photographic exposure meters, lighting control systems, automatic aperture control in cameral.

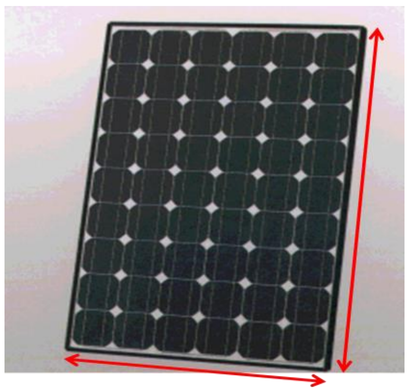


Figure 2.10 Solar Cell

2.10.4 Varistors

Varistor is a voltage dependent resistor. In varistor the resistance decreases when voltage increases, the word composed of the variable resistor. The resistance of semiconductors varies with the applied voltage. This property is used in devices called varistors. The most common type of VDR is MOV (metal oxide varistor).

Applications:

- They are used in voltage stabilizer and used for motor speed control
- Varistor are used in power supply system
- Varistor are used as telephone and other communication line protection

2.10.5 Hall Effect Generators

When current flows through a semiconductor bar placed in a magnetic field, a voltage is developed at right angles to both current and the magnetic field. This voltage is proportional to the current and the intensity of the magnetic field. This is called the "Hall effect". Consider the semiconductor bar shown in Figure 2.7, which has contacts on all four sides. If a voltage E_1 is applied across the two opposite sides A and B_2a current will flow. If the bar is placed perpendicular to magnetic field B as shown in the figure, an electrical potential EH is generated between the other two contacts C and D. This voltage EH is a direct measure of the magnetic field strength and can be detected with a simple voltammeter.

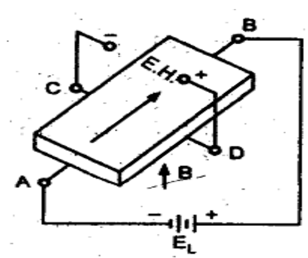


Figure 2.11 Hall Effect generators

Application

The Hall Effect generators may be used to measure magnet is fields. It is capable of measuring magnetic field strengths that have strength of 10-6 of the magnetic field of the earth.

2.10.6 Strain Gauges

Semiconductors are sensitive to heat, voltage and magnetic field; they are also sensitive to mechanical forces. If a long thin rod of silicon is pulled from end to end, its resistance increases considerably because the mechanical force pulls each silicon atom slightly away from its adjacent atom. This increases the breadth of the forbidden energy gap, which increases the resistivity of the rod. Silicon and other semiconductors are used in strain gauges.

Applications:
Strain gauges are used to find the small changes in length of solid substances or objects.

A strain gage (sometimes referred to as a Strain gauge) is a sensor whose resistance varies with applied force. It converts force, pressure, tension, weight, etc., into a change in electrical resistance which can then be measured. As their name indicates, they are used for the measurement of strain.

The Strain *Gauge Factor* is the ratio of electrical resistance to the actual change in length of the strain gauge.

Gauge factor $=\frac{\Delta R/R}{\Delta L/L}$

2.10.7 Transistors

It is a three terminal, two junction device: A transistor consists of two PN junctions formed by sandwiching either P-type or N-type semiconductor between a pair of opposite types.

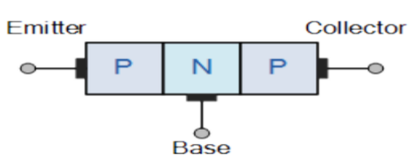


Figure 2.12 shows that PNP transistor

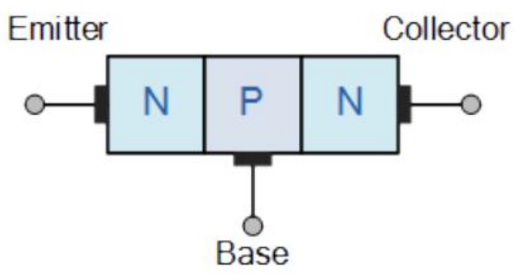


Figure 2.13 shows that NPN transistor

Transistor is used as an amplifier .it acts as a switch. it have three region 1)cut-off region 2)active region 3)saturation region

Transistor is a unilateral device

Transistor is classified in to two types 1) BJT 2) FET

BJT (bipolar junction transistor)

It is a three terminal device .It is a current controlled device. It is bipolar because two polarities is responsible for current conduction. (Electron and holes)

Its three terminals are emitter, base and Collector

FET (field effect transistor)

It is a three terminal device .It is a voltage controlled device. It is a unipolar device because one polarities is responsible for current conduction. (Either electron or holes) its three terminals are gate, drain and source

Difference between BJT and FET

BJT	FET
It is a current controlled device	It is a voltage controlled device
It has higher switching speed	It has higher switching speed
It is Longer Life and High efficiency	It is shorter life and Low efficiency
It is bipolar because two polarities is responsible for current conduction.(electron and holes)	It is a unipolar device because one polarities is responsible for current conduction. (Either electron or holes)
Its three terminals are emitter, base and Collector	its three terminals are gate, drain and source

Current amplification factor:

$\beta = \Delta I_c / \Delta I_B$ (in AC) but in dc $\beta = I_c / I_B$ so $I_c = \beta I_B$

$\alpha = \Delta I_c / \Delta I_E$

Relationship between β and α

$\alpha = \beta / 1 + \beta$ β=output current/input current

$\beta = \alpha / 1 - \alpha$

Figure 2.14 Transistor

Advantages:

1. Usually smaller size, lower cost and longer life.
2. Can handle small current
3. Can be combined in the millions on one cheap die to make an integrated circuit.
4. Lower power consumption, less waste heat, and high efficiency than equivalent tubes, especially in small-signal circuits.
5. Can operate on lower-voltage supplies for greater safety, lower costs,

Disadvantages

1. Maintenance more difficult; devices are not easily replaced by user.
2. Semiconductors Commonly Used

MODEL QUESTIONS

1. What is the difference between conductor and semiconductor?
2. What is strain gauge?
3. What is p-type material?
4. What is Transistors?
5. What is gauge factor?
6. What is PV cell?
7. What is Hall Effect DC Generators?

3

Chapter

INSULTING MATERIALS

3.1 Introduction

For safe and satisfactory operation of all electrical and electronics equipment insulator plays important role. Basically current carrying wires, surfaces need to be cove red with insulating material. Let us see the structure of the material on the basis of energy band. In this type of material, the highest occupied energy band (Valence Band) is completely filled. The next higher band (Conduction Band) is quite empty. The gap between these two bands is too large. When the electric field is applied across these materials, the electrons from valence band cannot reach the conduction band and conduction of electron stops. Such materials are known as insulators. Diamond is an example of this kind of material with a separation of nearly 6eV between valence band and conduction band.

