Chapter-3

Current Electricity

Current Electricity ⇒ The study of charges in motion is called current electricity.

Electric Current ⇒ It is defined as the rate of flow of charges through any cross section of substance.

$$\boxed{I_{av} = \frac{\Delta q}{\Delta t}}$$

$$I_{inst} = \lim_{\Delta t \to 0} \frac{\Delta q}{\Delta t} = \frac{dq}{dt}$$

$$\boxed{I_{inst} = \frac{dq}{dt}}$$

* SI unit of current = Ampere [A]
* It is a scalar quantity.

Charge Carriers

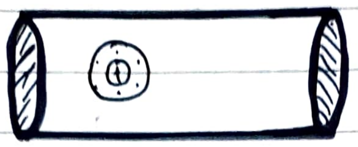
I **In Metal or Conductor** ⇒

\# At very low temperature all the atoms of conductor are electrically neutral and no charge carriers are there ~~are~~ in conductor.

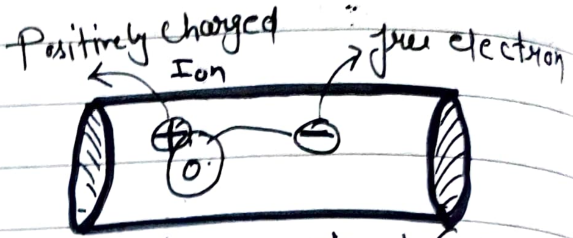
* But as temperature increases the valence electrons in the atom of conductor gain energy and leave the valence cell due to which two species are created

(i) Electron ⇒ It can easily move.
(ii) Positively charged Ion = It can not move.

The electrons also known as free electrons they are in large number (around $10^{29} m^{-3}$ and carries Charge.



at extremely low temp ($-273°C$ or $0K$)



at room temp (300K)

Free electrons are about $10^{28}/m^3$

II In Electrolyte ⇒ When electrolyte ionised it creates cations and anions which are responsible for carrying charge.

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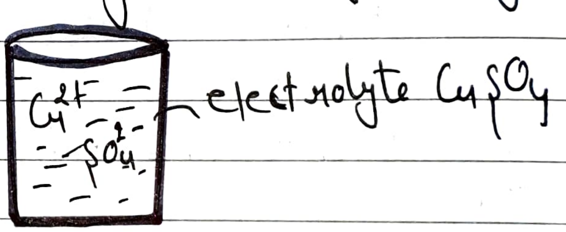
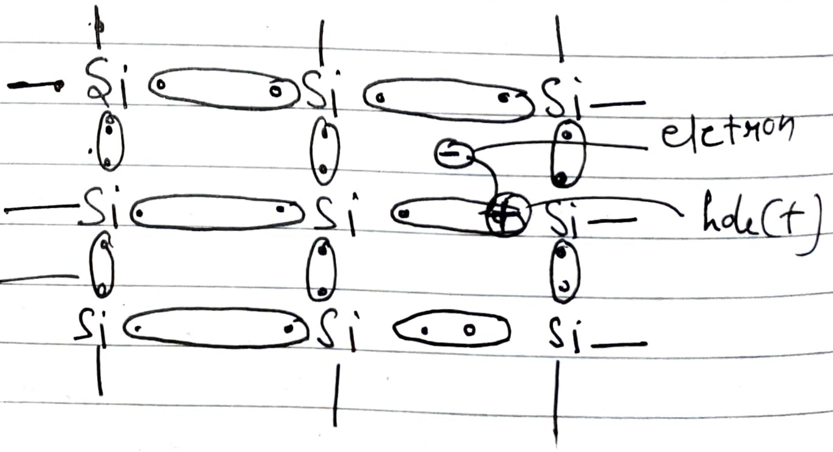
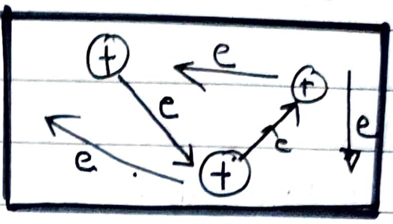


III In Semiconductors ⇒ In Semiconductors electron and hole Conducts electric Charges.

For Example



Thermal Velocity [10^4 km/s] ⇒ It is the velocity of an electron inside a conductor due to heat acquired by it from surrounding.



