POSTAL Book Package 2021

Electrical Engineering

Conventional Practice Sets

Electrical Materials

Contents

MADE EASY Publications

4 CHAPTER
Conductive Materials and Superconductor

Q.1 Define conductive materials? Explain its group with appropriate examples.

Solution:

The materials through which electric current passes easily or in another words we can say that materials in which valence band and conduction band are overlapped are called conductive materials.

Group of electric materials.

High conductive type:

These materials posses following properties:

- Highest possible coductivity
- Lowest temperature coefficient
- Good reliability and drawability for wire manufacturing
- High mechanical strength
- Resistive to corrosion
- Easily solderable
- Important examples of these materials are copper, aluminium, zinc, silver, mercury, tungsten selenium, platinum, nickel, tin, lead, steel etc.

High resistive type:

Generally, high resistive materials are alloys of different materials:

- Materials used in making of precision electrical measuring instruments and for standard resistance and resistance boxes.
- Materials for resistance elements for all kinds of rheostats and other control devices.
- Materials for furnaces, heating devices and loading rheostats and also to make thermocouples etc.

This group contains :– Manganin (Cu + Mn + Ni), constantan (Cu + Ni).

Q.2 Explain the components of resistivity of alloy? Also show that temperature coefficient of metal is greater than that of temperature coefficient of alloys.

Solution:

There are two components of the resistivity of alloy, they are:

Thermal component:

- For a conducting material this component is due to the lattice vibration caused by the thermal energy. This component reduces with decrease in temperature and finally becomes zero at the absolute zero temperature.

Residual component:

- This component of resistivity arises due to impurity of material and lattice imperfections. This components is independent of temperature and will be existing even at absolute zero temperature. Therefore, alloying can induce the resistivity.

  The resistivity of conducting material as a function of temperature is given by

$$\rho_T = \rho_t + \alpha\rho_t \Delta T \qquad ...(i)$$

$$\Delta T = T_2 - T_1 = \text{difference of temperature}$$

$$\alpha = \text{Temperature coefficient}$$

We also know that,

$$\alpha_{metal} = \frac{1}{\rho_{th}}\frac{d}{dT}(\rho_{thermal}) \quad \text{...(ii)}$$

$$\alpha_{alloy} = \frac{1}{(\rho_{residual} + \rho_{thermal})} \times \frac{d}{dt}(\rho_{thermal}) \quad \text{...(iii)}$$

$$\alpha_{alloy} = \frac{1}{1+\frac{\rho_{res}}{\rho_{th}}} \times \frac{1}{\rho_{th}} \times \frac{d}{dt}(\rho_{th}) \quad \text{...(iv)}$$

From equation (ii) and (iv) we have,

Note:
$$\alpha_{alloy} = \frac{\alpha_{metal}}{1+\frac{\rho_{res}}{\rho_{th}}}$$

Q3 Explain the term Resistors? Which are most widely used materials for precision resistors. Also describe the characteristics of resistance wire in the strain gauges used as transducers?

Solution:

- Resistors are integral part of all electronic circuits and some electrical circuits. They can be general purpose resistors or highly stable resistors. General purpose resistors are of carbon composition having a tolerance of 5 to 20% in value. High stability resistors include metal film, metal foil and wire wound resistors with tolerance of 0.1 to 5%.

Materials used for precision resistors:

- The most widely used materials for precision resistors are: Manganin (84% Copper, 12% manganese and 4% nickel) Constantan (alloy of copper with 40 to 60% nickel), Nickel-chromium alloys (for small size and high temperature) and Gold chromium alloys (special applications for heat resistance standards). The other materials used for resistors include Tungsten, Carbon and Platinum.

Resistors used for strain gauges as transducer:

- The materials used for strain gauges used as transducers for the measurement of strain and stress should have high resistance, low temperature coefficient, should not have any hysteresis effect in its response, have linear characteristics and good frequency response. The popular metals and alloys used for construction of resistance wire strain gauges are 'Nicrome' (Ni = 80%, Cr = 20%), 'Constantan' (Ni = 45%, Cu = 55%), 'Isoelastic' (Ni = 36%, Cr = 8%, Mo = 0.5% etc.), 'Nickel' and 'Platinum'.

Q4 The resistivity of copper rod as measured by Kelvin double bridge is 1.74 micro-ohm cm at 20° C. If the resistivity of the copper is 1.73 micro-ohm-cm at 20° C, calculate the impurity (%) contents in the rod.

Solution:

The resistivity ρ(Scattering phenomenon),

$$\rho = \frac{m}{ne^2}\left[\frac{1}{\tau_i} + \frac{1}{\tau_T}\right]$$

$\therefore$ Percentage of impurity $= \dfrac{\sigma_{actual} - \sigma_{meas.}}{\sigma_{actual}} \times 100\%$

$$= \frac{\frac{1}{\rho_{actual}} - \frac{1}{\rho_{meas.}}}{\frac{1}{\rho_{actual}}} = \frac{\frac{1}{1.73} - \frac{1}{1.74}}{\frac{1}{1.73}} \times 100\% = 0.574\%$$

Q.5 Find the mean velocity of electron flow in a conductor having a cross-sectional area of 2.1×10^{-6} m^2 when a current of 20 amperes flows through it. Assume that there are 8.5×10^{28} electrons/m^3 of the material. Charge on an electron is 1.6×10^{-19} coulombs.