3.2 Insulating Materials for Electrical Engineering

The insulating materials used for various applications in electrical engineering are classified in three categories:

1. **Solid insulating material**
2. **Liquid insulating material**
3. **Gases insulating material**

1. **Solid Insulating Material:**
    - Fibrous material
    - Impregnated fibrous material
    - PVC
    - Rubber materials
    - Glass materials
    - Mineral materials
    - Ceramic material
    - Non –resinous material
2. **Liquid Insulating Material:**
    - Mineral oil (kerosene oil, alcohols, lubricating oils, waxes etc)
    - Synthetic liquids
    - Vegetable oils (obtained from seeds of cotton, sunflower, soybean, pulp, etc)
    - Fluorinated liquids
    - Silicon fluids
    - Vaseline
    - Varnish
3. **Gaseous Insulating Material:**
    - Air
    - Nitrogen
    - Hydrogen
    - Inert gases
    - Halogen
    - Sulphur hexafluoride(SF_6)
    - Carbon dioxide (CO_2)

3.3 Classification of Materials on the basis of Structure of Material

- Fibrous material (Wood, Paper, Cotton, Adhesive Tapes)
- Insulating liquids (Transformer Oils, Cable Oils, Silicone Fluids)
- Non-resinous material (Bitumen's, Wax)

- Glass and ceramics (Glass, Porcelain etc.)
- Plastics (Molding Powder, Rubber laminations)
- Mineral (Mica)
- Gaseous (Air, H_2, N_2, Ne, CO2, SF_6, Hg and Na vapor)

Fibrous Material:

These are obtained from animal origin or from cellulose which is the main constituent of vegetables plants .the following materials are:

1. Wood

- High dielectric constant, Highly hygroscopic, dry wood can bear a Voltage gradient of 10kV/inch
- Wood is naturally available material and obtained from trees
- It is a good insulating material
- It is used for low voltage only
- It is used for wooden switch boards
- It is light in weight
- It is easily available in nature
- Its working temperature is low
- It is used in switchboards, terminals, casing and capping, it is used in instrument and equipments etc.

Figure 3.1 Wood Switchboards

Applications:

Terminal block, wedges of armature winding, operating rods in high voltage switch gears, Cardboard, electrical wood poles are used for transmission and distribution of electric power .

2. Cardboard

- It is similar to paper but only difference is that it is thick made by wood pulp through a calendaring machine
- Its thickness is more than paper
- It is strong
- It is less effective
- It is less flexible
- It is used in switch board.

Applications:

It is used in switchboards, terminals, casing and capping, it is used in instrument and equipments, round box in house wiring etc.

3. Asbestos

- It is a mineral fibrous material
- It can with stand very high temperature
- It is available in Kadapa district of Andhra Pradesh
- It can be used up to a voltage 33kv
- It is strong and flexible

Applications

Asbestos find application in electrical equipment and machine, it is used in electric board, It is used in heating device like oven, electric oven, panel board constructions, it is used in roofs of building

Figure 3.2 Asbestos

Impregnated Fibrous Insulating Material:

- Impregnated paper
- Mineral insulating materials
- Ceramic insulating materials
- Glass insulating materials
- Plastic insulating materials or insulating resins

1. Rubber

- Stretchable, Moisture repellant,
- Good insulating properties,
- Good corrosion resistance. Can be obtained as hard rubber, synthetic rubber, butadiene rubber, butyl rubber, chloroprene rubber and silicon rubber.

Applications:

Used as protective clothing such as boots and gloves, also used as insulation covering for wires and cables. Hard rubber is used in housing for storage batteries, panel board, jacketing material

2. Polyvinyl Chloride (PVC)

- It is obtained by polymerization of vinyl chloride in the presence of a catalyst at 500C. PVC exhibits good electrical and mechanical properties.
- It is hard, brittle, and non-hygroscopic and can resist flame and sun light.
- PVC used as insulation material for dry batteries, jacketing material for wires and cables.

Properties:

- It is hard
- It is rigid
- It is less weight
- It is cheep
- It is obtained in different colour

- It can with stand very high temperature above 800c
- It is obtained by polymerization of vinyl chlorides in presence of catalyst at 500c
- Its dielectric constant is 5 to 6
- It has good mechanical and electrical properties
- Its insulation resistance is 1012 to 10 13 ohm meter.
- It is slightly hygroscopic
- Its dielectric strength is 15KV/mm to 30KV/mm
- It never gets corrosion

Applications:

- It is used in wire and cable
- It is used in dry batteries
- It is used in pipes in electrical wiring system
- PVC cable are commonly used in low and medium voltage
- PVC Wire is used in radio, television, aircraft system

Figure 3.3 PVC pipes

3. Epoxy Glass

Epoxy glass is made by bonding two or more layer of material. The layers used reinforcing glass fibers impregnated with an epoxy resin. It is water resistant and not affected by alkalis and acids.

It is used as base material for copper-clad sheets used for PCBs, terminal port, instrument case etc.

4. Bakelite

It is hard, dark colored thermosetting material, which is a type of phenol formaldehyde. It is widely used for manufacture of lamp holders, switches, plug socket and bases and small panel boards.

5. MICA

Two kind of mica are used as neutral insulating material in electrical engineering. Those are Muscovite mica and Phlogophite mica.

Figure 3.4 Biotite-Mica-Healing-Crystal-45mm

(a) Muscovite Mica:

- The chemical composition of muscovite mica is $KAI_3SiO_3O_{10}(OH)_{2.}$ It is translucent green, ruby, silver or brown and is strong, tough and flexible.
- It exhibits good corrosion resistance and is not affected by alkalis.
- It is used in capacitors and commutators.

(b) Phlogophite Mica:

- The chemical composition of this is, $KMg_3AlSiO_3O_{10}(OH)_2$.
- It possesses less flexibility.
- It is amber, yellow, green or grey in colour.
- It is more stable, but electrical properties are poorer compared to Muscovite Mica. It is used in thermal stability requirements, such as in domestic appliances like iron, hotplates etc.

6. Polyethylene

- It is obtained by polymerization of ethylene.
- The polymerization is performed in the presence of catalyst at atmospheric temperature and pressure around 100^0C.

- To obtain heat resistance property polythene is subjected to ionizing radiation. Polyethylene exhibits good electrical and mechanical properties, moisture resistant and not soluble in many solvents except benzene and petroleum at high temperature.
- It is used as general purpose insulation, insulations of wires and cable conductors, in high frequency cables and television circuits, jacketing material of cables. Polyurethane films are also used as dielectric material in capacitors.

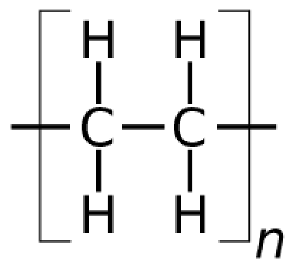


Figure 3.5 Crystal Structures of Polyethylene

7. Teflon

The chemical name of Teflon is Polytetrafluoro-ethylene. This is synthesized by polymerization of tetrafluro ethylene. It bears good electrical, mechanical and thermal properties. Its dielectric constant is 2 to 2.2, which does not change with time, frequency and temperature. Its insulation resistance is very high and water resistant.

It is used as dielectric materials in capacitors, covering of conductors and cables, as base material for PCBs.

3.4 Liquid Insulating Material: Properties and Applications

1. Mineral Oils

The operating temperature range of mineral oil is 50-110^{0}C. These hydrocarbon oils are used as insulating oils in transformers, circuit breakers, switch gears, capacitors etc.

In transformers, light fraction oil, such as transit oil is used to allow convection cooling. Its high flash point is 130^{0}C, so it is able to prevent fire hazard.

Highly purified oil has a dielectric strength of 180 kv/mm and if the oil contains polar and ionizing material its dielectric loss increases.

The examples of mineral oils are kerosene oil, alcohol, lubricant oil.

2. Askarels

These are non-inflammable, synthetic insulating liquids, used in temperature range of 50 –110^0C. Chlorinated hydrocarbons are the most widely used among the askarels because of high dielectric strength, low dielectric constant (4 to 6) and small dielectric loss. They do not decompose under the influence of electric arc and have good thermal, chemical and electrical stability.

The most widely used hydrocarbons or askarels. Askarels are generally used to impregnate a cellulose insulating material, such as paper or press board etc., for its high breakdown strength.

3. Silicon Fluids

It is clear water like liquid. It is used in the temperature range of 90-220^0C and it is clear, water like liquid. It is available in wide range of viscosity and stable in high temperature. They are non-corrosive to metal up to 200^0C and bear excellent dielectric properties in wide range of temperature. So it is used as coolants in radio pulse and aircraft transformers.