※ Due to thermal velocity electrons are moving in random direction.

※ Since the velocity is vector quantity then net thermal velocity is equal to zero

$$\vec{u}_{av} = \frac{\vec{u}_1 + \vec{u}_2 + \vec{u}_3 + \cdots \vec{u}_n}{n} = 0$$

$$\vec{u}_{av} = 0$$

※ No current flows through conductor due to thermal velocit of electron.

Drift Velocity

It is the average velocity with which electrons inside a conductor move under the influence of electric field.

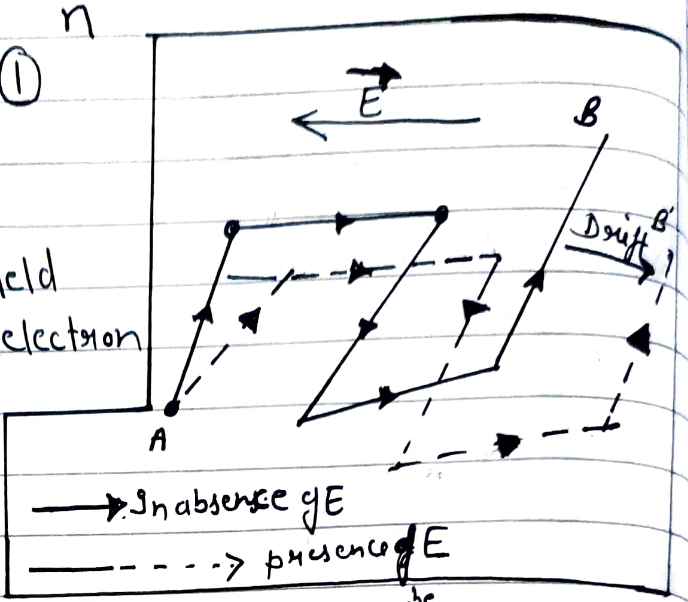
Derivation for drift velocity ⇒

When no electric field is applied then electrons of the conductor are moving with thermal velocity and their average velocity is zero.

When electric current flows through a conductor then electric field is not zero

$$\vec{u}_{av} = \frac{\vec{u}_1 + \vec{u}_2 + \vec{u}_3 + \cdots \vec{u}_n}{n} = 0$$

$$\boxed{\vec{u}_{av} = 0} \quad - ①$$



But when electric field is applied then each electron will experience force

$\vec{F} = q\vec{E}$ $q = -e$

$\vec{F} = -e\vec{E}$

so due to this force electrons will be accelerated

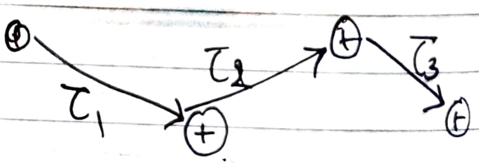
$$\vec{a} = \frac{\vec{F}}{m} = \frac{-e\vec{E}}{m} \Rightarrow \boxed{a = \frac{-eE}{m}} \quad - ②$$

As the electrons collide they frequently collide with positive metal ions or other electrons of the metal

Between two succesive collision an electron gains velocity but it last for very short period of time and is lost during next collision.

$\tau_{av} = \tau =$ relaxation time $= \dfrac{\tau_1 + \tau_2 + \tau_3 + \tau_4 \cdots \tau_n}{n}$

$$\boxed{\tau = \frac{\tau_1 + \tau_2 + \tau_3 + \cdots \tau_n}{n}}$$



Relaxation time $(10^{-14}s)$ ⇒ It is the averge time gap b/w two sucessive collision suffer by electron

The average velocity attain by each electron ~~due~~ after collision is

$$\vec{V}_1 = \vec{u}_1 + \vec{a}\tau_1$$

$$V_2 = \vec{u}_2 + \vec{a}\tau_2$$

$$\vdots$$

$$\vec{V}_n = \vec{u}_n + \vec{a}\tau_n$$

average velocity of N electrons after collision

$$\vec{V}_{av} = \frac{\vec{v}_1 + \vec{V}_2 + \vec{V}_3 + \cdots \vec{V}_n}{N}$$

$$\vec{V}_{av} = \frac{(\vec{u}_1 + \vec{a}\tau_1) + (\vec{u}_2 + \vec{a}\tau_2) + \cdots (\vec{u}_n + \vec{a}\tau_n)}{N}$$

