CERAMICS CONDUCTORS

ELECTRONIC CONDUCTOR APPLICATIONS: HEATING ELEMENTS, RESISTORS, VARISTORS, THERMISTORS, TEMPERATURE-SENSITIVE RESISTORS

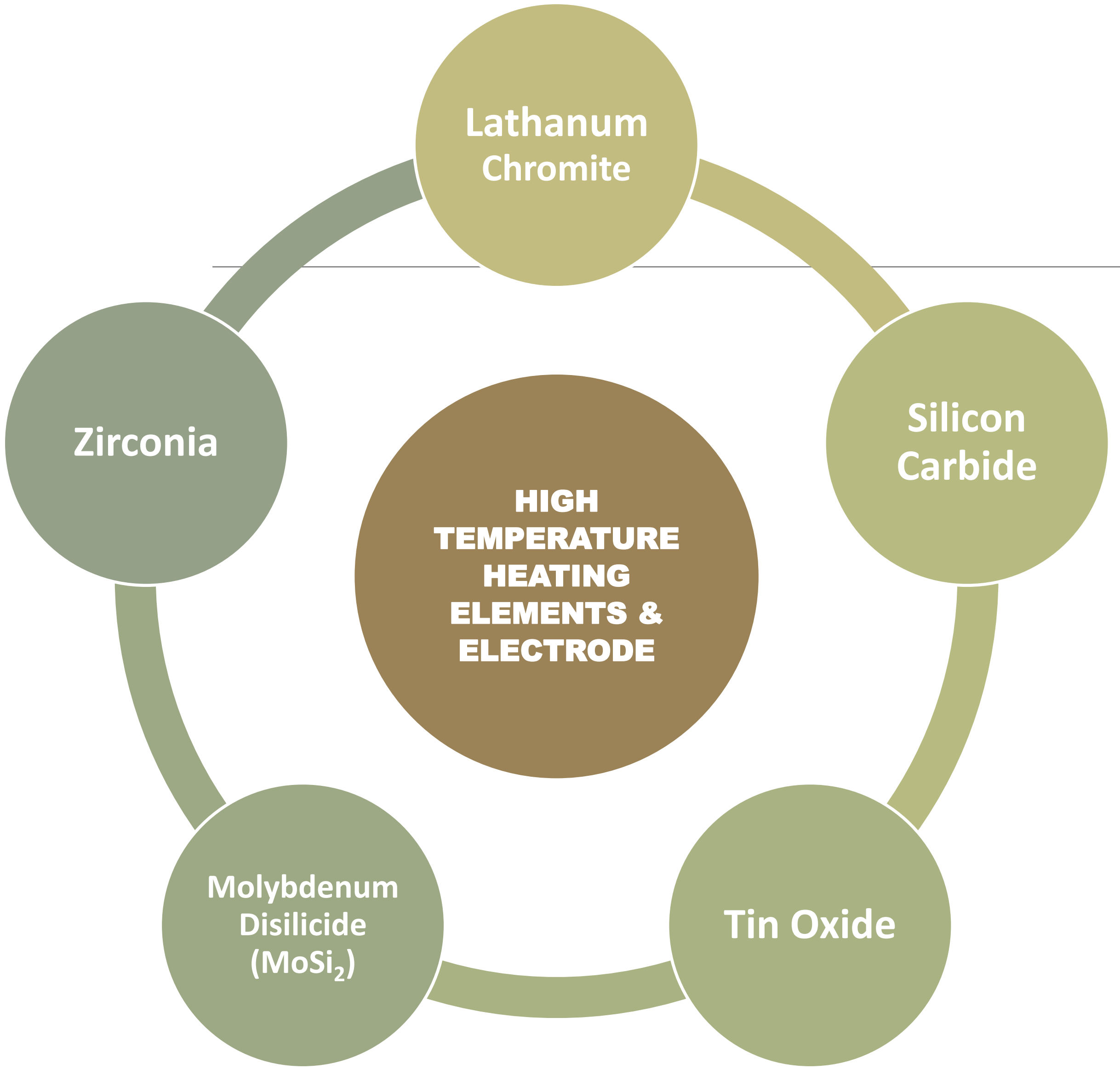
HIGH TEMPERATURE HEATING ELEMENTS & ELECTRODE