4. Fluorinated Liquids

These are non inflammable, chemically stable oils used in temperature range of 50-200^0C. They provide efficient heat transfer from the winding and magnetic circuits in comparison to hydrocarbon oils and used in small electric and radio devices, transformers etc. In presence of moisture electrical properties are deteriorated.

5. Synthetic Hydrocarbon oils

Polybutylene, Polypropylene is the example of synthetic hydrocarbon oils. They have similar dielectric strength; thermal stability and susceptibility to oxidation properties are Similar as that of mineral oils. The operating temperature range is 50-110^{0}C. These are used in high pressure gas filled cables and dc voltage capacitors.

6. Organic Esters

These organic fluids are used in the temperature range of 50-110^{0}C. They have dielectric constant and very low dielectric losses. The dielectric constant ranges from 2 to 3.5.

7. Vegetable Oils

It is obtained from seeds of cotton, sunflower, soybean pulp etc**.** These insulating liquids have temperature range of 20-100^{0}C. Drying oils are generally suitable in the formation of insulating varnishes, while non-drying oils are used as plasticizers in insulating resin compositions.

8. Varnish

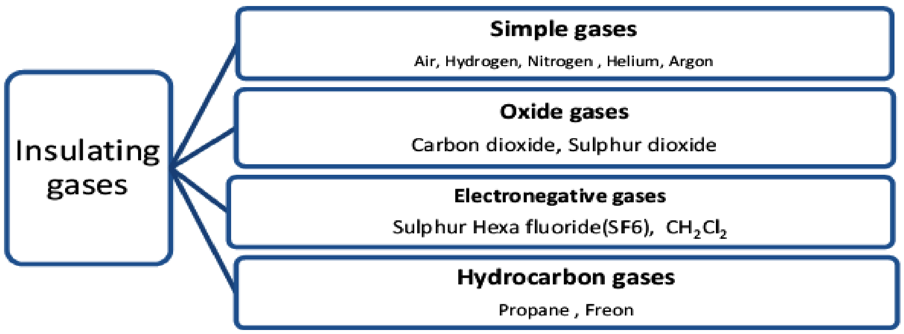
Varnish is a transparent. It is a primarily used in wood finishing. It is combination of drying oil, a resin and a thinner. It is the liquid form of resinous matter in oil or a volatile liquid. Hence by applying, it dries out by evaporation or chemical action to form hard, lustrous coating, which is resistant to air and water.

It is used to improve the insulation properties, mechanical strength and to reduce degradation caused by oxidation and adverse atmospheric condition.

3.5 Gaseous Insulating Materials

Commonly used gaseous materials are

1. Air
2. Nitrogen
3. Hydrogen
4. SF_6



1. Air

- Air is gaseous insulating material and it is naturally available.
- It forms about 80% of earth's atmosphere under normal condition.
- It is colour less
- It is order less
- It is test less
- Its permittivity is 1
- Its dielectric strength is 30kv/cm at 50hz
- Oxygen in air helps a fire
- It is reliable at low voltage
- It can occupies space

Applications:

Air is needed to hear a sound. It carries cloud to different place and beginning a rain, Moving air is used to drive blades of wind mills.

2. Nitrogen

- It is non metal
- it is chemically inert
- it is used in both chemical and electrical purpose
- It s dielectric strength is 3 to 5 kv/mm.

Applications:

It is used in cooling medium in selected gas in insulated transformer; it is used as a fertilizer.

3. Hydrogen

- It is rarely used as a insulator
- At normal temperature and pressure it is colourless, order less and test less
- It reacts with oxygen to form water (H_2O) and hydrogen peroxide(H_2O_2)
- It is commonly used in cooling purpose in electrical machine due to its lightness.
- Its dielectric strength is 2.5 to 4.5 kv/mm

Applications:

It is used in cooling purpose in electrical machine, it is used in fuel and it is used to prepare tungsten filaments.

4. SF_6

- Sulfur Hexafluoride (SF_6) is, colorless, odorless. The electromagnetic gases have high dielectric strength compared to other traditional dielectric gases like nitrogen and air. The dielectric strength of SF_6 is 2.35 times more than air.
- More than 10,000 tons of SF_6 are produced per year, most of which (over 8,000 tons)
- It is a gaseous insulating materials
- It is a colorless
- It is a order less

Applications:

SF_6 is mostly used in high voltage application and its use is most satisfactory in dielectric machines, like X-ray apparatus, Van de Graff generators, voltage stabilizers, high-voltage switch gears, gas lasers etc.

SF_6 bears some special properties as follows:

- SF_6 is colorless, nontoxic and non-inflammable gas. It is the heaviest gas and has low solubility in water. The gas can be liquefied by compression. Its cooling characteristic is better than air and nitrogen.
- Under normal temperature conditions it is chemically inert and completely stable with high dielectric strength.
- This gas has very good electronegative property. Its relatively large molecules have a great affinity for free electrons, with which they combine making the gas-filled break much more resistant to dielectric breakdown.

3.6 General Properties of Insulating Material

The suitability of an insulating material for a specific purpose use can be decided by knowing its different properties. So we have to know the exact requirement of the application and the required property hold by the insulating material. Based on uses in different applications following properties of materials are useful.

3.6.1. Electrical Properties

The insulating material used in electrical or electronics appliances, should be considered for following:

- Insulation resistance
- Dielectric constant or permittivity
- Breakdown voltage or dielectric strength
- Dielectric loss

Insulation Resistance:

This is the ohmic resistance offered by an insulation coating, cover or material in an electric circuit which tends to produce a leakage current through the same with an impressed voltage across it.

Dielectric Constant or Permittivity:

The permittivity of the insulating material varies with temperature and frequency in some cases. The materials like HCl, H_2O, CO, NH_3 have permittivity variation with change in temperature

Dielectric Strength:

It is the maximum impressed voltage bearing capacity of insulator per unit thickness of material, up to which current does not flow through it. When current flows through the insulator is known as dielectric failure.

The dielectric strength of an insulating material decreases with the duration of time the voltage is applied, moisture, contamination, high temperature, heat ageing, mechanical stress etc. and decreases up to 10% of laboratory values.

Dielectric Loss:

Dielectric losses occur in all solid and liquid dielectric due to: a conduction current and hysteresis. The conduction current is due to imperfect insulating qualities of the dielectric and is calculated by the application of Ohm’s law. It is in phase with the voltage and results in the power loss (I^2R) in the material, which is dissipated as heat. Dielectric hysteresis is defined as the lagging of electric flux behind the electric force producing it so that under varying electric forces a dissipation of energy occurs. The energy loss due to above cause is called the dielectric hysteresis loss. The energy is dissipated as heat. This loss gives an indication of the amount of energy absorbed by the material, when subjected to AC fields

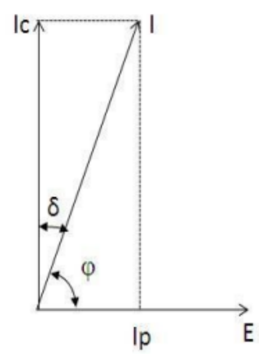


Figure 3.6 Plot of E against I_c

3.6.2 Visual Properties

An insulating material possessing two opposite properties: transparency and thermal insulation is suitable in case of reduction of energy consumption for heating and air conditioning and electrical energy savings. This is known as visual properties. Study of appearance, color and crystalline structure are the measures of this property.

3.6.3 Mechanical Properties

Mechanical properties such as tensile strength, impact strength, toughness, hardness, elongation, flexibility, mechanical strength, abrasion resistance etc. are to be considered for choosing the insulating material.

