SCY 1102 CHEMISTRY OF ELECTRONIC MATERISALS

UNIT 4 INSULATING MATERIALS

Electrical Insulating Materials: Introduction - Requirements. Classification based on substances: Gaseous, liquid and solid insulating materials. Preparation, properties and applications of SF6, Epoxy resin, ceramic products: white wares and glass - Transformer oil. Electrical resistivity: Factors influencing electrical resistivity of materials - Composition, properties and applications of high resistivity materials: Manganin - Constantan - Molybdenum disilcide - Nichrome.

ELECTRICAL INSULATING MATERIALS (DIELECTRICS)

Introduction

A dielectric material is a substance that is a poor conductor of electricity, but an efficient supporter of electrostatic field. If the flow of current between opposite electric charge poles is kept to a minimum while the electrostatic lines of flux are not impeded or interrupted, an electrostatic field can store energy. This property is useful in capacitors, especially at radio frequencies. Dielectric materials are also used in the construction of radio-frequency transmission lines.

When the main function is that of insulations, the materials are called insulators; when the main function is that of charge storage, they are called dielectrics.

CHARACTERISTICS OF DIELECTRICS

A. Resistivity

Electrical resistivity is a measure of how strongly a material opposes the flow of electric current. Resistivity is the electrical resistance of a conductor of unit cross-sectional area and unit length. A characteristic property of each material, resistivity is useful in comparing various materials on the basis of their ability to conduct electric currents. High resistivity designates poor conductors. Good insulators, or dielectrics, have high resistivities and low conductivities. Electrical resistivity is represented by the Greek letter (rho).

B. Dielectric Polarization

Dielectrics are non-conducting substances. They do not have charge carriers or free electrons. If an external field is applied, it turns out that charges are induced on the surface which in turn produces a field and opposes the external field. The opposing field does not exactly cancel the external field but only reduces it.

To understand this concept, one has to look into the charge distribution of a dielectric in its molecular level. The molecules of a dielectric are classified as polar or non-polar.

The “Polar molecules” is one in which the centre of gravity of protons (positive charges) and electrons (negative charges) do not coincide. They have an asymmetrical distribution of charge and have permanent dipole moments in the range of 10^{-30} cm. Examples: H_2O, CO_2, NO_2 etc. In the absence of an external electric field, the electric dipole moment of molecules is in random direction and cancels with each other and the average electric dipole moment per unit volume of a dielectric is zero. In the presence of an external electric field, the molecules align in the direction of the electric field, and is complete when working at a low temperature and stronger electric field.

The “Non-polar” is that molecule in which the centre of gravity of protons (positive charges) and electrons (negative charges) coincide. In normal state, they have no dipole moment. Example: O_2, N_2, H_2 etc. When an external electric field is applied, the protons as a whole are pulled in the direction of the electric field, while electrons are pulled in the opposite direction. The separation of charges continues till the external electric fields are balanced by the internal forces. This creates two new centre of charge, the molecule is said to be polarised and is known as induced electric dipole. The dipole moment so acquired is known as induced electric dipole moment.
The induced dipole moment is proportional to the applied field and is almost independent of the temperature. The direction of induced dipole moment is parallel to the direction of electric field. Polarisation is the alignment of the dipole moments of the permanent or induced dipoles in the direction of the applied electric field.

C. Dielectric constant

Dielectric constant, a property of an electrical insulating material (a dielectric) is equal to the ratio of the capacitance of a capacitor filled with the given material to the capacitance of an identical capacitor in a vacuum without the dielectric material. If C is the value of the capacitance of a capacitor filled with a given dielectric and C_0 is the capacitance of an identical capacitor in a vacuum, then the dielectric constant, symbolized by the Greek letter kappa, κ, is simply expressed as

$$\kappa = C/C_0.$$

This gives the capacity of a material to store electric charge in the presence of an applied electric field. A good electrical insulator should have a low dielectric constant.

D. Dielectric strength

Dielectric Strength is a measure of the electrical strength of a material as an insulator. Dielectric strength is the maximum electric field strength that it can withstand intrinsically without breaking down, i.e., without experiencing failure of its insulating properties. Dielectric strength is defined as the maximum voltage required to produce a dielectric breakdown through the material and is expressed as Volts per unit thickness. The higher the dielectric strength of a material the better its quality as an insulator.