$$V_{av} = \left(\frac{\vec{u}_1 + \vec{u}_2 + \cdots \vec{u}_n}{n}\right) + \vec{a}\left(\frac{\tau_1 + \tau_2 + \tau_3 + \cdots + \tau_n}{N}\right)$$

$$\vec{V}_d = 0 + \vec{a}\tau$$

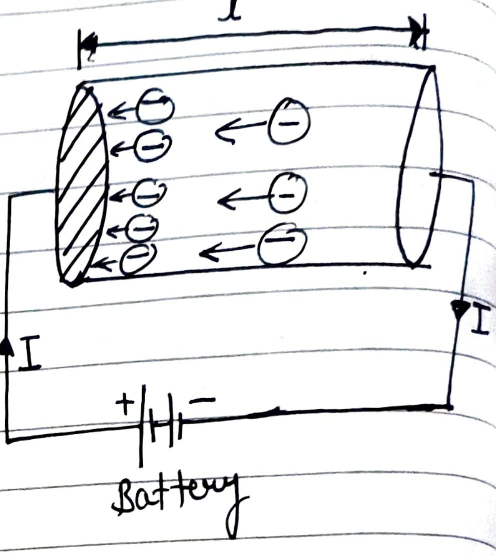
$$\left\{ \begin{array}{l} \vec{V}_{av} = \vec{V}_d \\ \vec{a} = \frac{-e\vec{E}}{m} \end{array} \right.$$

$$\boxed{V_d = \frac{-e\vec{E}}{m}\tau}$$

Drift velocity decreases with increase in temperature

Drift velocity is very slow and it is of order of mm/s

Relationship b/w drift velocity and Electric Current



Let

N = Total No. of electrons
n = Total No. of electrons per unit Volume

$N = n \times \text{volume of conductor}$
$N = n(Al)$

$$I = \frac{Q}{t} \quad — ①$$

$Q = Ne$
$Q = nAle \quad — ②$

Put the value of ② in equation ①

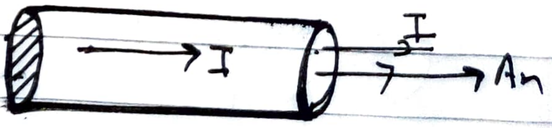
$$I = \frac{nAle}{t}$$

$$\boxed{I = neAV_d}$$

$$\left\{ V_d = \frac{l}{t} \right\}$$

Current Density ⇒ The current density at any point inside a conductor is defined as amount of charge flowing per second through unit area held normal to the direction of flow of charge at that point.

$$J = \frac{I}{A}$$

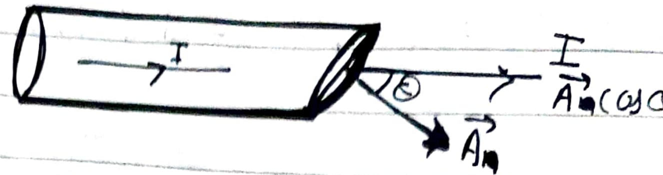


$J = \frac{I}{A_n}$

$J = \frac{I}{A\cos Q}$

$I = J\,A\cos Q$

$$\boxed{I = \vec{J}\cdot\vec{A}}$$



from this relationship we can conclude that current density is a vector quantity

Mobility ⇒ It is defined as magnitude of the drift velocity per unit electric field.

$$\mu = \frac{|\vec{V_d}|}{E}$$

since $V_d = \frac{Ee\tau}{m}$

so $\mu = \frac{Ee\tau}{Em}$

$$\boxed{\mu = \frac{e\tau}{m}}$$

Mobility is positive for both electron and hole

OHM'S LAW

According to ohm's law the current flowing through a conductor is directly proportional to the potential difference applied across its ends, provided the temprature and other physical conditions like length and area of cross-section remain same.

$$V \propto I$$

$$V = IR \Rightarrow \frac{V}{I} = R = \text{constant}$$

where R = Resistance

Derivation for ohm's law

$$I = neAV_d$$

$\left\{ V_d = \frac{eE\tau}{m} \right.$

$$I = neA\left(\frac{eE\tau}{m}\right)$$

$\left\{ E = \frac{V}{l} \right.$

$$I = \frac{ne^2A\tau}{m}\left(\frac{V}{l}\right)$$

$$\frac{I}{V} = \frac{ne^2A\tau}{ml}$$

$$\frac{V}{I} = \frac{ml}{ne^2A\tau}$$

taking Reciprocal on both side

$$\frac{V}{I} = \text{constant} = R$$

$$\boxed{R = \frac{ml}{ne^2A\tau}}$$

Resistance depends upon length, area and temprature

Resistance ⇒ The tendency of a conductor to resist flow of charges through it is known as resistance.