Mechanical Strength: The insulating material should possess sufficient mechanical strength to respond mechanical stress. Mechanical strength is affected by following factors.

Temperature Rise: It badly affects the mechanical strength of the insulating material.

Humidity: It is the climatic effect which affects also the mechanical strength.

Porosity: An insulating material of high porosity will absorb more moisture and thereby affects the electrical properties as well as mechanical strength.

3.6.4 Thermal Properties

Following thermal properties are considered for selecting insulating material of different applications.

- **Thermal stability:** The insulating material must be stable (no change in physical state) within the allowed temperatures. Certain materials like wax and plastic get soft at moderate temperatures. So the mechanical property of the material is affected. Hence the operating temperature of the material is to be noted before its use.
- **Melting point**: The insulating material should have melting point (temperature bearing capacity without being melt), above that of operating temperature.
- **Flash point**: This is an important property of insulating oils used in transformer. Flash point of a liquid insulator is that temperature at which the liquid begins to ignite.
- **Thermal conductivity:** In electrical appliances heat is generated during operation, which should be transferred to atmosphere, to maintain the operating temperature within the limit. Hence the insulators should have very low thermal conductivity.
- **Thermal expansions:** Rapid and repeated load cycle on electrical appliances cause corresponding expansion and contraction of the insulators. In a result voids are created and affect the breakdown phenomenon. Thus two insulating material of different coefficient of thermal expansion should be wisely selected.
- **Heat Resistance:** The insulating material used must be able to withstand the heat produced due to continuous operation and remain stable during the operation. At the same time it should not damage the other desired properties.

3.6.5 Chemical Properties

Certain chemical properties are also required to be considered for the insulating materials.

- **Chemical Resistance**: It is the ability of the insulating material to fight against corrosion in the presence of gases, water, acids and alkalis. For materials which are subjected to high voltage, high chemical resistance is also necessary.
- **Hygroscopity:** Many insulating materials are hygroscopic. Sometimes the insulation may come in direct contact with water. The porous materials are more hygroscopic than dense ones. Small amount of moisture absorbed by an insulating material affects its electrical properties drastically.
- **Moisture Permeability:** The tendency of an insulating material to pass moisture through them is known as moisture permeability. Moisture can penetrate through very small pores as the size of water molecule is very small. So this property is vital for selecting the protective coating, cable sheaths etc.

3.6.6 Ageing

Ageing is the long term effect of heat, chemical action and voltage application. These factors decide the natural life of insulators and hence of an electrical apparatus.

MODEL QUESTIONS

1. What is PVC?
2. What is Teflon?
3. What is Wood?
4. Write General Properties of Insulating Material?
5. What is Rubber?
6. What is SF_6 gas?
7. What do you mean by Dielectric loss?

4
Chapter

DIELECTRIC MATERIALS

4.1 Introduction

The material which store electrical energy are known as dielectric material ,all dielectric material are essentially insulating material .all dielectric are insulator but all insulators are not dielectric .

The materials which are capable of retarding the flow of electricity or heat through them are known as dielectric or insulators. The safe handling of heat and electricity is almost impossible without use of an insulator. The material when used to prevent the loss of electrical energy and provides a safety in its operation is named as Electrical Insulating Material. The properties which are taken into consideration for an insulator are the operating temperature and breakdown voltage. However when it is used to store electrical charge, it is known as Dielectric Material.

The electrical conductivity of Dielectric material is quite low and the band gap energy is more than 3eV. This is the reason why the current cannot flow through them. The capacity of a capacitor can be increased by inserting with a dielectric material, which was discovered by Michael Faraday.

4.2 Dielectric Parameters

The knowledge of dielectric parameter is highly essential to choose the specific purpose dielectric for use. Those are Dielectric constant, Dipole moment, Polarization and Polari ability.

Dielectric constant:

The proportionality constant in the relation between the electric flux density (D) and the electric field intensity (E) is known as permittivity (ε) or dielectric constant. If the medium to which the electric field is applied is a free space (or vacuum), the proportionality constant of vacuum is ε_0 of value 8.854×10^{-12} farad. Meter.

Dipole Moment:

Two charges (Q+ and Q-) of equal magnitude but of opposite polarity, separated with distance d, constitutes a dipole moment, given as:

$$p = Qd$$

p is the dipole moment in coulomb-meter.

Dipole moment is a vector pointing from the negative charge to the positive charge and its unit is Debye (1 Debye = 3.33×10^{30}coulomb-metre)

Polarization:

The dipole moment per unit volume is called the polarization P.

Polarizability:

The application of an electric field to a dielectric material causes a displacement of electric charges giving rise to the creation or reorientation of the dipoles in the material. The average dipole moment ‘p’ of an elementary particle may be assumed to be proportional to electric field strength E, that acts on the particle so that; The proportionality factor α is called polarizability, measures the average dipole moment per unit field strength. The unit of the polarizability is farad.meter^2.

4.3 Mechanism of Polarization

The centre of gravity of positive charges and negative charges coincide in neutral atoms and symmetric molecules. When an electric field is applied to it, causes relative displacement of charges, leading to the creation of dipoles and hence polarization takes place. Un-symmetric arrangement of atom in a molecule results in a dipole even in the absence of an external field and in those cases the applied electric field tends to orient the dipole moments parallel to the field direction. The mechanism for forming the dipoles are categorized as

1. Electronic or Induced polarization,
2. Ionic polarization,
3. Orientation polarization,
4. Interfacial or Space charge Polarization.

4.4 Dielectric Loss

The dielectric material separating the two electrodes or conductors is stressed when subject to a potential. When the potential is reversed, the stress also reversed. This change of stress involves molecularly arrangement within the dielectric. This involves the energy loss with each reversal. This is because the molecules have to overcome a certain amount of internal friction in the process of alignment. The energy expanded in the process is released as heat in the dielectric. The loss appearing in the form of heat due to reversal of electric stresses, compelling molecular arrangement is known as dielectric loss.

When a dielectric material is subjected to an ac voltage, the leakage current I does not lead the applied voltage E by exactly 90^0As shown in vector diagram the

Phase angle φ is always less than 90^0. The dielectric loss can be calculated as Follows: Figure 4.1 plot of E against I_c

$$P = E\ I\ \cos\phi$$

$$\therefore P = E\frac{I_c}{\cos\delta}.\cos 90^0 - \delta = E\frac{I_c}{\cos\delta}.\sin\delta = E\,I_c\tan\delta = E.\frac{E}{X_c}\tan\delta$$

Where $\phi = 90^0 - \delta$ and $I = \dfrac{I_c}{\cos\delta}$

Hence $P = E^2\,2\pi fc.\tan\delta$

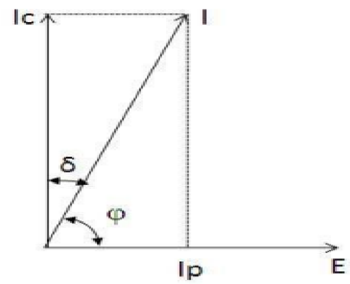


Figure 4.1 Plot of E against I_c

δ is the complement angle to φ and is called dielectric loss angle. tanδ is the measure of dielectric loss known as dissipation factor.

4.5 Factors Affecting Dielectric Loss

As observed from the equation of dielectric loss, the loss depends on the frequency and square of applied voltage. Dielectric loss increases with the presence of humidity and temperature rise**.**

4.6 Electrical conductivity of Dielectric and their Breakdown

The dielectric material is used in electrical and electronic circuits as insulators and as a medium in capacitors. When the applied electric field is increased, the potential difference across it also increases. A limit is reached when the dielectric ceases to work as an insulator and a spark occurs. This limiting value of the voltage is known as Breakdown Voltage, which measures the strength of dielectric.