Factors affecting dielectric strength

- It increases with the increase in thickness of the specimen.
- It decreases with the increase in operating temperature.
- It decreases with the increase in frequency.
- It decreases with the increase in humidity.

E. Dielectric losses

Dielectric loss is the loss of energy that goes into heating a dielectric material in a varying electric field. These are caused by internal dipole friction called absorption of electrical energy and by leakage of current through the medium. A good insulating material should have minimum dielectric loss.

F. Heat and temperature resistances

Some insulators are used at elevated temperatures. Insulators must resist the heat as well as temperature.

G. Thermal ageing

Due to continued working at elevated temperatures, certain insulators become weak particularly in contact with oxygen or air of the surroundings. A good insulator should have least thermal ageing.

H. Thermal expansion and aontraction

An ideal insulating material should have minimum thermal expansion and contraction as they lead to gaps in the insulator.

I. Porosity

Porosity of a dielectric material affects the properties because porosity increases the moisture holding capacity.

CLASSIFICATION BASED ON SUBSTANCES: GASEOUS, LIQUID AND SOLID INSULATING MATERIALS.

They are classified into solids, liquid and gaseous insulating materials depending on their physical state.

GASEOUS INSULATORS

A. Air

Air is a good insulator, both of heat and electricity. It is a good insulator of electricity as it does not contain any delocalised electrons, which carry electrical charge. The dielectric strength of air is small. Pressure has considerable effect on the dielectric strength of air. With the increase of pressure, dielectric strength of air increases. Oxygen of air causes oxidation which reduces the life of an electrical equipment.

B. Nitrogen

Nitrogen is used as a dielectric where chemical resistance is of importance (transformers) in place of air which causes oxidation. Nitrogen under high pressure is used as dielectric in certain types of electrical capacitors. Nitrogen under pressure in conjunction with oil treated paper is used in gas pressure cables.

C. Sulphur hexafluoride

Sulphur hexafluoride (SF_6) is a nonflammable, nontoxic electron-attracting gas with a breakdown voltage at atmospheric pressure more than twice that of air. It possesses cooling characteristics far better than air and nitrogen. It is chemically stable and does not decompose even when heated up to 800^{o}C. Because of these properties it is used in electrical devices like capacitors, cables etc.

LIQUID INSULATORS

A. Mineral oils

The electrical properties and resistance to thermal oxidation of mineral oils are due to the presence of non – hydrocarbon compounds, oxygen, sulphur, nitrogen etc. Highly purified oils have a dielectric strength as high as 180kV/mm. Mineral oils find extensive applications as insulating oils in cables, capacitors, transformers, switch gears etc.

B. Askarels

Askarels are synthetic insulating liquids which are non – inflammable and under the influence of dielectric arc does not decompose to form inflammable gases. Chlorinated hydrocarbons are the most widely used askarels. They possess excellent arc resistant, high dielectric strength, dielectric constant of the order of 4 to 6, tolerable dielectric loss at normal temperature and power frequencies and adequate thermal, chemical and electrical stability. They are used as transformer fluids. Example for an askarel is polychlorinated biphenyl. They are widely used as dielectric and coolant fluids, for example in transformers, capacitors, and electric motors.

C. Silicone Fluids

They are clear water like white liquids with an oil consistency and are available with a wide range of viscosity. Silicone liquids are highly stable at high temperatures. They possess relatively flat viscosity temperature characteristics. They are non-corrosive to metals up to $200^{0}C$. Due to the good dielectric properties over a wide range of temperature and frequency, they are used as coolants for radar pulse, air crafts and radio transformers. Silicone oils can break down to give considerable quantities of gases and the residue consists of silicon dioxide, silicon carbide and carbon. Hence, silicone oils are not recommended as switch gear oils.

D. Fluorinated Fluids

They have very high chemical stability, are non-inflammable and their vapours are non-explosive. They are used in small size electric and radio devices, electronic transformers etc. However, fluorinated liquids are degraded in their electrical properties under the influence of moisture. Moreover, they possess high volatility.

E. Vegetable Oils

They are the oldest insulating liquids used. The drying oils (linseed) and non-drying oils (caster, palm, coconut, olive) are important from dielectric point of view. Drying oils are used in the form of insulating varnishes, which are used in the treatment of transformers and motor coils etc. Non-drying oils are used as plasticizers in insulating resin compositions which are applied as insulating materials and coating compositions in electrical equipments.