Resistance depends upon

(i) It is directly proportional to length

$R \propto l$ —①

(ii) It is inversely proportional to Area

$R \propto \frac{1}{A}$ —②

from ① and ②

$R \propto \frac{l}{A} \Rightarrow \boxed{R = \frac{\rho l}{A}}$ where ρ = Resistivity

SI unit of Resistance = Ω

Resistivity ⇒ It is the resistance offered by a conductor having unit length and unit cross-sectional area.

$$R = \frac{\rho l}{A}$$

$$\rho = \frac{RA}{l}$$

$$\rho = \left(\frac{ml}{ne^2 A \tau}\right) \times \frac{A}{l} \Rightarrow \boxed{\rho = \frac{m}{ne^2 \tau}}$$

※ Above equation proves that resistivity is independent of length and cross sectional area.

※ Resistivity depends upon temp.

Conductance ⇒ The reciprocal of resistance is known as conductance.

$$\boxed{G = \frac{1}{R}}$$

SI unit = Ω^{-1} OR mho OR Siemens.

Conductivity ⇒ The reciprocal of resistivity is known as conductivity

$$\boxed{\sigma = \frac{1}{\rho}}$$ SI unit = $ohm^{-1}m^{-1}$

Ohm's law In Vector form

$V = IR$

$V = I\frac{\rho l}{A}$ $\left\{ R = \frac{\rho l}{A} \right.$

$El = \cancel{I}\, J\rho l$ $\left\{ \begin{array}{l} V = El \\ J = \frac{I}{A} \end{array} \right.$

$E = J\rho$

$J = \frac{E}{\rho}$ $\left\{ \frac{1}{\rho} = \sigma \right.$

$$\boxed{\vec{J} = \sigma\vec{E}}$$

Temperature Coefficient of Resistivity

The resistivity increases linearly with increase in temp around the room temp. Resistivity at any temp (T) is given by

$$\rho = \rho_0 [1 + \alpha(T - T_0)] \quad ①$$

$$\boxed{\alpha = \frac{\rho - \rho_0}{\rho_0(T - T_0)}}$$

Coefficient of Resistivity (α) ⇒ It is defined as increase in resistivity per unit resistivity per degree rise in temp.