4.7 Conduction of Gaseous Dielectric

Air is the common gaseous dielectric. Cosmic rays and Ultraviolet rays cause the natural ionization in air. Since the opposite charges are equal, natural recombination takes place continuously to check further ionization of whole air. The free charges do not go for recombination if the medium is within an Electric field. Due to application of the electric field, free charges move to their respective potential plates, causing a flow of current known as leakage current. The magnitude of current is dependent upon the applied voltage. With the increase in voltage the directed flow of electrons and ions increases as compared to random motion in low voltage. If the applied voltage is further increased, the energy of free charges becomes sufficient to force out electrons even from neutral atom. Each free electron moves at a great velocity, collides with other neutral atoms and knocks out free electron out of them. This process increases in geometric progression. The leakage current increases sharply in result to cause the breakdown of dielectric. The corresponding voltage is known as Breakdown voltage**.**

4.8 Conduction of Liquid Dielectric

The liquid dielectric along with impurities of solid particle has more ability to conduct. The impurities get electrically charged and act as a current carrier. The fibrous impurities make the alignment of ions in a straight path for which the conductivity in liquid gets faster. In an uncontaminated liquid dielectric, such ion bridge cannot be formed. The breakdown of an uncontaminated liquid dielectric takes place due to the ionization of gases present in the liquid. The applied voltage ionizes the gas in liquid and the electric field intensity increases. It causes further ionization and ultimately the breakdown of dielectric takes place.

4.9 Conduction of Solid Dielectric

Electrical conductivity of solid dielectrics may be electronic, ionic or both. In electronics current flow the flow of current is due to the movement of electrons towards the positive electrodes, while ionic current flow is due to the movement of positively charged ions towards the negative electrode. The impurities also play the role of conductivity in the dielectric. At low temperatures, the conductivity of solid dielectric is due to the impurities only. At higher temperature the leakage current depends upon the contribution of free ions of the base dielectric. Breakdown of solid dielectrics may be electro-thermal or electrical. The heat produced due to dielectric loss causes electro thermal breakdown and in effect destruction of dielectric takes place. If the dielectric is not able to radiate away the generated heat caused by dielectric loss and the applied voltage is retained for a long period the material gets melted. The electrodes get short circuited. Solid dielectric is not recoverable after its break down like liquid or gaseous dielectrics.

Table 4.1 some of the dielectric material and their relative permittivity

Sl.no	Dielectric material	Relative permittivity
1	Air	1.o
2	Bakelite	5 to 6
3	Glass	5 to 8
4	Mica	3 to 8
5	Paper	2 to 2.5
6	Porcelain	4 to 7
7	Transformer oil	2.0

4.10 Application of dielectric

The most common application of dielectric is as a capacitor to store energy.

Capacitor are classified according to the dielectric used in there manufacturer they can be broadly classified as following categories

a) Capacitor using vacuum as dielectric

b) Capacitor using mineral oil as dielectric

c) Capacitor using combination solid-liquid dielectric

d) Capacitor with only solid dielectric

MODEL QUESTIONS	
1.	What do you mean by dipole moment?

5

Chapter

MAGNETIC MATERIALS

5.1 Introduction

The material which can be magnetized and are attracted by magnet is called as a magnetic material .magnetic material have two magnetic poles named as a south pole and north pole .like poles are repel with each other and unlike poles are attracted with each other. Magnetic pole always in pair. There is no isolated single pole .if bar magnet is broken in to two parts .two new poles is formed.

Materials in which a state of magnetization can be induced are called magnetic materials when magnetized such materials create a magnetic field in the surrounding space. The property of a material by virtue of which it allows itself to be magnetized is called permeability. Magnets are two types' natural magnets and artificial magnets .natural magnets are come from mines which are comparatively weak. Artificial magnets are made from iron, nickel, cobalt, steel or alloy material.

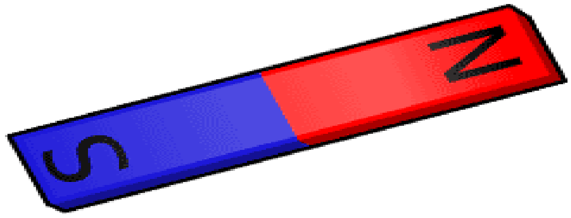


Figure 5.1 Shows the Bar Magnet

5.2 Terms are related to Magnetic Circuit

Magnetic flux:

The total no of lines of force in a magnetic field is known as magnetic flux. Its unit is webers.

B = Flux / area

B - Flux density

1 Weber $=10^8$ lines

Magnetic flux density:

μ = B / H

B - Flux density

H - Magnetizing force

B α H

μ = B / H

Permeability:

Permeability is a material property that describes the ease with which a magnetic flux is established in the component. It is the ratio of the magnetic flux density to the magnetic intensity and, therefore, represented by the following equation:

$$\mu = \frac{B}{H}$$

It is clear that this equation describes the slope of the curve at any point on the hysteresis loop. The permeability value given in papers and reference materials is usually the maximum permeability or the maximum relative permeability. The maximum permeability is the point where the slope of the B/H curve for un magnetized material is the greatest. This point is often taken as the point where a straight line from the origin is tangent to the B/H curve.

The relative permeability μ_r is arrived at by taking the ratio of the material's permeability μ to the permeability in free space (air) μ_o.

5.3 Classification of Magnetic Materials

Magnetic materials classified as:

1. Diamagnetic Material:

- The materials which are repelled by a magnet are known as diamagnetic materials.
- Examples of diamagnetic materials are Zinc, Mercury, lead, Sulphur, Copper, and Silver.
- Their permeability is slightly less than one.
- They are slightly magnetized when placed in a strong magnetic field and act in the direction opposite to that of applied magnetic field.
- They are repelled by magnet
- They do not retain the magnetic properties when external field is removed.

2. Paramagnetic Materials:

- The materials which are not strongly attracted by a magnet are known as paramagnetic materials.
- Examples of paramagnetic materials are Aluminum, Tin, Platinum, Magnesium, Manganese, etc.
- Their relative permeability's is small but positive.
- Such materials are slightly magnetized when placed in a strong magnetic field.
- They do not retain the magnetic properties when external field is removed.
- They are weakly attracted by magnet.

3. Ferro-Magnetic Materials

- The materials which are strongly attracted by a magnet are known as ferro-magnetic materials.
- Their permeability is very high.
- Examples of ferro-magnetic material. Iron, Nickel, Cobalt, etc.

5.4 Magnetization Curve

The curve drawn giving relationship between induction density "B" and magnetizing force "H" is known as magnetization curve or B ~ H curve.

This figure shows the general shape of B ~ H curve of magnetic material. In general it has four distinct regions oa, ab, bc and the regions beyond c. During the region oa the increase in flux density is very small, in region ab the flux density B increases almost linearly with the magnetizing force H, in region bc the increase in flux density is again small and in region beyond point c, the flux density "B" is almost constant. The flat part of the magnetization curve corresponds to magnetic saturation of the material

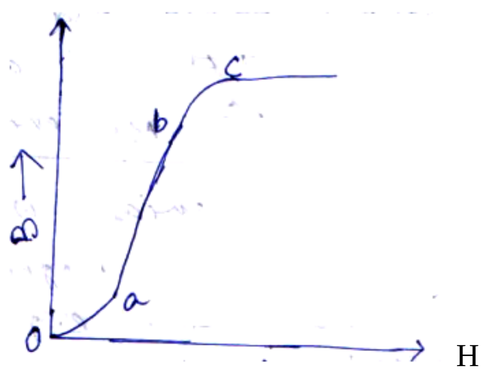


Figure 5.2 Magnetization curve

5.5 The Hysteresis Loop and Magnetic Properties

A great deal of information can be learned about the magnetic properties of a material by studying its **hysteresis** loop. A hysteresis loop shows the relationship between the induced magnetic flux density **B** and the magnetizing force **H.** It is often referred to as the B-H loop. An example hysteresis loop is shown below.