SOLID INSULATORS

Most of the non-metals and compounds like mica, polymers, silk, paper, asbestos etc fall under this category. These are capable of retaining their insulating properties up to a fixed temperature called limiting temperature.

A. Cellulose Materials

Paper and cardboard made from alkaline wood cellulose are mechanically stronger and have heat resistance. Cellulose has a stronger affinity for water. Since moisture content has a very strong effect on the physical as well as electrical properties of paper, for best insulating applications, paper should have minimum moisture content. Hence, paper is dried and then impregnated with mineral oil chlorinated diphenyls and vegetable oils. Such impregnated paper possesses a dielectric strength of the order of 300 kv/mm.

When paper is treated with a solution of $ZnCl_2$ and then pressed to obtain thickness varying from 1.5 to 25 mm, it is known as vulcanized fiber sheet or board. This material has high mechanical strength and can be made less hydroscopic by impregnating with diphenyls and vegetable oils.

Papers and press boards are used for windings and cable coil insulation, backing for conductor insulation, primary dielectrics in capacitors, windings and mica insulation, transformer insulation etc.

Low density paper (0.7 to 0.8 glcm3) is preferred in high frequency capacitors and cables as the Low density paper (0.7 to 0.8 glcm3) is preferred in high frequency capacitors and cables as the dielectric loss and the discharge current will be lower.

Medium density papers (1 – 1.25 glcm3) are used in power capacitors while high density papers (above 1.25 glcm3) are preferred in DC and energy storage capacitors and other DC insulation.

Mineral oil impregnated papers and boards are advantageous in bushing and cables while diphenyl and vegetable oil impregnated papers are preferred for capacitors.

B. Fibrous Insulators

(COTTON, SILK, WOOL, JUTE, RAYON, NYLON, TERYLENE, TEFLON, FIBRE-GLASS ETC)

They have high mechanical strength, durability combined with extreme fineness, flexibility and easy processing. But they are hygroscopic and have low dielectric strength.

Varnish cloth is made by impregnating cotton or silk cloth with varnish. This treatment increases their breakdown strength.

Fibrous material are used in conductor insulation, manufacture of varnished cloth which finds wide applications in electrical machines and cables.

Inorganic fibrous materials like asbestos, glass fibres possess much greater heat resistance than organic fibrous materials and they can operate at high temperatures. But they posses poor elasticity and poor flexibility . Varnished glass cloths find applications in insulating the ends and windings of electric machines, working at high temperatures.

C. Synthetic Polymers

Polymers have low dielectric constants ranging from 2 to 5. Normal polymers like poly ethylene and polystyrene are excellent insulators for low temperature operations but undergo softening at high temperatures. They are used as thin films and find their use in chokes, capacitors, electrical bushings and telephones. Telflon is a good synthetic polymer with a dielectric constant of 2. Epoxy resins possess excellent electrical and mechanical properties and are widely used n making insulators, bushings etc for high voltage operations. Laminates and insulating varnishes are also prepared using epoxy resins.

D. Rigid Insulators (Glass, Ceramics And Refractories)

Glass has excellent electrical insulating properties. Their major application is in lighting systems. Glasses have similar coefficient of expansion of metals and are therefore used as insulating materials and metal claddings. Normal porcelains are used for low voltage applications while at high voltages glazed ceramics are used. Zircon and alumina porcelains are used in spark plug cores. High dielectric constant porcelains are prepared using titanates and are used for high capacity condensers with small spaces.

E. Impregnating Coatings and Bonding Materials

These are synthetic high molecular weight organic and organo-metallic compounds. Bitumen, resins, drying oils etc are known as insulating varnishes. They not only enhance the insulating properties but also help in stopping ageing of cheaply available materials like paper and cotton and reducing the hygroscopic properties of materials. Bonding materials are generally solutions of phenolic resins in alcohol and are used in low capacity electrical units. Other adhesives too could be used as bonding materials for low voltage and low temperature applications.

CLASSIFICATIONS OF ELECTRICAL INSULATORS ON THE BASIS OF OPERATING TEMPERATURES

S. No	Class	Max Working Temp	Examples of Insulating Materials
1	Y	90^{o}C	Cotton, silk, paper, wood
2	A	105^{o}C	Class Y materials impregnated with oils
3	E	120^{o}C	Materials operate at 15^{0}C higher than class A
4	B	130^{o}C	Mica, glass, Asbestos with suitable bonding materials
5	F	155^{o}C	Materials operate at 155^{0}C of class B
6	H	180^{o}C	Class B materials + Silicon resin
7	C	>180^{o}C	Class B materials + Inorganic binder

Preparation, properties and applications of SF6, epoxy resin, white wares, glass and transformer oil
SF_6 or sulfur hexafluoride

- **SF_6** or **sulfur hexafluoride** gas molecules are combined by one sulfur and six fluorine atoms.