✩ α is positive for metal.
✩✩ α is negative for semiconductor

equation ① can also written for resistance

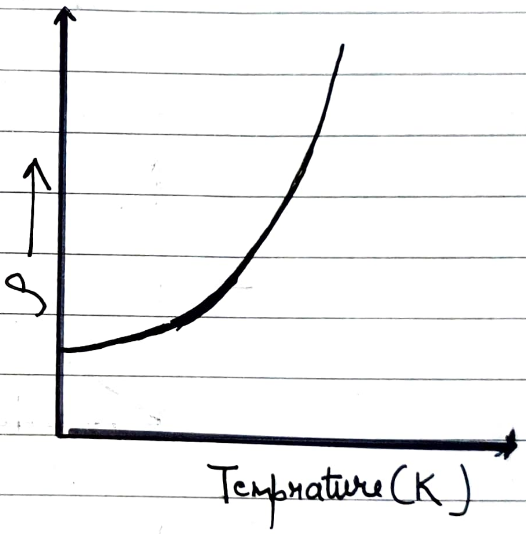
$$\boxed{R = R_0(1+\alpha\Delta t)}$$

Graph for Resistivity With temprature

(i) **For Metal (Copper, Aluminium)**

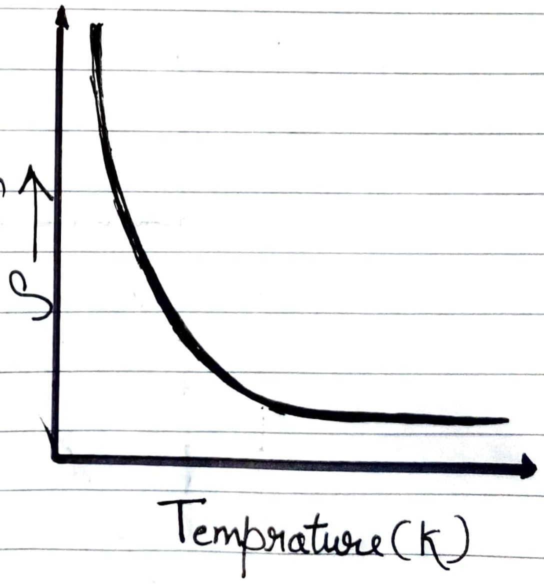
$$\rho = \frac{m}{ne^2\tau}$$

with increase in temp relaxation time decrease and no. of charge carriers remain same so resistivity increases.

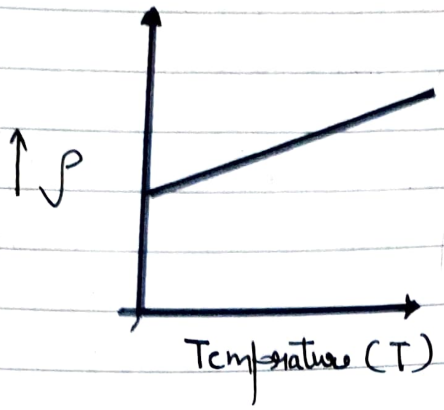


(ii) **For Semiconductor (Si, Ge)**

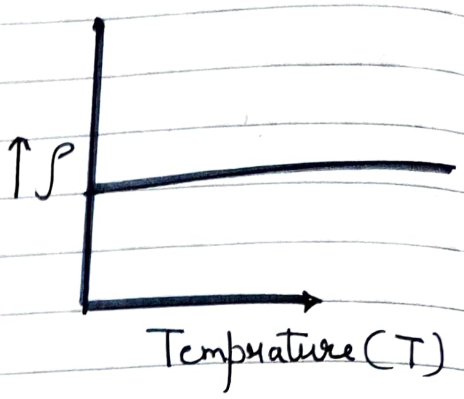
In semiconductor with increase in temp relaxation time decreases but due to increase in temprature Covalent bond breaks and large amount charge carriers are released which ultimately increases resistivity



III Alloy [Nichrome]