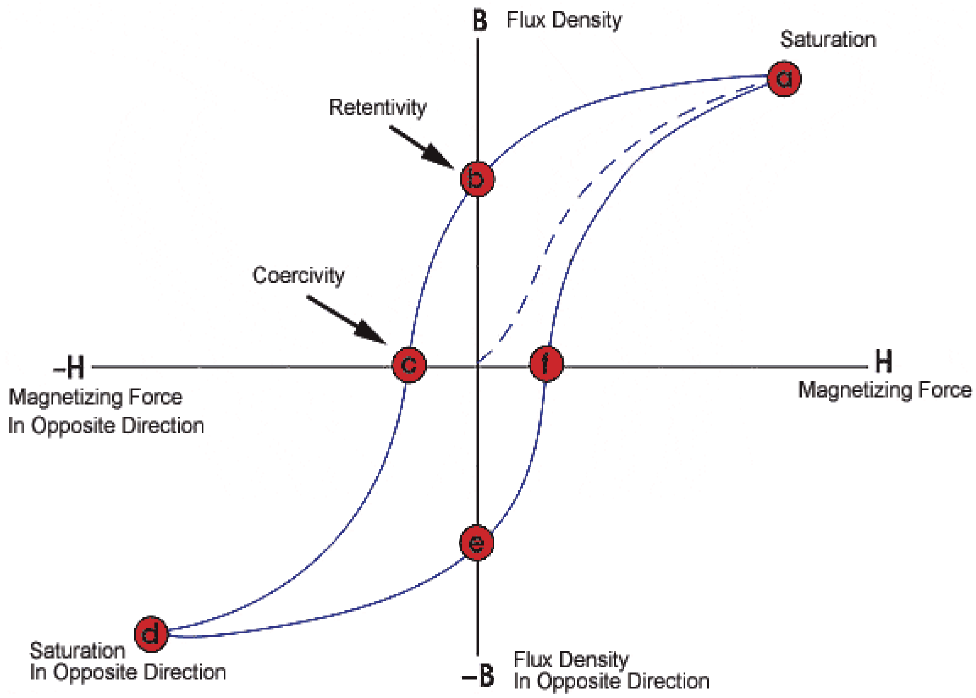


Figure 5.3 Hysteresis Loop

The loop is generated by measuring the magnetic flux **B** of a ferromagnetic material while the magnetizing force **H** is changed. A ferromagnetic material that has never been previously magnetized or has been thoroughly demagnetized will follow the dashed line as **H** is increased. As the line demonstrates, the greater the amount of current applied **(H+)**, the stronger the magnetic field in the component **(B+)**. At point "a" almost all of the magnetic domains are aligned and an additional increase in the magnetizing force will produce very little increase in magnetic flux. The material has reached the point of **magnetic saturation**. When **H** is reduced back down to zero, the curve will move from point "a" to point "b." At this point, it can be seen that some magnetic flux density remains in the material even though the magnetizing force is zero. This is referred to as the point of **retentivity** on the graph and indicates the level of residual magnetism in the material. Some of the magnetic domains remain aligned but some have lost their alignment. As the magnetizing force is reversed, the curve moves to point "c", where the magnetic flux density has been reduced to zero. This is called the point of **coercivity** on the curve. The reversed magnetizing force has flipped enough of the domains so that the net magnetic flux density within the material is zero. The H-field required to remove the residual magnetism from the material, is called the **coercive force** or **coercivity** of the material.

As the magnetizing force is increased in the negative direction, the material will again become magnetically saturated but in the opposite direction (point "d"). Reducing **H** to zero brings the curve to point "e." It will have a level of residual magnetism equal to that achieved in the other direction. Increasing **H** back in the positive direction will return **B** to zero. Notice that the curve did not return to the origin of the graph because some H-field is required to remove the residual magnetism. The curve will take a different path from point "f" back the saturation point where it with complete the loop.

5.6 Magnetizations or B-H Curve

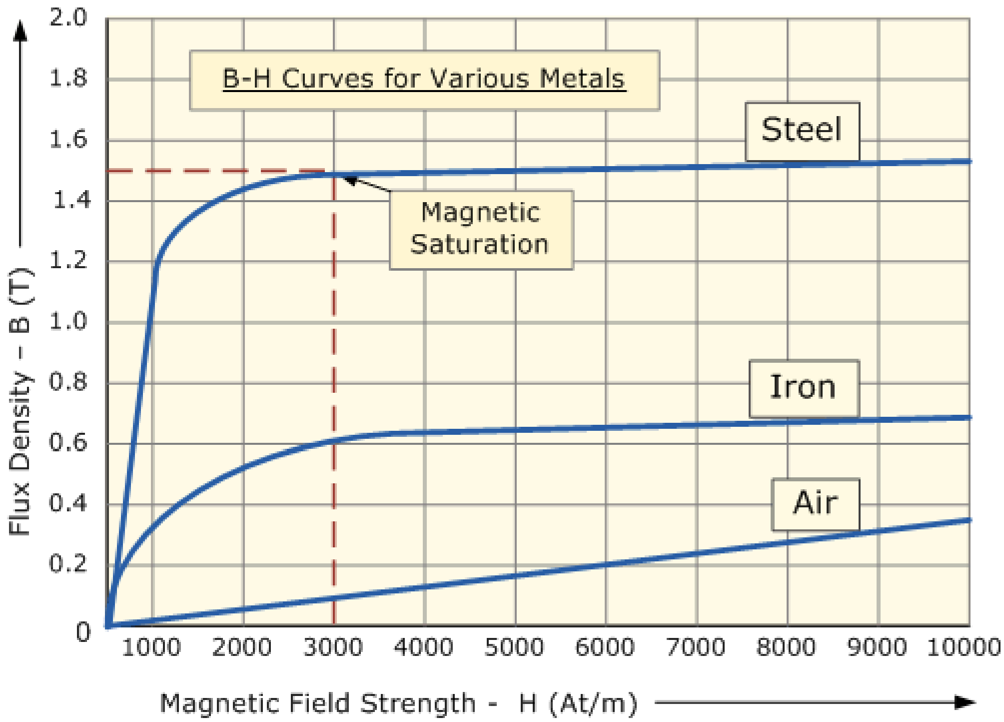
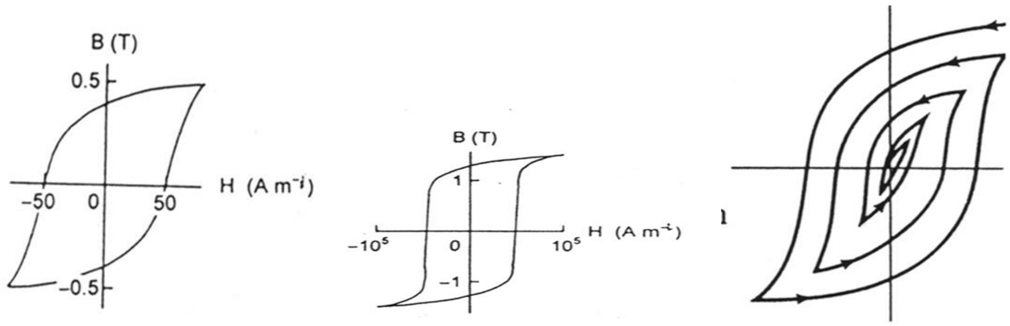


Figure 5.4 B-H Curves

Ferromagnetic materials also show a "**hysteresis" effect**, where decreasing the applied magnetic field, or *H*, doesn't produce the reverse effect of increasing the field.