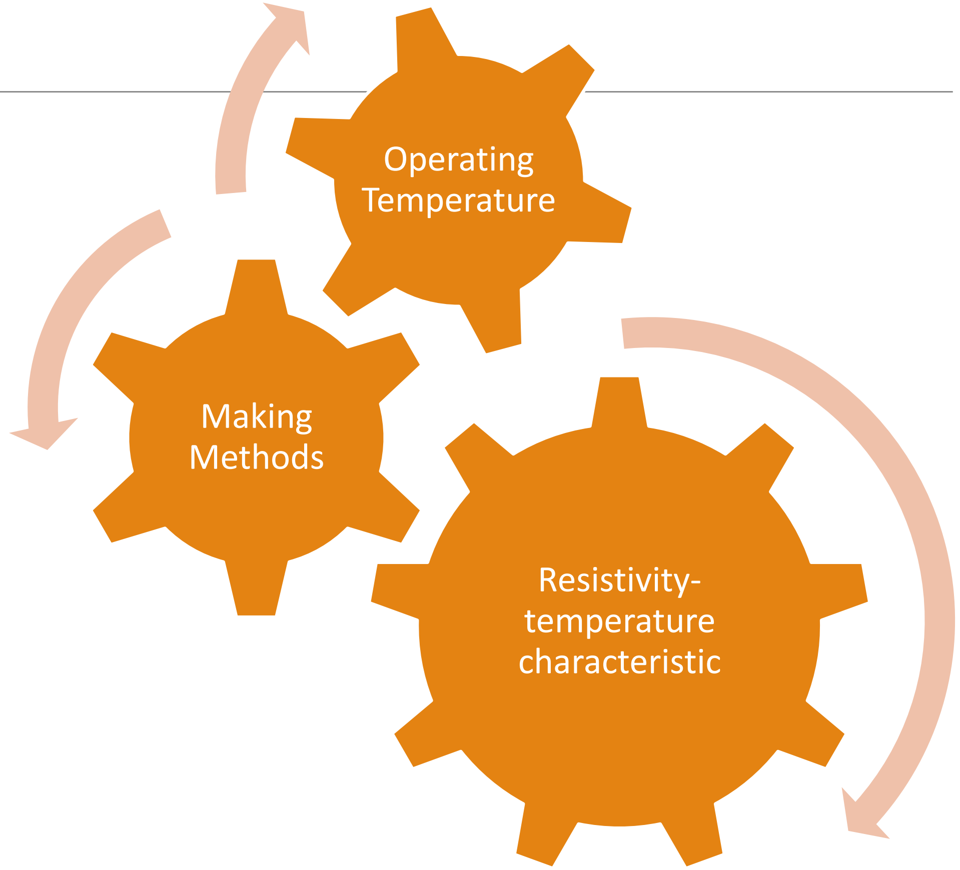
- In the high-temperature, most materials either oxidize or melt.
- For the high-temperature heating materials necessitate high resistivity.
- Highly resistive elements necessitate high voltage power supplies which lead to difficulties in furnace design since refractories all become conductive when hot so that it is difficult to avoid current leakage and often an accompanying risk of thermal breakdown

  (cf. Chapter 5, Section 5.2.2(b))
- In case where reducing atmospheres can be tolerated, graphite or refractory metals such as molybdenum and tungsten can be used, while platinum and its alloys can be used safely in air up to 1500°C. Ceramics allow the use of air atmospheres at relatively low cost.

Ceramic Heating Elements

- Metal and ceramic heating elements operate on the principle of electric resistance heating, which is defined **as the heat generated by a material with high electrical resistance as a current are passed through it**.
- **When a current flows through metal or ceramic heating elements, the material resists the flow of electricity and generates heat.**
- This is a basic explanation of a complex concept, but the principle generally holds true for common metal and ceramic heating elements in industrial furnaces.
- ceramic heaters generally fall into one of two groups: **exposed ceramic rods; or coils, ribbons, and wires of an alloy embedded in a plate of ceramic insulation.** At the simplest level, these heating element types operate on the same principle.
- The material's coefficient of electrical resistance determines its **ability to generate heat proportional to the amount of current flowing through it.**
- A ceramic heating element's thermal output, therefore, is determined by its electrical load and its intrinsic resistive properties.
- Under ideal conditions, the element will resist the flow of current and generate heat which will radiate outwards into the heat treatment chamber. The primary benefit of this compared to combustion is vastly increased efficacy, as 100% of electricity supplied is theoretically converted into heat.


