Drift

Drift *is the motion of charge carriers caused by an electric field. This means the voltage is applied to a semiconductor material.*

Note: The drift velocity is so much more important than the thermal velocity in semiconductor devices. A faster carrier velocity is desirable, for it allows a semiconductor device or circuit to operate at a higher speed.

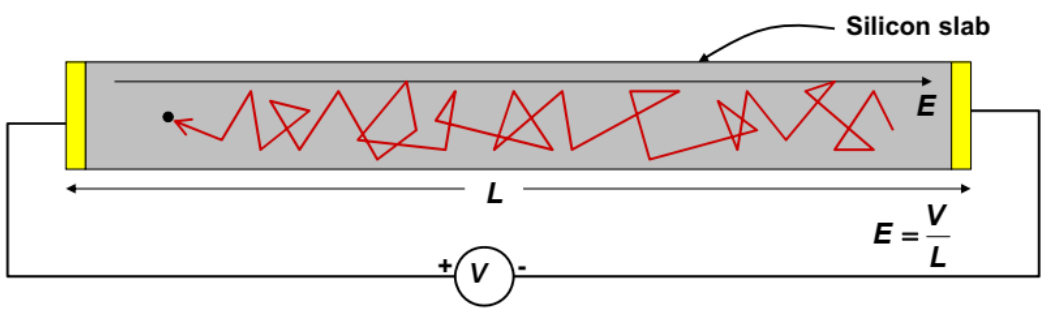
Mobility of carriers

When an electric field is applied to the semiconductor, both the free electrons (residing in the conduction band) and the holes (left behind in the valence band) move through the crystal, producing an electric current. The electrical conductivity of a material depends on the number of free electrons and holes (charge carriers) per unit volume and the mobility of carriers. Mobility *is the parameter that determines how fast a carrier, i.e., electron or hole, can move in a solid material under an applied electric field.* It is limited by collisions of electrons and holes with other carriers, with crystal defects, and with phonons (lattice vibrations). These scattering events slow down the carriers and constitute the electrical resistance of the material.

A. Electron mobility

Figure 16 shows the motion of electrons in Si material under an applied electric field. The electron moves in the direction opposite to the applied field with a constant drift velocity equal to v_{dn}.

Figure 16.



The electron drift velocity v_{dn} is proportional to the electric field

$$v_{dn} \propto -E$$

So, $$v_{dn} = -\mu_n E \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The force on the electron because of the electric field (E) is

$$F_{ext} = -qE \ldots\ldots\ldots\ldots\ldots (2)$$

where q is an electron charge (= 1.6 x 10^{-19} C).

The acceleration of electron, $a = \frac{F_{ext}}{m_n^*} \ldots\ldots\ldots\ldots\ldots (3)$

Substitute eq.(2) in eq.(3), we get:

$$a = -\frac{q\,E}{m_n^*} \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

The average drift velocity of the electron is

$$v_{dn} = a\,\tau_n \ \ldots\ldots\ldots\ldots\ldots\ldots (5)$$

where τ_n is the mean time between collisions (scattering time of electrons).

Substitute eq.(4) in eq.(5), we get:

$$v_{dn} = -\frac{q\,\tau_n}{m_n^*}\,E \ \ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Comparing eq.(1) with eq.(6), we get:

$$\mu_n = \frac{q\,\tau_n}{m_n^*} \ldots\ldots\ldots\ldots\ldots\ldots (7)$$

The constant μ_n is called electron mobility, which its unit is : $\frac{\text{m}^2}{\text{V.s}}$. For example, the electron mobility of pure silicon is $\approx$ 1350 $\frac{\text{cm}^2}{\text{V.s}}$.

B. Hole mobility

Figure 17 shows the motion of holes in Si material under an applied electric field. The hole moves in the direction of the applied field with a constant drift velocity equal to v_{dp}.

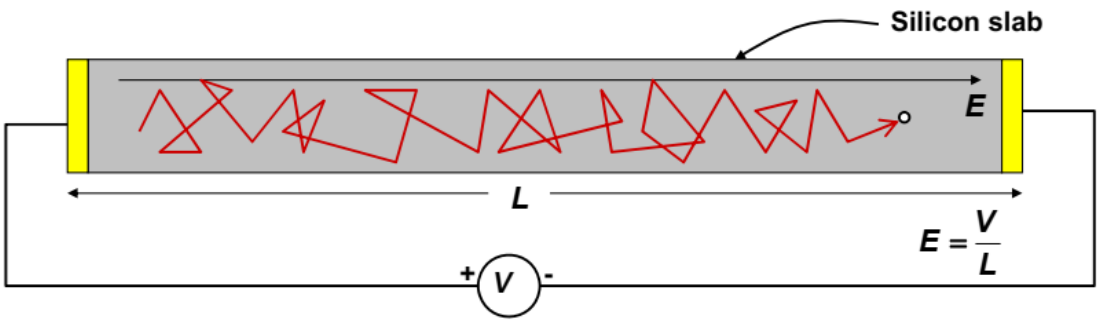


Figure 17.

The hole drift velocity v_{dp} is proportional to the electric field

$$v_{dp} \propto E$$

So, $$v_{dp} = \mu_p E$$

The force on the hole because of the electric field (E) is

$$F_{ext} = qE$$

Similarly, for holes, hole mobility is

$$\mu_p = \frac{q\,\tau_p}{m_p^*} \quad \dots \dots \dots \dots \dots \dots (8)$$

where τ_p is the mean scattering time of holes. For example, the hole mobility of pure silicon is $\approx 450\ \frac{\text{cm}^2}{\text{V.s}}$.

Example: Consider the electron mobility of pure Si is 1350 $cm^2.V^{-1}.s^{-1}$ and μ_p is 450 $cm^2.V^{-1}.s^{-1}$. The effective masses are m_n^* is 0.26m_e and m_p^* is 0.38m_e. Find the scattering time for electrons and holes.

Solution:

For electrons,

$$\mu_n = \frac{q\ \tau_n}{m_n^*}$$

$$\tau_n = \frac{\mu_n m_n^*}{q} = \frac{(0.135) \times (0.26 \times 9.1 \times 10^{-31})}{1.6 \times 10^{-19}} = 2 \times 10^{-13}\text{s}$$

For holes,

$$\mu_p = \frac{q\ \tau_p}{m_p^*}$$

$$\tau_p = \frac{\mu_p m_p^*}{q} = \frac{(0.045) \times (0.38 \times 9.1 \times 10^{-31})}{1.6 \times 10^{-19}} = 1 \times 10^{-13}\text{s}$$