The shape of the hysteresis loop tells a great deal about the material being magnetized. The hysteresis curves of two different materials are shown in the graphs below. "Hard" magnetic materials: H_c (coercivity) is high; area of the loop is large, used for permanent magnets. "Soft" magnetic materials: H_c is small; area of loop is small, used for transformer cores & electromagnets.



(a) **(b)**

Figure 5.5 (a) Soft magnetic material **Figure 5.5(b) Hard magnetic material**

Material can be demagnetized by striking or heating it, or go round the hysteresis loop, gradually reducing its size. *"Degaussing"*

5.7 Soft Magnetic Materials

Materials which retain their magnetism and are difficult to demagnetize are called hard magnetic materials. These materials retain their magnetism even after the removal of the applied magnetic field. Soft magnetic materials are easy to magnetize and demagnetize. These materials are used for making temporary magnets. Materials that can be magnetized, which are also the ones that are strongly attracted to a magnet, are called **ferromagnetic.** These include iron, nickel, cobalt, some alloys of rare-earth metals, and some naturally occurring minerals. **Hard** magnets, also referred to as permanent magnets, are **magnetic materials** that retain their magnetism after being magnetized such as lodestone.

Soft magnetic materials are used for the construction of cores for electric machines, transformers, electromagnets, reactors, relays. In order to keeps the magnetizing current and iron losses low using a low flux density.

Pure Iron:

Pure iron is a ferrous material with extra-low carbon content. Examples Low-carbon steel, electrolytic iron. The resistivity of pure iron is very low by virtue of which it gives rise to large eddy current losses when operated at high flux densities in alternating magnetic fields. Pure iron is used in many kinds of electrical apparatus and instruments as magnetic material core for electromagnets, components for relay electrical instruments.

Iron Silicon Alloys:

The chief alloying constituent is silicon which is added to iron in amounts from about 0.5 to 5% by weight. Iron-Silicon alloy usually known as Silicon steel. Silicon steel generally used in transformers, electrical rotating machines, reactors, electro magnets and relays. Silicon sharply increases the electrical resistivity of iron thus decreasing the iron losses due to eddy currents. It increases the permeability at low and moderate flux densities but decreases it at high densities. Addition of silicon to iron reduces the hysteresis loss. The magnetostriction effect is reduced. Addition of silicon is valuable because it facilitates the steel making process. Alloying of low carbon steel with silicon increases the tensile strength; it reduces ductivity making steel brittle. This makes silicon alloyed steel difficult to punch and shear.

Grain Oriented Sheet Steel:

As the ferromagnetic materials have a crystal structure. So every crystal of ferromagnetic substance has a particular direction along which it offers high permeability. So it most easily magnetized. Such axes along which the crystals have high permeability and are move easily magnetized are called as easy or soft direction. Along any axis other than the easy direction, the crystal has low permeability and is therefore more difficult to magnetize. Such axes along which the crystal has low permeability are called as hard direction. For easy magnetization the crystal directions of electrical sheet should be so oriented that their axes are parallel to the direction in which the external magnetic field is applied. This is achieved in practice by carefully controlling the rolling and annealing of silicon iron sheets. The direction of easy magnetization then lies in the direction in which the steel is rolled in the mill. Sheet steel which has been rolled such as to give easy direction to all its crystals is called „textured" or grain oriented steel.

Magnetic Anisotropy:

The directional dependence of magnetic property under heading grain oriented sheet steel is known as magnetic anisotropy. It is clear that in bulk magnet a great improvement will result if the individual preferred axes are aligned parallel and along the axis of magnetization.

Annealing:

The magnetic properties of Ferro-magnetic materials are affected by strain due to mechanical working like punching, milling, grinding, machineries, etc. The magnetic properties including the correct crystal direction by heat treatment. Since mechanical stressing disturbs the crystal orientation, it is essential to perform that treatment once again after all mechanical operations have been completed.

Soft Ferrites:

Ceramic magnet called as ferro magnetic ceramic and ferrites. Ceramic magnet is made of an iron oxide, Fe_2O_3 with one or more divalent oxides such as NiO, MnO or ZnO. These magnets have a square hysteresis loop and high resistance to demagnetization. The great advantages of ferrites are their high resistivity. Their resistivity's are as 109 Ohm-cm. Ferrites are carefully made by mixing power oxides compacting and sintering at high temperatures. High frequency transformers in television and frequency modulated receivers are almost always made with ferrite core.

5.8 Hard Magnetic Materials

Hard magnets, also referred to as permanent magnets, are magnetic materials that retain their magnetism after being magnetized.

Hard-magnetic materials are used for making permanent magnets. The properties of material required of making permanent magnets are high saturation values, high coercive force and high residual magnetism.

The hard-magnetic materials are carbon steel, tungsten steel, cobalt steel, alnico, hard ferrites.

Carbon Steel, Tungsten Steel, Cobalt Steel:

As the soft-magnetic materials have narrow hysteresis loops, so when carbon is added in a material its hysteresis loop area is increased. Although it is cheap, magnets are made from carbon steel loss their magnetic properties very fast under influence of knocks and vibrations. When materials like tungsten, chromium or cobalt are added to carbon steel, its magnetic properties are improved.

Alnico:

It is known as Aluminum-nickel-iron-cobalt. Alnico is commercially the most important of the hard magnetic materials. Large magnets are made by special casting techniques and small one by powder metallurgy. As cobalt steel is cheaper so far these reason permanent magnets are most commonly made of Alnico.

Hard Ferrites:

Hard magnetic ferrites like BaO $(Fe_2O_3)_6$ are used for the manufacture of light weight permanent magnets due to their low specific weight

MODEL QUESTIONS
1. What is hard ferrite? 2. What is Paramagnetic material? 3. What is diamagnetic material?

6

Chapter

MATERIALS FOR SPECIAL PURPOSES

6.1 Introduction

Some materials used for special purposes such as fuses, solder, bimetal, storage battery plates.

Those materials used for special purposes are in structural materials or protective materials. In electrical engineering special purpose of material is

1. **Structural Material**
2. **Protective Material**
3. **Thermocouple Material**
4. **Bi Metal**
5. **Soldering Material**
6. **Fusing Material**

6.1.1 Structural Materials

Cast iron, steel, timber, reinforced concrete are common materials for this purpose. Cast iron is used as materials for the frames of small and medium sized electrical machines. Steel is used in fabricated frames in large electrical machine, tanks in transformers, fabrication of transmission towers. Timber and reinforced concrete are used for poles in OH lines.

6.1.2 Protective Materials

Lead: Lead is soft, heavy and bluish grey metal. It is highly resistant to much chemical action, but it can corrode by nitric acid, acetic acid, line and rotten organic substance. The electrical conductivity is 7.8% of copper. Lead is used in storage batteries and sheathing of cables. Pure lead cable sheathing is liable to fail in service due to formation of cracks formed because of vibration. Lead alloys with tin and zinc and forms alloys which are used for solders and bearing metals.

Steel Tapes, Wires and Strips: Steel tapes, wires and strips are used as protective materials for mining cables, underground cable, and weather proof cables.

