Electrical Properties Of Materials (2)

Electron Mobility :

When an electric field is applied, a force is applied on the free electrons; The free electrons are accelerated in a direction opposite to that of the field because of their negative charge. In perfect lattice, the free electrons should accelerate as long as the electric field is applied, which would give rise to an electric current that is continuously increasing with time. However, the current reaches a constant value the instant that a field is applied, indicating that there exist what might be termed frictional forces, which counter this acceleration from the external field. These frictional forces result from the scattering of electrons by imperfections in the crystal lattice, including impurity atoms, vacancies, interstitial atoms, dislocations, and even the thermal vibrations of the atoms themselves. Each scattering event causes an electron to lose kinetic energy and to change its direction of motion, as represented schematically in Figure 1.

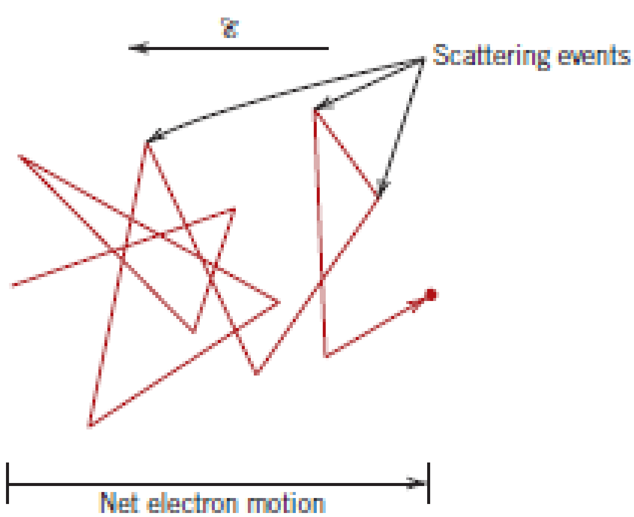

Figure 1

There is, some net electron motion in the direction opposite to the field, and this flow of charge is the electric current. The scattering phenomenon is manifested as a resistance to the passage of an electric current. Several parameters are used to describe the extent of this scattering; these include the drift velocity and the mobility of an electron. The drift velocity $\boldsymbol{v_d}$ represents the average electron velocity in the direction of the force imposed by the applied field. It is directly proportional to the electric field as follows:

$$v_d = \mu_e E \qquad (1)$$

The constant of proportionality $\boldsymbol{\mu_e}$ is called the electron mobility and is an indication of the frequency of scattering events; its units are square meters per volt-second ($m^2/V\cdot s$). The conductivity $\boldsymbol{\sigma}$ of most materials may be expressed as:

$$\sigma = n|e|\mu_e \qquad (2)$$

where n is the number of free or conducting electrons per unit volume (e.g., per cubic meter) and |e| is the absolute magnitude of the electrical charge on an electron (1.6 × 10−19 C). Thus, the electrical conductivity is proportional to both the number of free electrons and the electron mobility.

Example: A metal object having a length (10 m), cross section area (0.5 mm2), and resistance (0.34 Ω) is connected to a potential difference source (5 V). If the density (concentration) of free electrons equals (8.5*1028 electron/m3), Calculate:

1) The object’s conductivity.

2) The electron’s mobility.

3) The current density through the object.

Electrical Resistivity Of Metals

Most metals are extremely good conductors of electricity; room-temperature conductivities for several of the more common metals are given in Table 1.

Metal	*Electrical Conductivity* $[(\Omega \cdot m)^{-1}]$
Silver	6.8×10^7
Copper	6.0×10^7
Gold	4.3×10^7
Aluminum	3.8×10^7
Brass (70 Cu–30 Zn)	1.6×10^7
Iron	1.0×10^7
Platinum	0.94×10^7
Plain carbon steel	0.6×10^7
Stainless steel	0.2×10^7

Table 1

Metals have high conductivities because of the large numbers of free electrons that have been excited into empty states above the Fermi energy. At this point it is convenient to discuss conduction in metals in terms of the resistivity, the reciprocal of conductivity. Because crystalline defects serve as scattering centers for conduction electrons in metals, increasing their number raises the resistivity (or lowers the conductivity). The concentration of these imperfections depends on temperature and composition. In fact, it has been observed experimentally that the total resistivity of a metal is the sum of the contributions from thermal vibrations, impurities, and plastic deformation—that is, the scattering mechanisms act independently of one another. This may be represented in mathematical form as follows:

$$\rho_{total} = \rho_t + \rho_i + \rho_d$$

in which ρ_t, ρ_i, and ρ_d represent the individual thermal, impurity, and deformation resistivity contributions, respectively. The influence of temperature and impurity content on total resistivity is demonstrated in Figure 2, a plot of resistivity versus temperature for high-purity copper and several copper–nickel alloys. For all four metals, resistivity increases with increasing temperature. Furthermore, at a specific emperature (for example, −100°C), resistivity for the three Cu–Ni alloys is greater than for "pure" copper, and increases with nickel content.