Lathanum Chromite
Silicon Carbide
Tin Oxide
Molybdenum Disilicide ($MoSi_2$)
Zirconia
HIGH TEMPERATURE HEATING ELEMENTS & ELECTRODE


Operating Temperature
Making Methods
Resistivity-temperature characteristic

Silicon Carbide

- Silicon carbide (SiC) is a hard material and, because of a protective oxide layer, is stable in air up to 1650°C.
  - Application : Abrasive, furnace heating elements, varistors.
  - Making method : Heating a mixture of finely divided carbon and silicon to about 1000°C.
- SiC is covalently bonded with a structure similar to that of diamond.
  - α-SiC : hexagonal form
  - β-SiC : cubic form (Pure cubic β-SiC is a semiconductor with a band gap of approximately 2.2eV)
- Important property : electrical conductivity, hardness (approximately 9 on the Mohs scale).
- The colours arise from a variety of impurities including boron, aluminium, nitrogen and phosphorus, and are useful for selecting grades suitable for particular applications.

- There are three principal methods of manufacturing SiC heating elements:
  1. in situ formation of SiC from carbon and SiC.
  2. reaction-bonding of SiC
  3. pressureless sintering.
- SiC can be used up to about 1650℃ in air, because SiC rely on a thin native passivating silica film for their protection against oxidation.
- Below approximately 800℃ the resistance from batch to batch is determined by impurities.
- About 600℃ SiC is an intrinsic semiconductor With a NTCR.

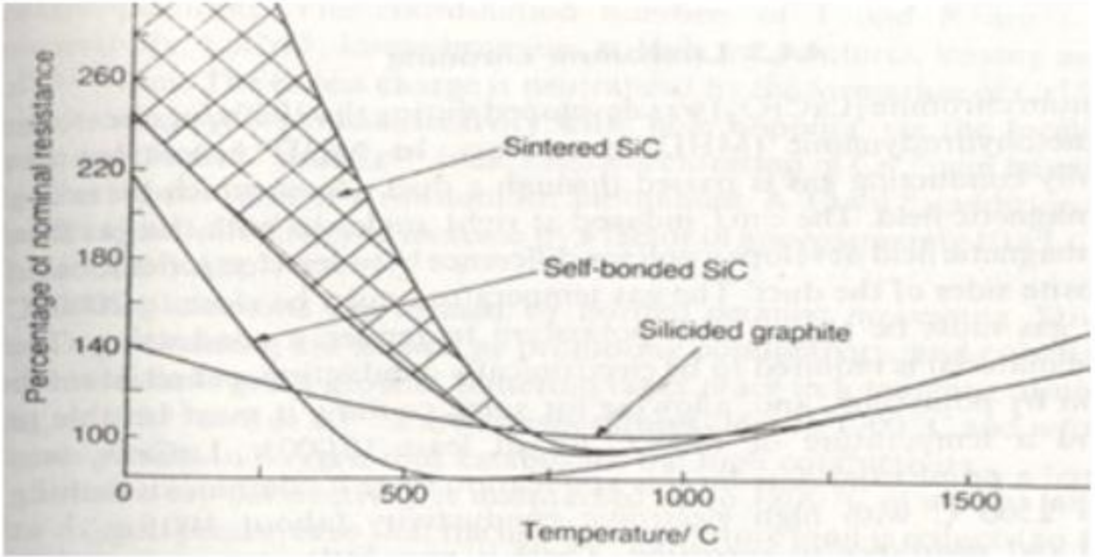


Fig.4.2 Resistance-temperature characteristics of SiC elements prepared by various methods.

Molybdenum Disilicide ($MoSi_2$)

- Molybdenum disilicide ($MoSi_2$) has been developed as a heating element for use in air at temperature above 1500°C.