- In the year of 1937, General Electrical Company first realized that S_{F6} gas i.e. sulfur hexafluoride gas can be used as insulating material.
- SF_6 or sulfur hexafluoride gas commercially is manufactured by reaction of fluorine (obtained by electrolysis) with sulfur. During process of producing of this gas, other by products like SF_4, SF_2, S_2F_2, S_2F_{10} are also produced in small percentages.

$$S + 3F_2 = SF_6 + 262\ KCal$$

- The SF_6 gas is one of the heaviest gases. Density of this gas at 20°C an one atmospheric pressure, is about 6.139 kg/m^3 which is about 5 times higher than air at same conditions.
- It is around 3.7 times more than that of air and it has also tremendous cooling effect in electrical equipment.
- The thermal conductivity of this gas is lower than air. SF_6 gas is highly electronegative.
- Sulphur hexafluoride has very excellent dielectric property. Dielectric strength of sulfur hexafluoride gas is about 2.5 times more than that of air.
- It is chemically inert, gaseous even at low temperature, non flammable, non toxic, non corrosive.
- SF_6 is used in several non-electric and electronic applications.
- magnesium casting in which a protective atmosphere of SF_6 based gas mixture prevent the formation of undesirable hyproducts.
- SF_6 is also used in the semi-conductor industry, as etching gases for plasma etching or as cleaning gases to clean the chambers after the etching process.
- Several minor applications are regarding leak detection, tracer gas studies, loud speakers and lasers.

Glass

- It is a thermoplastic organic material obtained by fusion of different oxides. After cooling glass remains in amorphous state.
- The raw materials used are sand (SiO_2), boric acid (H_2Bo_3), soda (Na_2Co_3), potash (K_2Co_3), chalk ($CaCo_3$), magnesite ($MgCo_3$), dolomite ($CaCo_3$, $MgCo_3$), Red lead (Pb_3O_4), kaoline and feldspar.
- Glasses are normally transparent, brittle and hard.
- Glasses are resistant to chemicals.
- They are fragile, dense and heavy.
- Thay have low dielectric loss and high dielectric strength.
- The three types of glass are quartz, pyrex and fibre glass.
- It is used as transformer bushings, line insulators, fuse bodies etc.
- It is also used as dielectric in capacitors.

- It is used in vacuum tubes and lamps.

Epoxy resin

- This is the product of alkaline condensation of epichlorohydrin and polyhydric compounds. These are hardened by using hardeners like organic acids.
- A particularly versatile group of epoxy resins are manufactured from epichlorohydrin and a dihydric phenol such as 2,2-bis(4-hydroxyphenyl)propane, often called p,p'-bisphenol A or simply bisphenol A.
- They have good electrical and mechanical strength, excellent stability and used as good adhesive metals.
- They are extensively used for the casting of insulators, bushing, etc for high voltages since these have less shrinkage, excellent dimensional stability after casting.
- The compounds of epoxide resin are used in the manufacture of high quality insulating material for high voltage electrical machines.
- It is used for laminated insulating boards and insulated varnishes.
- They can easily be casted into any desired shape at temperature below 150°C.

Transformer oil

- Transformer oil is a mineral oil and it should be perfectly free from moisture.
- It is prepared by hydrocarbon oil distillate from any available crude naphthenic petroleum oil of low sulphur content (below 0.7 wt %), viscosity is 100° F, flash point is between 200 and 300° F in the presence of hydrogen under specified conditions.
- It is non-flammable, non-sludging and has high permittivity.
- It has oxidation resistance, low moisture formation and low acid production.
- It transforms heat by convection from windings and core to the cooling surfaces.
- It maintains the insulation of the windings.
- The electrical properties and resistance to thermal expansion of mineral oils are influenced by the presence of non-hrdrocarbon compounds like oxygen, nitrogen, sulphur etc.
- They are used in transformers.

