* حول جميع الارقام إلى وحدة Cm.
* حول درجات الحرارة الى K كلفن

TABLE 3.2 Summary of Important Equations for *pn*-Junction Operation

Quantity	Relationship	Values of Constants and Parameters (for Intrinsic *Si* at $T = 300$ K)
Carrier concentration in intrinsic silicon (/cm³)	$n_i^2 = BT^3 e^{-E_G/kT}$ [/cm³] تعتمد فقط على الحرارة.	$B = 5.4 \times 10^{31}/(K^3 cm^6)$ $E_G = 1.12$ eV $k = 8.62 \times 10^{-5}$ eV/K $n_i = 1.5 \times 10^{10}/cm^3$
Diffusion current density (A/cm²)	$J_p = -qD_p \frac{dp}{dx}$ $J_n = qD_n \frac{dn}{dx}$	$q = 1.60 \times 10^{-19}$ coulomb $D_p = 12\ cm^2/s$ $D_n = 34\ cm^2/s$ يجب معرفة الوحدات.
Drift current density (A/cm²)	$J_{drift} = q(p\mu_p + n\mu_n)E$	$\mu_p = 480\ cm^2/V \cdot s$ $\mu_n = 1350\ cm^2/V \cdot s$
Resistivity (Ω·cm)	$\rho = 1/[q(p\mu_p + n\mu_n)]$ [Ω·cm] $R = \rho\, L/A$ [Ω]	μ_p and μ_n decrease with the increase in doping concentration
Relationship between mobility and diffusivity	$\frac{D_n}{\mu_n} = \frac{D_p}{\mu_p} = V_T$	$V_T = kT/q$ $\simeq 25.8$ mV
Carrier concentration in *n*-type silicon (/cm³)	$n_{n0} \simeq N_D$ $p_{n0} = n_i^2/N_D$	

Quantity	Relationship	Values of Constants and Parameters (for Intrinsic *Si* at $T = 300$ K)
Carrier concentration in *p*-type silicon (/cm³)	majority: $p_{p0} \simeq N_A$ (function of doping only!) minority: $n_{p0} = n_i^2/N_A$ (function of temperature)	
Junction built-in voltage (V)	$V_0 = V_T \ln\left(\frac{N_A N_D}{n_i^2}\right)$	
Width of depletion region (cm)	$\frac{x_n}{x_p} = \frac{N_A}{N_D}$ $W_{dep} = x_n + x_p$ $= \sqrt{\frac{2\varepsilon_s}{q}\left(\frac{1}{N_A} + \frac{1}{N_D}\right)(V_0 + V_R)}$	$\varepsilon_s = 11.7\varepsilon_0$ $\varepsilon_0 = 8.854 \times 10^{-14}$ F/cm
Charge stored in depletion layer (coulomb)	$q_J = q\frac{N_A N_D}{N_A + N_D} A W_{dep}$	
Depletion capacitance (F)	$C_j = \frac{\varepsilon_s A}{W_{dep}}$, $C_{j0} = \frac{\varepsilon_s A}{W_{dep}\vert_{V_R=0}}$ $C_j = C_{j0}\Big/\left(1 + \frac{V_R}{V_0}\right)^m$ $C_j \simeq 2C_{j0}$ (for forward bias)	$m = \frac{1}{3}$ to $\frac{1}{2}$
Forward current (A)	$I = I_p + I_n$ $I_p = Aqn_i^2 \frac{D_p}{L_p N_D}(e^{V/V_T} - 1)$ $I_n = Aqn_i^2 \frac{D_n}{L_n N_A}(e^{V/V_T} - 1)$	
Saturation current (A)	$I_S = Aqn_i^2\left(\frac{D_p}{L_p N_D} + \frac{D_n}{L_n N_A}\right)$	
Minority-carrier lifetime (s)	$\tau_p = L_p^2/D_p$ $\quad \tau_n = L_n^2/D_n$	$L_p, L_n = 1\ \mu m$ to $100\ \mu m$ $\tau_p, \tau_n = 1$ ns to 10^4 ns
Minority-carrier charge storage (coulomb)	$Q_p = \tau_p I_p$ $\quad Q_n = \tau_n I_n$ $Q = Q_p + Q_n = \tau_T I$	
Diffusion capacitance (F)	$C_d = \left(\frac{\tau_T}{V_T}\right) I$	

mass action low ⇒ $n \cdot p = n_i^2$ (for intrinsic)

" " " ⇒ $n_{p_0} \cdot p_{p_0} = n_i^2$ (for doped)

Doped:
p_{p_0} → Concentration of holes → when doped with acceptor → at equilibrium.
n_{p_0} → Concentration of electrons → when doped with acceptor → at steady state.

for intrinsic
* $n_i = n = p$
* at $T=0 \Rightarrow n = p = 0$
* There is only THERMAL: generation & recombination

Ex 3.29 p. 106

Q, Calculate the intrinsic carrier density (n_i)

at: 250K, 300 k, 200 °C

① $n_i^2 = BT^3 e^{-\frac{EG}{KT}}$

$n_i^2 = 5.4 \times 10^{31} \times (250)^3 e^{\left(\frac{-1.12}{8.62 \times 10^{-5} \times 250}\right)}$