- Resistivity : 2.5 X 10-7 Ωm (Room temperature)
  4 X 10-6 Ωm (1800°C)

- Fabrication of molybdenum disilicide ($MoSi_2$)
  -A mixture of fine $MoSi_2$ powder with a carefully chosen clay is extruded into rods of suitable diameters for the thermal sections and heating zones.
  -The rods are dried, sintered and cut to various lengths.

- The best grade of $MoSi_2$ element is capable of operating up to 1800°C.

Lathanum Chromite

- $LaCrO_3$ combines a melt point of 2500°C with high electronic conductivity (about 100Sm-1 at 1400°C) and resistance to corrosion.

- $LaCrO_3$ is one of the family of lanthanide perovskites RTO_3, where R is a lanthanide ant T is a period 4 transition element.

  - The cubic unit cell R occupies the cube corners, T occupies the cube centre and O occupies the face-centre positions.
  - The coordination numbers of T and R are 6 and 8 respectively.

- Sintering takes place in a reducing atmosphere at temperatures close to 1700°C and is followed by an anneal in oxygen that establishes the high conductivity.

- Satisfactory conductivity is maintained up to 1800°C in air but falls off at low oxygen pressures so that the upper temperature limit is reduced to 1400°C when the pressure is reduced to 0.1 Pa.

Tin Oxide

- Tin oxide (SnO_2) has found applications in high-Temperature conductor, ohmic resistors, transparent thin-film electrodes and gas sensors.
- Crystal structure : tetragonal rutile structure

- It is wide band gap semiconductor which the band gap at 0K is 3.7eV, and therefore pure stoichiometric SnO_2 is a good insulator at room temperature when its resistivity is probably of the order of $10^6 \Omega m$.
- A typical resistivity-temperature characteristic is shown in Fig.4.3.

- An important application of SnO_2 in ceramic form is in conducting electrodes for melting special glasses, such as those used for optical components and lead 'crystal' tableware.
- SnO_2 itself does not readily sinter to a dense ceramic and so sintering aids such as ZnO ($r_6(Zn^{2+})$=75pm) and CuO ($r_6(Cu^{2+})$=73pm) are added, together with group V elements such as antimony and arsenic to induce semiconductivity.

Zirconia

- Zirconia (ZrO_2) improve a defect (fragile, inconvenient resistivities).
- The 'Nurnst filament', one used as a light source, consisted of zirconia (ZrO_2) doped with thoria and ceria.
- Preheating the filament to about 600°C using an external source reduces its resistance to a value which permits direct Joule heating to be effective whereupon temperatures of up to 1800°C can be attained.
- Its high negative temperature coefficient made it necessary to have a resistor, preferably with a high positive temperature coefficient, in series with it to limit current.
- Zirconia always require preheating to reduce the resistance to a level at which Joule heating is effective.
- Ones the element has reached temperatures exceeding about 700°C it can be used as a susceptor and heated by eddy currents generated by an induction coil and a high-frequency (0.1-10MHz) power source.