White wares

- The composition of the whirewares is 35 wt.% kaolin, 28 wt.% quartz, and 37 wt.% feldspar.
- The raw material is wet milled and homogenised to obtain the typical size distribution and it was dried. A part of the powdered batches was calcined separately to remove water from the mixture. It was uniaxially compacted into discs shape at 75 MPa. The dried discs or samples were

subsequently sintered at 1125-1250 °C for 2 h. After heating, the samples were naturally cooled to room temperature. Finally, the fired samples were subjected to physical analysis.

- Whiteware products are differentiated into three main classes such as porous, semivitreous, and vitreous according to their degree of vitrification (and resulting porosity). All vitreous whitewares are often referred to as porcelains.
- They are strong and impact-resistant, but they are also chemically inert in corrosive environments and are excellent insulators against electricity.
- It is used in include chemical ware, dental implants, electric insulators, including spark-plug insulators in automobile engines.
- They are used in the production of glass, ceramics and in polymer, paper and paint industries as fillers and extenders.
- Technical porcelain is an excellent insulation material for electrical engineering (high and low voltage), is dielectric – even under the influence of humidity – tracking-resistant, non-combustible and absolutely heat resistant up to 1000 °C.
- Thread guides for textile machines made of pore-free glazed hard porcelain guide modern carbon-, kevlar- and aramid fibres especially reliably.
- Products that are produced in large quanitities include lamp sockets.
- Ceramics made from alumina (aluminum oxide) and porcelain are widely used in insulators that protect electrical equipment outdoors.
- High-temperature superconductors such as this are expected to find many new applications, including high-speed, magnetic levitation ("maglev") trains and super-fast computers.

ELETRICAL RESISTIVITY

One of the significant characteristics of the materials is their ability to permit or resist the flow of electricity. Materials to be used in electrical equipments can be selected on the basis of their electrical properties such as, 1. resistivity 2. conductivity 3. temperature coefficient of resistance 4. dielectric strength 5. thermoelectricity etc. Metals with high electrical resistance are used as heating elements and metals with low electrical resistance are used for long distance transmission lines.

Resistivity is an electrical property of the material which impedes or resists the flow of electricity through it. Resistance offered by a unit cube of a material is given by

Resistivity, ohm m

R is the resistance of a conductor (ohms)

A is the area of the conductor (m^2)

L is the length of the conductor (m)

Materials	**Resistivity (m)**
Superconductors	0
Metals	10^{-8}
Semiconductors	variable
Insulators	10^{16}

FACTORS AFFECTING ELECTRICAL RESISTIVITY

The electrical resistivity is affected by the following factors.

1. Effect of temperature

Higher temperature results in higher resistance. Higher the temperature, faster will be the oscillations of the ions in the conductor and the moving electrons will have to undergo more number of collisions per unit length of the wire, which results in lesser current and higher resistance.

2. Effect of mechanical cold work

Resistivity of the metal can be increased by mechanical pressing or rolling or drawing (cold work) as it changes the crystal structure and the localized strain interferes with the movement of electrons. However subsequent annealing decreases the resistivity. Eg. Hand drawn copper wire has higher resistivity than annealed copper.

3. Effect of alloying elements

Alloying elements increase the resistivity of the materials due to the presence of solute atoms in solid solutions. The solute atoms interfere with the flow of electrons. In Cu-Ni alloy, the copper atoms do not impede the motion of free electrons but solute nickel atoms impede their motion.

4. Effect of impurities

A small amount of impurities can increase the resistivity. Eg. presence of 0.05% of phosphorous reduces the conductivity of copper by 40%.

CLASSIFICATION OF ELECTRICAL RESISTIVITY MATERIALS

Electrical resistivity materials are of two types.

1. Low resistivity materials
2. High resistivity materials

1) LOW RESISTIVITY MATERIALS

- They have low value of resistivity.
- They have low coefficient of temperature resistance values. (i.e. the change of resistance with change in temperature is low)This property will avoid variation in voltage drop and power loss with the changes in temperature and is essentially used in transmission lines.
- They are used for transmitting power from a generating station to other places.
- They are used in house wiring, windings of transformer, motors and in generators.
- Eg. copper and aluminium

2) HIGH RESISTIVITY MATERIALS

- They have high value of resistivity
- They have low coefficient of temperature resistance
- They have high melting point
- There is no tendency of oxidation
- Has high mechanical strength
- They are ductile
- They are used in heating devices, electric motor starters, filaments of incandescent lamps, loading resistances, rheostats and resistances for precise measuring instruments.
- Eg. Nichrome, Molybdenum silicide, tungsten, constantan,german silver, manganin.