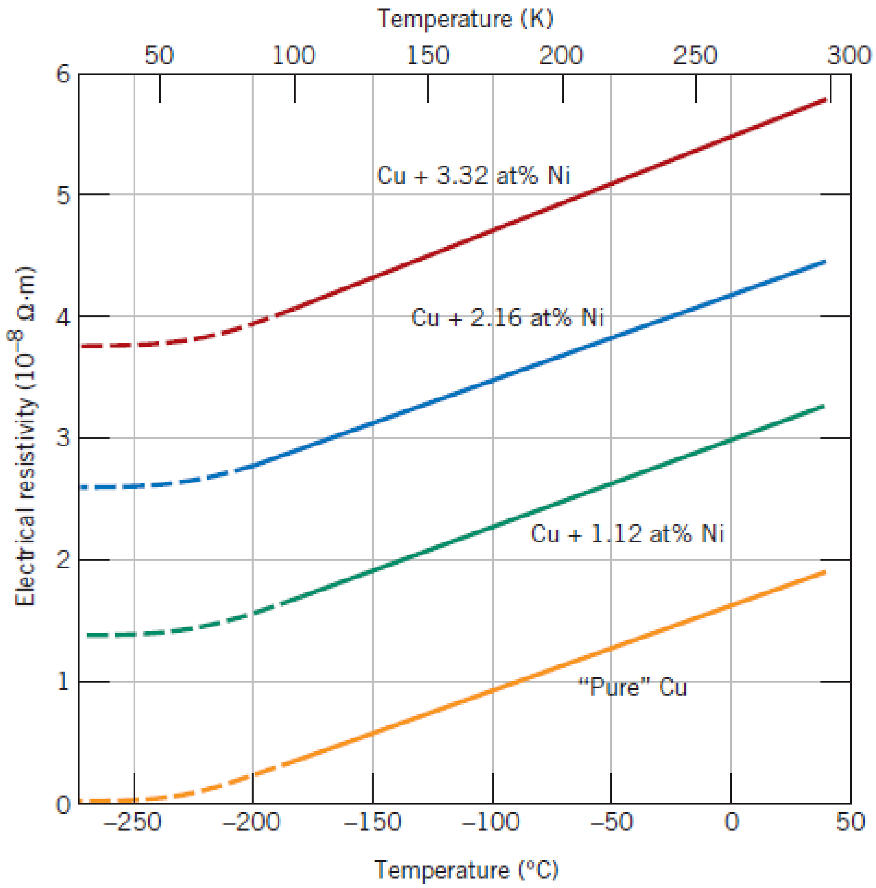

Figure 2

For the pure metal and all the copper–nickel alloys shown in Figure 2, the resistivity rises linearly with temperature above about −200°C. Thus,

$$\rho_t = \rho_0 + aT$$

where ρ_0 and a are constants for each particular metal. This dependence of the thermal resistivity component on temperature is due to the increase with temperature in thermal vibrations and other lattice irregularities (e.g., vacancies), which serve as electron scattering centers.

Electrical Characteristics of Commercial Alloys

Electrical and other properties of copper render it the most widely used metallic conductor. Oxygen-free high-conductivity (OFHC) copper, having extremely low oxygen and other impurity contents, is produced for many electrical applications. Aluminum, having a conductivity only about one-half that of copper, is also frequently used as an electrical conductor. Silver has a higher conductivity than either copper or aluminum; however, its use is restricted on the basis of cost.

For some applications, such as furnace heating elements, a high electrical resistivity is desirable. The energy loss by electrons that are scattered is dissipated as heat energy. Such materials must have not only a high resistivity, but also a resistance to oxidation at elevated temperatures and, of course, a high melting temperature. Nichrome, a nickel–chromium alloy, is commonly employed in heating elements.