OHMIC RESISTORS

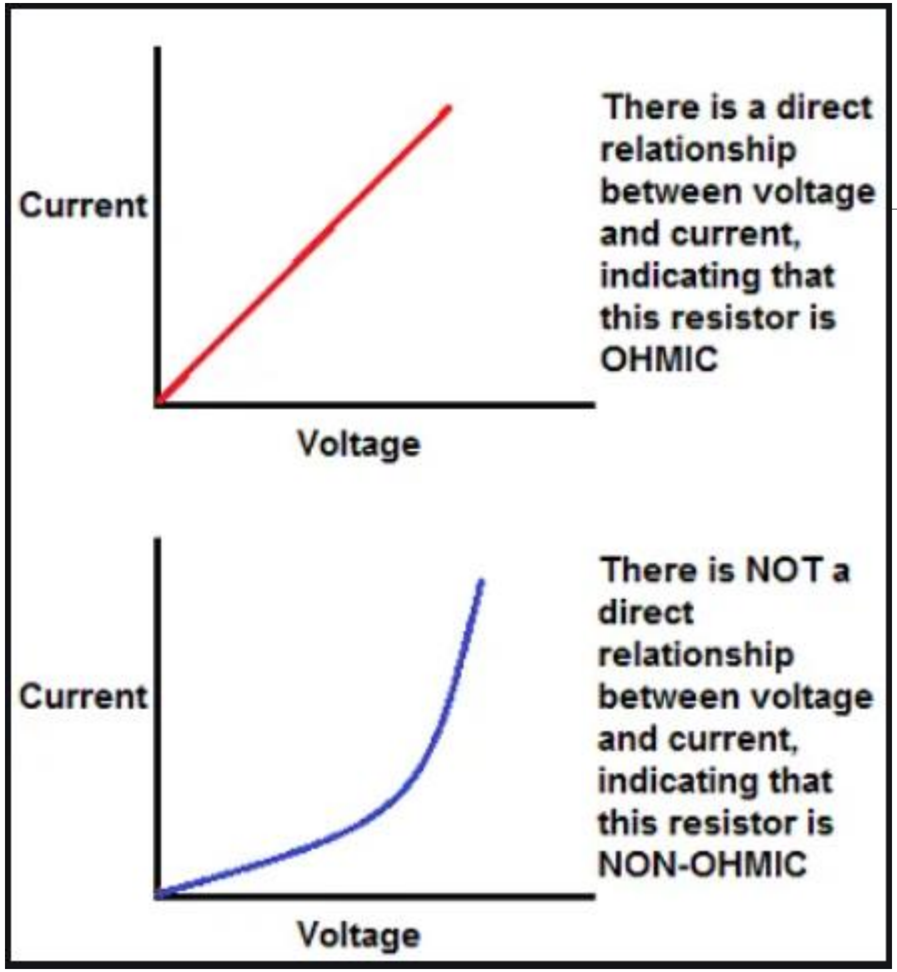
- Most resistors for electrical and electronic applications are required to be ohmic and to have small temperature coefficients of resistance.

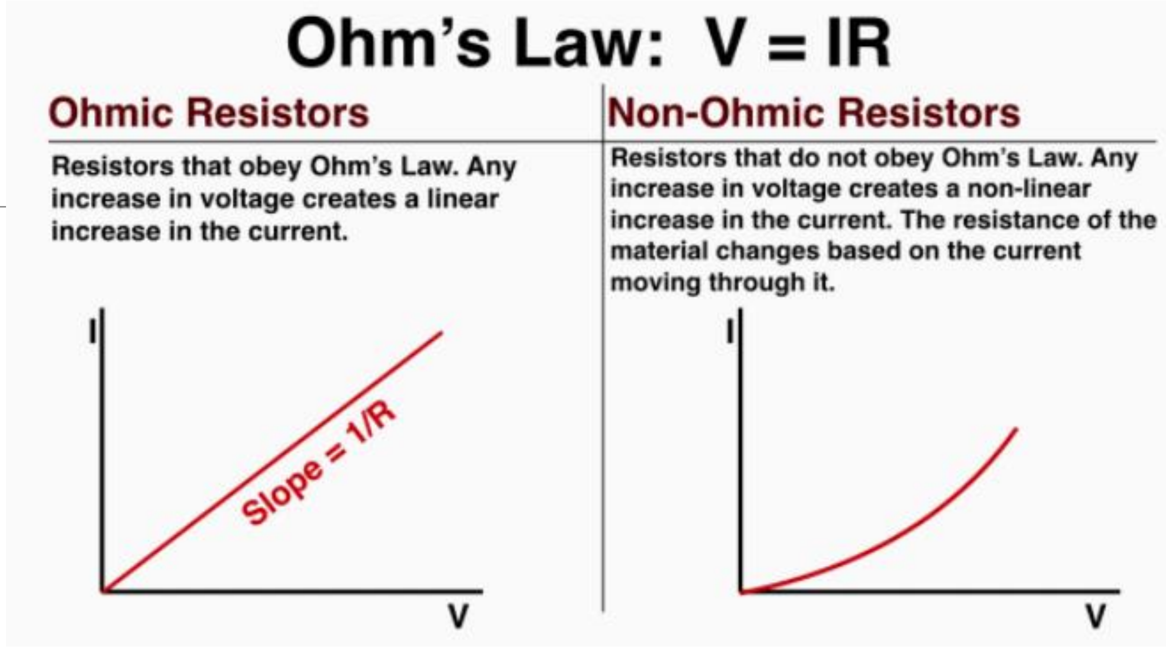
- The major requirement in electronics is for resistor in the range 10^3-10^8 Ω, while materials with suitable electrical properties usually have resistivities less than $10^{-6}\Omega$m.

