P-1.16

$$N(x,t) = \underbrace{\frac{\Phi}{\sqrt{\pi D t}}}_{N_s} e^{-\frac{x^2}{4Dt}}$$

At the P-N junction ($x = x_j$), $N(x,t) = N_A$:

$$N_A = N_s e^{-\frac{x_j^2}{4Dt}} \Rightarrow t = \frac{x_j^2}{4D \ln \frac{N_s}{N_A}} ,$$

$$t = \frac{(2 \times 10^{-6})^2}{4 \times \underbrace{3.43 \times 10^{-17}}_{} \times \ln \frac{5 \times 10^{16}}{10^{15}}} ,$$

in m^2/s

$$\boxed{t = 7452s}$$

$$N_s = \frac{\Phi}{\sqrt{\pi D t}} \Rightarrow \Phi = N_s \sqrt{\pi D t} = 5 \times 10^{22} \sqrt{\pi 3.43 \times 10^{-17} \times 7452} , \qquad \text{(M.13)}$$

m^{-3}

$$\boxed{\Phi = 4.48 \times 10^{12} cm^{-2}}$$

P-1.17

$$R_S = \frac{1}{x_j \bar{\sigma}} = \frac{1}{\int_0^\infty q\mu_n n(x) dx} = \frac{1}{q\mu_n \int_0^\infty n(x) dx} , \qquad \text{(M.14)}$$

where

$$n(x) = N_s e^{-\frac{x^2}{4Dt}} ,$$

To calculate the integral

$$\int_0^\infty n(x) dx = N_s \int_0^\infty e^{-\frac{x^2}{4Dt}} dx ,$$

we use $x/\sqrt{4Dt} = u/\sqrt{2}$ and $dx = \sqrt{2Dt} du$:

$$\int_0^\infty n(x) dx = \sqrt{2Dt} N_s \underbrace{\int_0^\infty e^{-\frac{u^2}{2}} du}_{\sqrt{\pi/2}} = \sqrt{\pi D t} N_s . \qquad \text{(M.15)}$$

From Eqs. (M.15) and (M.14),

$$R_S = \frac{1}{q\mu_n \sqrt{\pi D t} N_s} \qquad \text{(M.16)}$$

$$= \frac{1}{1.6 \times 10^{-19} \times 0.125 \sqrt{\pi 3.43 \times 10^{-17} \times 7452} \times 5 \times 10^{22}} ,$$

$$\boxed{R_S = 1116 \Omega / \square}$$

P-1.25

According to the result of Example 1.14,

$$TCR = \frac{3}{2T} \times 100 = \frac{3}{2 \times (273.15 + 75)} \times 100 = 0.43\%/^{\circ}C \ ,$$

$$\Delta R = \frac{TCR}{100} R \Delta T = 0.0043 \times 1000 \times 10 = 43\Omega \ ,$$

$$\boxed{R \pm \Delta R = 1000 \pm 43\Omega}$$

P-1.31

As

$$n = N_C \mathrm{e}^{-\frac{E_C - E_F}{kT}} \ ,$$

we need to find $E_C - E_F$. From the text, we can conclude that E_F is a quarter of the band-gap below E_i:

$$E_i - E_F = \frac{E_g}{4}$$

$$E_C - E_F = \frac{E_g}{2} + \frac{E_g}{4} = \frac{3}{4} E_g = 0.84eV \ .$$

Therefore,

$$n = 2.86 \times 10^{19} \mathrm{e}^{-\frac{0.84}{0.026}} \ ,$$

$$\boxed{n = 2.66 \times 10^5 cm^{-3}} \text{ It is P-type.}$$

P-1.32

From Table 1.6, we find

$$N_C = A_C T^{3/2} \ , \ N_V = A_V T^{3/2} \ ,$$

and the room-temperature values $N_C(300K) = 2.86 \times 10^{19} cm^{-3}$, $N_V(300K) = 3.10 \times 10^{19} cm^{-3}$. To be able to calculate the density of states at any other temperature, we need to find A_C and A_V constants:

$$A_C = N_C T^{-3/2} = 2.86 \times 10^{19} \times 300^{-3/2} = \underline{5.50 \times 10^{15} cm^{-3} K^{-3/2}} \ ,$$

$$A_V = N_V T^{-3/2} = 3.10 \times 10^{19} \times 300^{-3/2} = \underline{5.97 \times 10^{15} cm^{-3} K^{-3/2}} \ .$$

Therefore, at $300°C$ we have

$$N_C = 5.50 \times 10^{15} \times (273.15 + 300)^{3/2} = 7.55 \times 10^{19} cm^{-3} \ ,$$

$$N_V = 5.97 \times 10^{15} \times (273.15 + 300)^{3/2} = 8.19 \times 10^{19} cm^{-3} \ ,$$

The energy gap at $300°C$ is:

$$E_g = 1.17 - \frac{7.02 \times 10^{-4} T^2}{T + 1108} = 1.17 - \frac{7.02 \times 10^{-4} (273.15 + 300)^2}{273.15 + 300 + 1108} = 1.03eV \ .$$

The intrinsic carrier concentration is given by Eq. (1.69)

$$n_i = \sqrt{N_C N_V} \ e^{-\frac{E_g}{2kT}} ,$$

$$n_i = \sqrt{7.55 \times 10^{19} \times 8.19 \times 10^{19}} \ e^{-\frac{1.03}{2 \times 8.62 \times 10^{-5} (273.15 + 300)}} ,$$

$$\boxed{n_i = 2.34 \times 10^{15} cm^{-3}}$$

The intrinsic carrier concentration is higher than the doping level of $N_D = 10^{15} cm^{-3}$.