6.1.3 Thermocouple Materials

- Thermo couple material are used for measurement of temperature depending on the range of temperature to be measured
- Proper material are to be selected for thermo couple thermo couple is a device used extensively for measuring temperature a thermo couple consist of two metal join together to from two junction 1)cold junction 2)hot junction
- When two wires of different metals are joined together an EMF exists across the junction. This EMF is directly proportional to the temperature of the junction.
- When one tries to measure this EMF more junctions are to be made which will give rise to EMFs. When all the junctions are at the same temperature, the resultant EMF will not be zero. This resultant EMF is proportional to the temperature difference of the junctions and is known as thermoelectric EMF.
- Thermo couples are made of different materials such that copper / constantan, iron / constantan, platinum / platinum rhodium. Thermo couples can be used for the measurement of temperature.

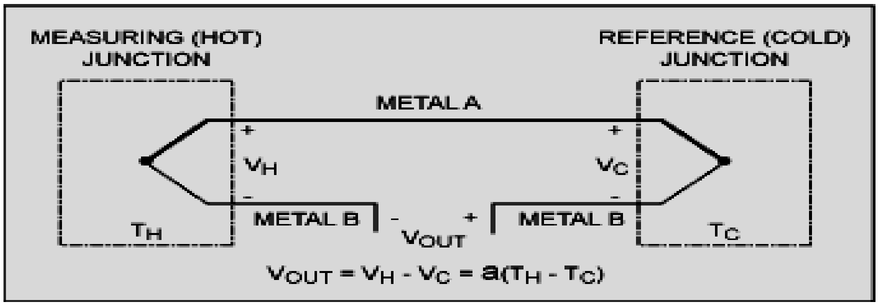


Figure 6.1 the loop voltage generated by the temperature difference between two junction

6.1.4 Bimetals

- Bimetals is based on the theory that expands on heating and contract on cooling. It works on the principle of heating effect of electric current .the bi metal heated directly or indirectly ‘a bimetal is made of two metallic strips. Bimetallic strips are used in electrical apparatus and device as relay and regulator for example in order to maintain a constant temperature in a heater a simple bimetallic regulator may be used bimetal relay can be used for over load protection of electrical motor or any electric circuit .if the current exceeds certain value ,the strip will heated enough to bend and break the circuit so in order to maintain constant temperature in electric heater, oven, furnace etc simple bimetallic regulator is used many bimetallic device are adjustable for a particular current.
- A bimetal is made of two metallic strips of unlike metal alloys with different coefficient of thermal expansion. At a certain temperature the strip will bend and actuate a switch or a lever of a switch. The bimetal can be heated directly or indirectly. When heated the element bends so that the metal with the greater coefficient of expansion is on the outside they are formed while that with smaller coefficient is on the inside. Bimetallic strips are used in electrical apparatus and such as relays and regulators.

6.1.5 Soldering Materials

- Solder is an alloy of two pieces of metals of low melting point which is used to join two or more pieces of metals. The process of joining the pieces of metal is known as soldering
- A piece of solder wire is placed over the joint and heated with proper temperature
- It is necessary to heat the joint up to a proper temperature .if it is not properly heated, proper soldering cannot be done and if joint is over heated the metal is weakened.
- Solder in electrical purpose divided in to two types soft solder and hard solder
- An alloy of two or more metals of low melting point used for base metals is known as soldering. The alloy used for joining the metals is known as solder. The solder is composed of 50% lead and 50% tin. For proper soldering flux is to be used. In soldering process the application of flux serves to removes oxides from the surface to be soldered. They deoxidize the metals at the time the soldering element is added. Solders are two types such as soft solders and hard solders soft solders are composed of lead and tin in various proportions. Hard solders may be any solder with a melting point above that of lead tin solders.

Soft Solder

- Soft solders are composed of lead and tin
- It's melting point is lower than 4000c
- These are used for soldering copper, bronze, brass and other such metals .these are used in electronic devices

Hard Solder

- Hard solder is an alloy of copper and zinc
- It's melting point is higher than 4000c
- These are used for soldering iron ,gold, steel, silver etc
- These are used for making permanent connection

Figure 6.2 soldering irons with solder wire and flux stock

6.1.6 Fusing Material

A fuse is a protective device, which consists of a thin wire or strip. This wire is placed with the circuit which heave to protect, so that the circuit. Current flows through it. When this current is too high the temperature of the wire or strip will increase till the wire or strip melts. So breaking the circuit and interrupting the power supply.

A fuse is a safety device consisting of a strip of wire that melts and breaks an Electric circuit if the current exceeds the safe value.

Characteristics of a fuse are:-It should have low melting point.,It should have high conductivity (or low resistivity),It should be economical, It does not get oxidized and is oxide is unstable, The conductivity of silver is not deteriorated with oxidation, High conductivity.

Fuse elements materials:-The materials commonly used for fuse elements are tin, lead, silver, copper, zinc, aluminium, and alloys of lead and tin. An alloy of lead and tin (lead 37% and tin 63%) is used for fuses with a current rating below 15 A For current exceeding 15A copper wire fuses are employed. The present trend is to use silver as fuse element material despite its higher cost owing to the following advantages:

1. Low Voltage Fuses

Semi-Enclosed Rewire Able Fuses

It is also called as Kit-Kat fuse. It mainly consists of two parts:

a) Base

b) Carrier Base is made of porcelain which holds the wires.

The fuse element is located inside the carrier that is also made of porcelain. Fuse carrier can be remove without a risk of electrical shock. When there is a fault, the fuse element is blown out and the circuit is interrupted. The fuse carrier is then taken out and the blown out wire is replaced with new one and re-inserted to base to restore supply.

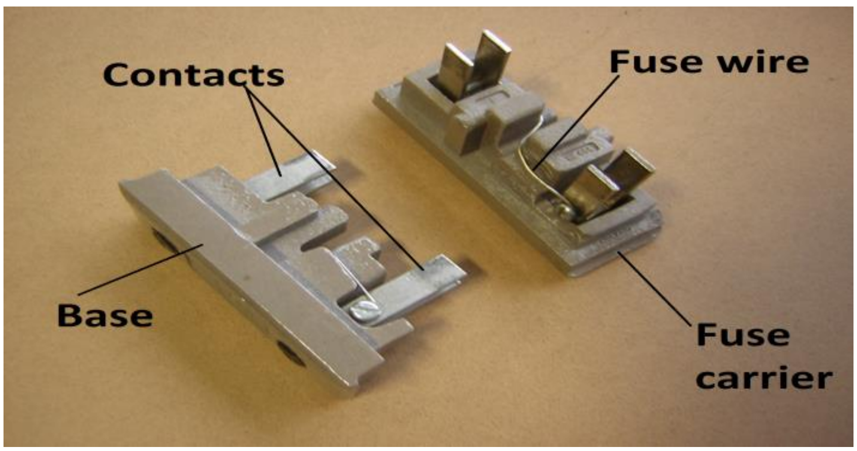


Figure 6.3 Semi-enclosed rewire able fuses

2. High Voltage Fuses

Cartridge Type

This type of fuses is similar in general construction to low voltage cartridge type except some special design features. There are two fuse elements are incorporated in parallel:

a) Low resistance wire (silver wire)

b) High resistance wire (tungsten wire)

When a fault occurs, the low resistance element is blown out and high resistance element reduces the short circuit current and finally breaks the circuit. These type of fuses are used up to 33kV with breaking capacity of about 8700A at that voltage.

Figure 6.4 Cartridge Fuse

6.2 Dehydrating Material – Silica Gel

It is in organic chemical, colloidal highly absorbent silica used as a de-humidifying and dehydrating agent as a catalyst carrier. Calcium chloride and silica gel are used in dehydrating breathers to remove moisture from the air entering a transformer as it breathes. Now silica gel is used for breather of a transformer. Its main advantage is that when it becomes saturated with moisture it does not restrict breathing. Silica gel when dry is blue in colour and the colour changes to pale pink as it becomes saturated with moisture.