$n_i^2 = 2.26 \times 10^{16} \Rightarrow n_i = 1.5 \times 10^8 /cm^3$

② $n_i^2 = 5.4 \times 10^{31} (300)^3 e^{\left(\frac{-1.12}{8.62 \times 10^{-5} \times 300}\right)}$

$n_i^2 = 2.26 \times 10^{20} \Rightarrow n_i = 1.5 \times 10^{10} /cm^3$

③ $T = 200 + 273 = 473$ k

$n_i^2 = 5.4 \times 10^{31} \times (473)^3 e^{\left(\frac{-1.12}{8.62 \times 10^{-5} \times 473}\right)}$

$n_i^2 = 6.71 \times 10^{27} \Rightarrow n_i = 8.19 \times 10^{13} /cm^3$

(3.30) if we doped with donor $N_D = 10^{17}$, find electron and hole concentration at prevuous temperature,

① $N_D = 10^{17} \Rightarrow$ electrons $= 10^{17} /cm^3 = n$

$n \cdot p = n_i^2 \Rightarrow$ holes $= \frac{n_i^2}{n} = \frac{2.26 \times 10^{16}}{10^{17}} = 0.226 /cm^3$

②

$n = N_D = 10^{17} /cm^3$

$p = \frac{n_i^2}{n} = \frac{2.26 \times 10^{20}}{10^{17}} = 2.26 \times 10^3 /cm^3$

③

$n = N_D = 10^{17} /cm^3$

$\frac{n_i^2}{n} = p = \frac{6.71 \times 10^{27}}{10^{17}} = 6.71 \times 10^{10} /cm^3$

Ex 3.31) p 3107 find the resistivity of

ⓐ intrinsic silicon ⓑ p-type with $N_A = 10^{16}/cm^3$

use $n_i = 1.5\times10^{10}/cm^3$, $\mu_n = 1350\ cm^2/V$, $\mu_p = 480\ cm^2/V$
for intrinsic

use for doped $\mu_n = 1110\ cm^2/V$, $\mu_p = 400\ cm^2/V$

ⓒ find the resistance if $L = 3\mu m$, width $= 3\mu m$, thick $= 1\mu m$

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① $\rho = \dfrac{1}{q(p\mu_p + n\mu_n)}$ $\Rightarrow$ $n = 1.5\times10^{10} = p$ for intrinsic

الوحدات كلها cm

$$\rho = \frac{1}{1.6\times10^{-19}\left[1.5\times10^{10}\times1350 + 1.5\times10^{10}\times480\right]} = 2.28\times10^{5}\ \Omega\cdot cm$$

$$R = \rho\frac{L}{A} = 2.28\times10^{5} * \frac{3\mu m}{3\mu m\times1\mu m} = \frac{2.28\times10^{5}}{1\times10^{-4}\ cm} = 2.28\times10^{9}\ \Omega$$

② $\rho = \dfrac{1}{q(p\mu_p + n\mu_n)}$; $p = N_A = 10^{16}/cm^3$

$n_i = 1.5\times10^{10} \Rightarrow n = \dfrac{n_i^2}{p} = \dfrac{(1.5\times10^{10})^2}{10^{16}}$

$= ~~225/cm^3~~$ $22.5\times10^3/cm^3$

لا تستغر الجزارة

$$\rho = \frac{1}{1.6\times10^{-19}(10^{16}\times400 + 22.5\times10^3\times1110)} = 1.56\ \Omega\cdot cm$$

$$R = \rho\frac{L}{A} = 1.56\times\frac{3\mu m}{3\mu m\times1\mu m} = 1.56\times\frac{1}{10^{-4}\ cm} = 1.56\times10^{4}\ \Omega.$$

حولها cm

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if doping is n-type $N_D = 10^{16}$

$n = N_D = 10^{16} \Rightarrow p = \dfrac{(1.5\times10^{10})^2}{10^{16}} = 22.5\times10^3\ /cm$

$$\rho = \frac{1}{q(n\mu_n + p\mu_p)} = \frac{1}{1.6\times10^{-19}(10^{16}\times1110 + 22.5\times10^3\times400)} = 0.563\ \Omega\cdot cm$$

Cont →

Cont / Some of problem 3.112

* If temperature was increased to 473 K what is ρ for previos case (2). (ni depends on T)

Ans: $N_A = 10^{16} /cm = p$ *لا يعتمد على الحرارة

$n_i^2 \Big|_{473} = 6.71 \times 10^{27}$ — see problem (1) $\Rightarrow n = \dfrac{n_i^2}{p} = \dfrac{6.71 \times 10^{27}}{1 \times 10^{16}} = 6.71 \times 10^{11} /cm^3$

* يعتمد على الحرارة.

$$\rho = \frac{1}{q(n\mu_n \times p\mu_p)} = \frac{1}{1.6 \times 10^{-19}(6.71 \times 10^{11} \times 1110 + 10^{16} \times 400)} = 1.56\ \Omega\text{-cm}$$

التسلسل المنطقي لحل المسائل

(1) ادرس تأثير درجة الحرارة بحساب n_i أولاً

(2) كتب n, p بمعرفة n_i, N_D, N_A

(3) كتب ρ مع أخذ المعطيات μ_n, μ_p لأنها قد تتغير في المعطيات.

إذا كان السؤال بأكثر من فقرة وتغير بعض المعطيات
ابدأ من الخطوة (1) حتى لا تخطئ بالحسابات.
