The Intrinsic Fermi-Level Position

Fermi energy level is located near the center of **the** forbidden bandgap for the intrinsic semiconductor. We can calculate the intrinsic Femi-level position. Since the electron and hole concentrations **are** equal

$$n_i = n_c = n_v = N_c\, exp\left(\frac{E_f - E_c)}{K_\beta T}\right) = N_v exp\left(\frac{E_v - E_f)}{K_\beta T}\right)$$

If we take the natural log of both sides of this equation and solve for E_F,. we obtain

$$E_{Fi} = \frac{1}{2}(E_c + E_v) + \frac{1}{2}K_\beta T \ln\frac{N_v}{N_c}$$

Substitute the value of N_c, N_v we get

$$E_{Fi} = \frac{1}{2}(E_c + E_v) + \frac{3}{4}K_\beta T \ln(\frac{m_p^*}{m_n^*})$$

The first term $\frac{1}{2}(E_c + E_v)$ is the energy exactly midway between E_c and E_v or the midgap energy. We can define

$$E_{midgap} = \frac{1}{2}(E_c + E_v)$$

So that

$$E_{Fi} - E_{midgap} = \frac{3}{4}K_\beta T \ln(\frac{m_p^*}{m_n^*})$$

If the electron and hole effective masses are equal so that $m_n^* = m_p^*$**,** then the intrinsic Fermi level is exactly in the center of the bandgap. If $m_n^* > m_p^*$**.** the intrinsic Fermi level is slightly above the center, and if $m_n^* < m_p^*$ it is slightly below the center of the bandgap. The density of states function is directly related to the carrier effective mass: thus a larger effective mass means a larger density of states function. The intrinsic Fermi level must shift away from the band with the larger density of states in order to maintain equal numbers of electrons and holes.

Exp :To calculate the position of the intrinsic Fermi level with respect to the center of the bandgap in silicon at T = *300 K.*

The density of states effective carrier masses in silicon are **,** $m_n^* = 1.08\, m_o$, $m_p^* = 056\, m_o$

SOLUTION : The intrinsic Fermi level with respect to the center of the bandgap is

$$E_{Fi} - E_{midgap} = \frac{3}{4}K_\beta T \ln(\frac{m_p^*}{m_n^*}) = \frac{3}{4}(0.0259)\ln(\frac{0.56}{1.08})$$

$$E_{Fi} - E_{midgap} = -0.0128\, eV = -12.8\, me\, V$$

Comment : The intrinsic Fermi level in silicon is 12.8 meV below the midgap energy. If we compare 12.8 meV to 560 meV, which is one-half of the bandgap energy of silicon, we can, in many applications, simply approximate the intrinsic Fermi level to be in the center of the bandgap

applying the Boltzmann approximation to Equation *(4.3),* the thermal-equilibrium density of electrons in the conduction band is found from

$$n_0 = \int_{E_c}^{\infty} \frac{4\pi(2m_n^*)^{3/2}}{h^3} \quad \int_0^{\infty} \eta^{1/2} \exp(-\eta)\, d\eta$$

$$\eta = \frac{E - E_c}{kT} \tag{4.6}$$

$$\int_0^{\infty} \eta^{1/2} \exp(-\eta)\, d\eta = \frac{1}{2}\sqrt{\pi}$$

$$n_0 = 2\left(\frac{2\pi m_n^* kT}{h^2}\right)^{3/2} \exp\left[\frac{-(E_c - E_F)}{kT}\right]$$

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$$n_0 = N_c \exp\left[\frac{-(E_c - E_F)}{kT}\right]$$

The parameter *N,* is called the *effective density states function in the conduc**tion** band.* If we were to assume that *m** = ***mo,*** then the value of the effective density of states function at T = 300 K is N_c = 2.5 x 10" cm^{-3}, which is the order of magnitude of *N,* for most semiconductors. If the effective mass of the electron is larger or smaller than ***mo,*** then the value of the effective density of states function changes accordingly, but is still of the same order of magnitude.