- Manufacturing method of material for thin and high-resistance is following.

1. Very thin conductive layers are deposited on an insulating substrate and large length-to-width ratios are obtained by etching a suitable pattern.
2. The conductive material is diluted with an insulating phase.

These methods are often combined.





Ohmic resistors are those **resistors** that have a constant resistance. In other words, they follow the **Ohm's** law. If you take such a **resistor**, apply voltage across it, whilst measuring current and voltage, and then draw a graph of current versus voltage, you get a straight line

https://www.youtube.com/watch?v=Ciasa_SH0cI

Thin Films

- Thin films of thickness typically 10nm are readily formed in a vacuum chamber by evaporation, ‘sputtering’, or chemical vapor deposition (CVD).
- Many metals and metal alloys can be evaporated from the molten state and condensed onto suitable substrates.
- Ni-Cr alloys with resistivity values of about $10^{-6}\Omega m$ are deposited in thin-film form and provide a basis for the manufacture of high-value resistors.
- Production thin-film oxide process is applied ‘sputtering’ for plazma.
- Thin-film is applied on glass and steatite substrates.

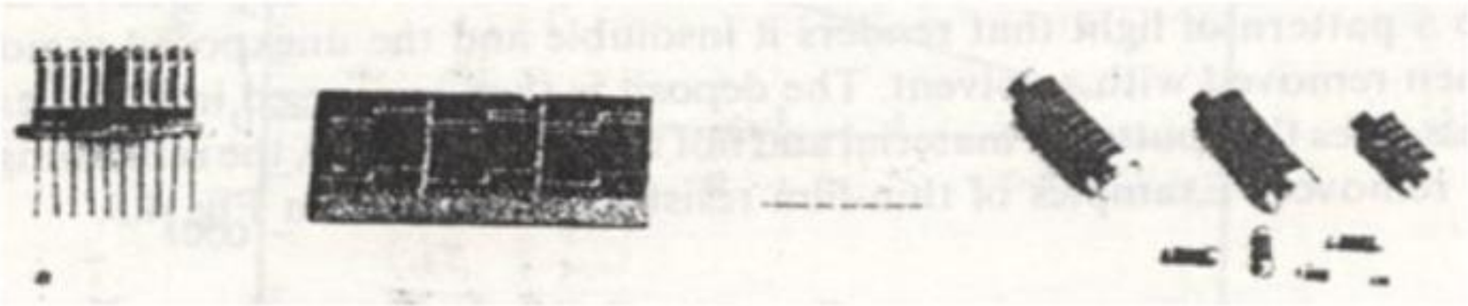


Fig 4.5 (a) thin-film resistors on glass and steatite substrates.

Thicker Films

- Rather thicker films with thicknesses typically in the range 10-15um are made by what is termed the ‘thick-film’ or ‘silk-screen’ technique.
- Silk screening is a well-established method for printing artwork.
- The screen is held taut in a frame that is fixed 1-3mm above the surface to be printed. A print of a stiff creamy consistency is swept across the screen by a hard rubber squeegee with sufficient pressure to force the screen, now loaded with paint, into contact with the underlying surface.
- Examples of thick-film devices and circuits.