IMPORTANT HIGH RESISTIVITY MATERIALS

Manganin

- Manganin is the trademarked name for an alloy that consists of three metallic elements – Copper, Nickel and Manganese.
- This metal alloy consists of the following metals in the following proportions: Copper (Cu): 86%, Manganese (Mn): 12% and Nickel (Ni): 2%.
- The chemical formula of this substance is CuMnNi. It consists of the formulas of all the constituent metals, namely CU for Copper, Mn for Manganese and Ni for Nickel.
- It has the formula weight (sum of the molecular masses of the atoms in the formula) of 177.18 g/mole.
- It has a low temperature coefficient of resistance (relative change of the physical properties of a substance with 1 K temperature change).
- The resistivity of this resistance alloy is 4.55×10^{-5} ohm centimeters and it is electrically conductive.
- It has a melting point of 960 °C. The tensile strength of this substance ranges between 300-600 MPa.
- The density of this alloy is 8.4 g/cm^3. It has a specific gravity of 8.5.
- Its electrical resistance is found to be constant over a range of temperatures.
- The wire and foil of this material are mainly used to manufacture various resistors – mainly ammeter shunts. Shunt refers to a device that controls the passage of electric current in different points of a circuit.

Constantan

- It is also known as Eureka, Advance and Ferry. It is a **copper-nickel alloy** usually consisting of 55% **copper** and 45% **nickel**.
- Constantan is a Nickel-Copper based alloy wire that has a high resistivity and is mainly used for thermocouples and electrical resistance heating.
- It has high specific heat resistance and negligible temperature coefficient.
- Easily ductile and resistant to atmospheric corrosion.
- Melting point – 1225 to 1300°C. Specific Gravity – 8.9 g/cc.
- Electrical resistivity is 52.0 μΩ/cm at room temperature. Density is 8.89 g/cm^3.
- It is used for the formation of thermocouple, along with the wires of other metals such as copper, iron and chromel. It is especially used for resistance purpose since its resistance does not change much with the change in its temperature.

- Constantan is one of the most widely used alloys. Constantan has the highest resistivity among all the other alloys, which makes it insensitive to the level of strain and temperature.
- Constantan has a good fatigue life and a very high elongation capacity also.
- Constantan is an ideal alloy for the electric motor starter resistances and for heavy duty industrial rheostats.
- Constantan is one of the most widely used alloys in wire wound precision resistors, volume control devices and temperature stable potentiometers.

MOLYBDENUM SILICIDE

- Molybdenum silicide (($MoSi_2$) is an intermetallic compound of molybdenum and silicon.
- It is primarily used in heating elements.
- It has an electrical resistivity of $3.5X10^{-5}$ ohm m
- It has moderate density, with a melting point of 2230°C, and is electrically conductive.
- At high temperatures it forms a passive layer of silicon dioxide, protecting it from further oxidation.
- While $MoSi_2$ has excellent resistance to oxidation and high Young's modulus at temperatures above 1000 °C, it is brittle at lower temperatures. Also, at above 1200°C it loses creep resistance. These properties limits its use as a structural material, but may be offset by using it together with another material as a composite material. While the elements are brittle, they can operate at high power, and their electrical resistivity does not increase with operation time.
- The application area includes glass industry, ceramic sintering, furnaces, and gas turbine engines, microelectronics etc. It is frequently used as a shunt over polysilicon

NICHROME

- A heating element converts electricity into heat through the process of Joule heating. Electric current through the element encounters resistance, resulting in heating of the element.
- Most heating elements use Nichrome (80% nickel, 20% chromium) since it is an ideal material due to its relatively high resistance and its tendency to form an adherent layer of chromium oxide when it is heated for the first time. Material beneath this layer will not oxidize, preventing the wire from breaking or burning out. .

- It is silvery-grey in color, corrosion-resistant, and has a high melting point of about 1400°C. It has high electrical resistivity of 108×10^{-5} ohm m
- It has resistance to oxidation at high temperatures
- It is widely used in electric heating elements, such as in hair dryers, electric iron, room heaters, electric furnaces, electric ovens, soldering iron, toasters, and even electronic cigarettes. It can be easily drawn into thin wires.
- It has good mechanical strength