Solution:

Given, $A = 2.1 \times 10^{-6}\ \text{m}^2, \quad I = 20\ \text{A}$

$n = 8.5 \times 10^{28}\ \text{electrons/m}^3, \ e = 1.6 \times 10^{-19}\ \text{C}$

Current, $I = neAv_d$

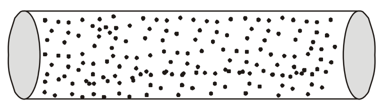
$$\Rightarrow \quad v_d = \frac{I}{neA} = \frac{20}{8.5\times10^{28}\times1.6\times10^{-19}\times2.1\times10^{-6}}$$

$$= 0.7 \times 10^{-3}\ \text{m/sec.} = 0.7\ \text{mm/sec.}$$

Q.6 Derive the expression for current density in a conductor and also define the conductivity of the materials and write the relation between the conductivity and current density?

Solution:

Let us consider a conductor having length 'L' contained N electrons as shown in the figure below:



If it takes an electron a time 'T' second to travel a distance 'L' meter in the conductor, the total no. of electrons passing through any cross-section of wire in unit area is N/T. Thus the total charge per second passing any area, now the current in ampere is,

$$I = \frac{Nq}{T} = \frac{Nqv}{L} \quad \text{...(i)}$$

Since, L/T is the average or drift speed 'v' in m/sec of the electrons. The current density denoted by the symbol 'J' is defined as the current per unit area of the conducting medium. Assuming a uniform current distributions.

$$J = \frac{I}{A} \quad \text{...(ii)}$$

Where 'J' is in amperes per square meter and 'A' is the cross-sectional area in meter^2.

Now from equation (i) and (ii),

$$J = \frac{Nqv}{LA} \quad \text{...(iii)}$$

Here LA = volume containing the N-electrons and N/LA = electrons concentration in electron/m^3

i.e. $$n = \frac{N}{LA} \quad \text{...(iv)}$$

From equation (iii) and (iv) we get, $J = nqv = \rho v$ ...(v)

where $\rho = nq$ is the charge density in Coulomb per cubic meter.

The conductivity of a material can be related to the number of charge carriers present in the materials.

Since, $v = \mu E$ ...(vi)

Now from equation (v) and (vi) we get,

$$J = nq\mu E = \sigma E$$

Here, conductivity, $\sigma = nq\mu\ (\Omega\text{-m})^{-1}$

Q.7 Certain metal works as superconductor below the critical temperature $T_C = 7.2°K$. The critical magnetic field for the metal at 0°K is 7.8×10^5 Amp/m. What is the critical magnetic field for the metal to be usable as superconductor at 5°K?

Solution:

Given that, Critical temperature = T_C = 7.2°K

Critical Magnetic field for the metal at 0°K

$$= H_{CO} = 7.8 \times 10^5 \text{ Amp/m}$$

$$T = 5°K$$

We know that,

$$H_{CT} = H_{CO}\left[1-\left(\frac{T}{T_C}\right)^2\right]$$

Where, H_{CT} = Critical magnetic field for the metal to be usable as superconductor at 5° K.

So,

$$H_{CT} = 7.8\times10^5\left[1-\left(\frac{5}{7.2}\right)^2\right] = 7.8\times10^5\left[1-\frac{25}{51.84}\right]$$

$$H_{CT} = 7.8\times10^5\left[\frac{51.84-25}{51.84}\right] = 7.8\times10^5\times\frac{26.84}{51.84} = 4.038\times10^5 \text{ Amp/m}$$

Q.8 Consider a 'Lead' material has critical temperature 7.19 K and critical magnetic flux is 0.0803 tesla. Determine the value of temperature at which 'lead' material must be cooled in a magnetic field of 15000 A/m for it to be super conductive. Assume magnetic constant value is $4\pi \times 10^{-7}$ H/m.

Solution:

The temperature dependence of the critical magnetic field strength is given as,

$$B_c(T) = B_c(0)\left[1-\left(\frac{T}{T_c}\right)^2\right]$$

T_c = Critical temperature = 7.19 K

$B_c(0)$ = Critical field strength at absolute zero = 0.0803 T

$H_c(T)$ = 15000 A/m

$B_c(T) = \mu_0 \times H_C(T) = 4\pi\times10^{-7}\times15000 = 0.01884$ T

Substituting the values, we get

$$0.01884 = 0.0803\left[1-\left(\frac{T}{7.19}\right)^2\right]$$

$$1-\left(\frac{T}{7.19}\right)^2 = 0.2346$$

$$T^2 = 39.57$$

$$T = 6.29 \text{ K}$$

Therefore, the material becomes super-conductive when cooled below 6.29 K in a magnetic field of 15000 A/m.

Q.9 Determine the diameter of the lead wire to pass maximum super current of 0.0021 mA at 5.0 K. The critical temperature and critical magnetic field for lead are respectively 7.18 K and 6.5×10^{-4} A/m.

Solution:

Given that:

Maximum supercurrent, I_m = 0.0021 mA at 5.0 K

The critical temperature = 7.18 K