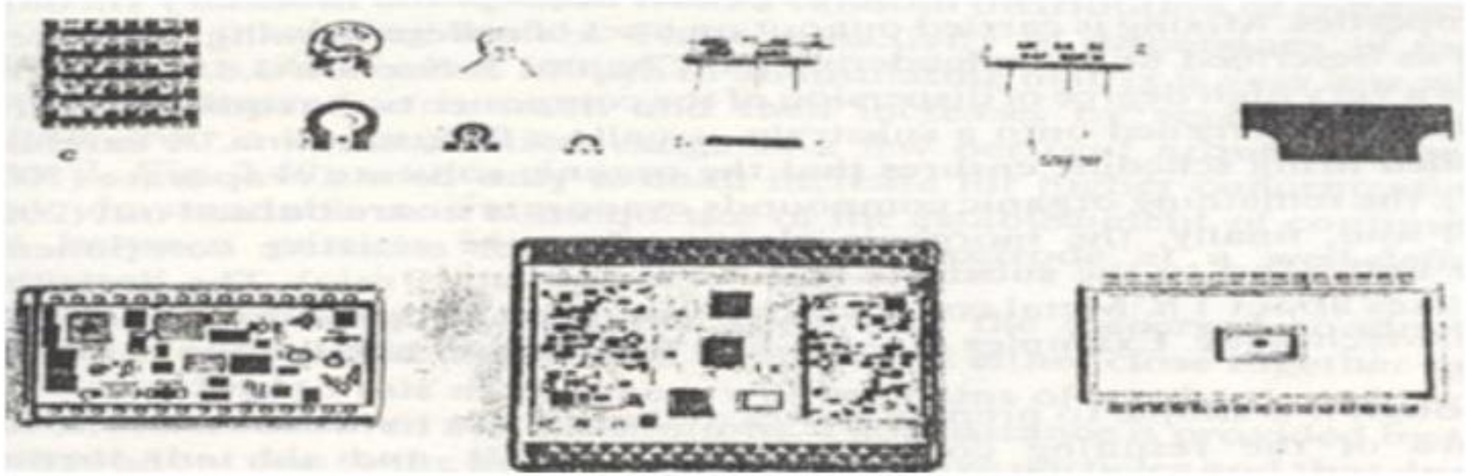
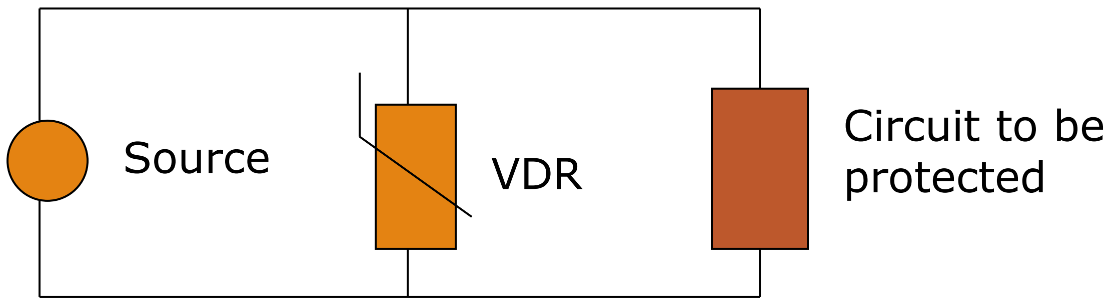


Fig. 4.5 (c) various thick-film resistor, (d) hybrid microcircuits

VOLTAGE-DEPENDENT RESISTORS (VARISTORS)

- A Varistor is a varying resistor whose resistance depends on the applied voltage ("varying" and "resistor")
- They are also known by the name VDR [voltage dependent resistor] and have non-ohmic characteristics. Therefore, they come under non linear type of resistors.
- There are a number of situations in which it is valuable to have a resistor which offers a high resistance at low voltages and a low resistance at high voltages.
- Such a devices can be used to protect a circuit from high-voltage transients by providing a path across the power suply that
  - takes only a small current under normal conditions but takes large current if the voltage rises abnormally,
  - thus preventing high-voltage pulses from reaching the circuit.
- Schematic use of a VDR to protect a circuit against transients