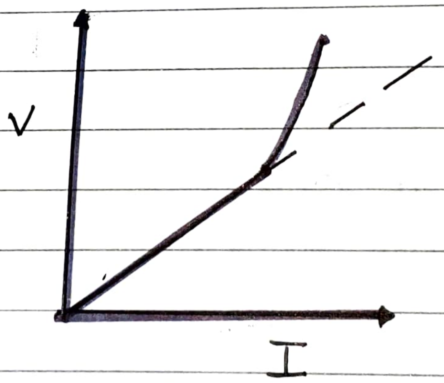


(iv) Insulator



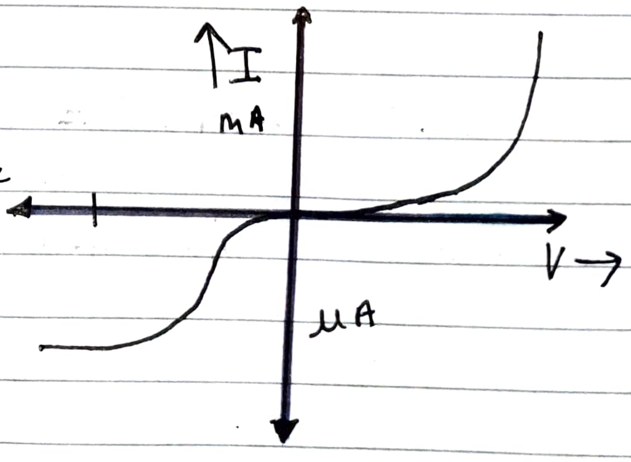
Limitations Of Ohm's law

(i) V does not remain proportional to I at higher value of current



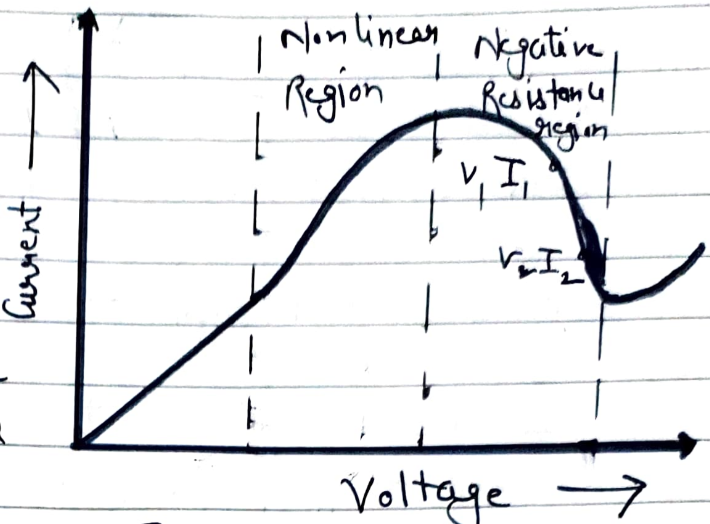
(ii) The relation b/w V and I depends upon sign of V

Characteristic curve of diode



(III) The relationship b/w V and I is not unique.

Graph of Semiconductor (GaAs)



★★ After certain voltage the current decreases with increase in voltage hence effective resistance is negative

$$\Delta R = \frac{\Delta V}{\Delta I}$$

$$\boxed{\text{so } \Delta R = -ve}$$

$\Delta I = I_2 - I_1$

$\Delta I = -ve$ since $I_2 < I_1$

Carbon Resistors

They are made from mixture of carbon black, clay and resin binder which are pressed and then moulded into cylindrical rods by heating.

The rods are enclosed in ceramic or plastic jackets.

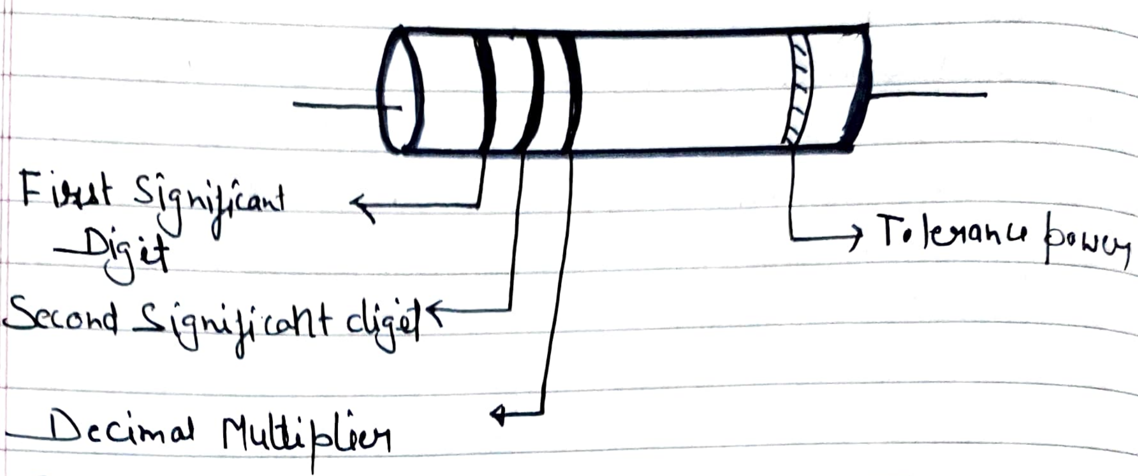
Advantage Of Carbon Resistance

(i) They can be made with resistance values ranging from few ohm's to several million ohm's.

(ii) They are quite cheap and compact.

(iii) They are good enough for many purposes.

Colour Code for Resistance.



0	1	2	3	4	5	6	7
Black	Brown	Red	Orange	Yellow	Green	Blue	Voit
B	B	R	O	Y	Great	Britain	Very

8	9
Grey	White
Good	Wife

Gold = ± 5%
Silver = ± 10%
No colour = ± 20%

Example ⇒ For a resistance having colour bands as Red, Yellow, Brown and Gold

$$\text{Resistance} = (24 \times 10^{\overset{\text{Brown}}{1}} \pm 5\%)\,\Omega$$

Red Yellow Gold

Similiarly for Yellow, Green, Blue and Silver

$$R = (45 \times 10^{6} \pm 10\%)\,\Omega$$