Electrical characteristics and applications

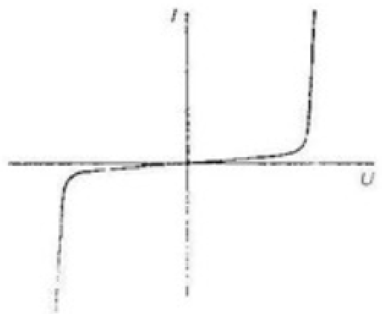


Fig.4.7 Typical current-voltage relation for voltage-dependent resistor

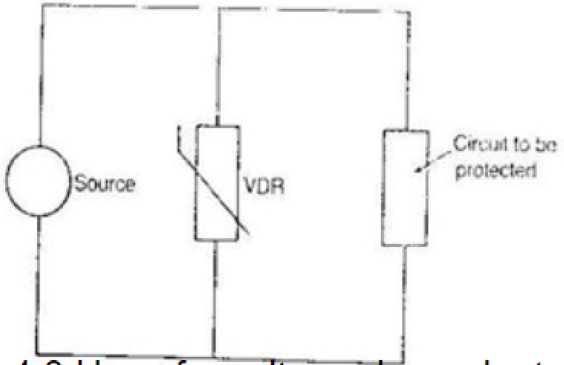


Fig.4.8 Use of a voltage-dependent

- **4.3.1 Electrical characteristics and applications**
- There are a number of situations in which it is valuable to have resistor which offers a high resistance at low voltages and a low resistance at high voltages as is 속 case in the current-voltage characteristic shown in Fig. 4.7
- Fig.4.8 Use of a voltage-dependent resistor to protect a circuit against transients

https://www.circuitstoday.com/varistor-working

VOLTAGE-DEPENDENT RESISTORS (VARISTORS)

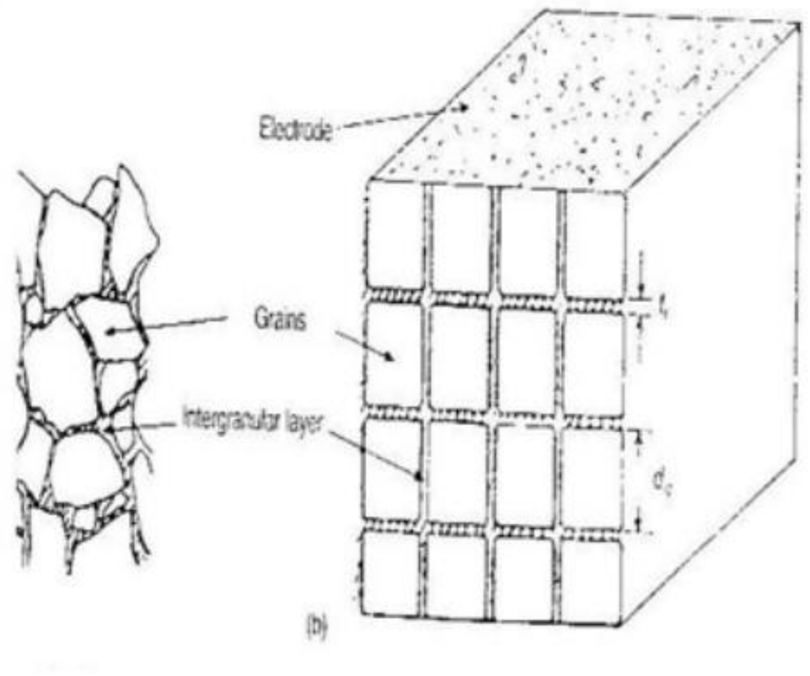


Fig.4.9 Illustrations of (a) actual and (b) idealized microstructure of varistor

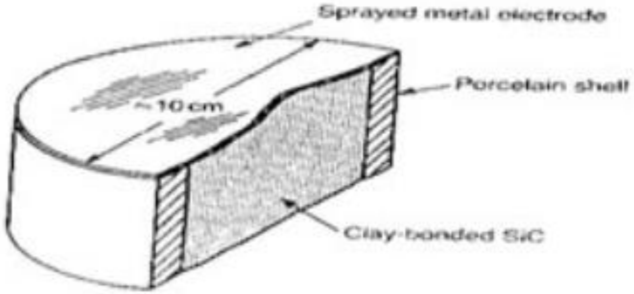


Fig.4,14 section though a commercial SiC surge arrester.

Fig.4.15 (a)Silicon carbide varistor;(b)zinc oxide varistors (components supplied by power Developments Ltd); (c) packaged themistors. Inset, various NCT and PTC thermistors (components supplied by Bowthorpe thermistors.)