VE320 Homework6

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2018-07-20

Ex 6.1

(a)

(i)

$$n_{p0} = \frac{n_i^2}{N_a} = \frac{(1.5 \times 10^{10}\,\mathrm{cm}^{-3})^2}{5 \times 10^{16}\,\mathrm{cm}^{-3}} = 4.5 \times 10^3\,\mathrm{cm}^{-3}$$
$$p_{n0} = \frac{n_i^2}{N_d} = \frac{(1.5 \times 10^{10}\,\mathrm{cm}^{-3})^2}{5 \times 10^{15}\,\mathrm{cm}^{-3}} = 4.5 \times 10^4\,\mathrm{cm}^{-3}$$
$$p_n(x_n) = p_{n0} \exp \frac{V_a}{V_t}$$
$$V_a = V_t \ln \frac{p_n(x_n)}{p_{n0}} = V_t \ln \frac{0.1N_d}{p_{n0}} = 0.599\,\mathrm{V}$$

(ii)

$n_{p0} < p_{n0}$, so n-region concentration is the factor.

(b)

(i)

$$n_{p0} = \frac{n_i^2}{N_a} = \frac{(1.5 \times 10^{10}\,\mathrm{cm}^{-3})^2}{7 \times 10^{15}\,\mathrm{cm}^{-3}} = 3.214 \times 10^4\,\mathrm{cm}^{-3}$$
$$p_{n0} = \frac{n_i^2}{N_d} = \frac{(1.5 \times 10^{10}\,\mathrm{cm}^{-3})^2}{3 \times 10^{16}\,\mathrm{cm}^{-3}} = 7.5 \times 10^3\,\mathrm{cm}^{-3}$$
$$n_p(-x_p) = n_{p0} \exp \frac{V_a}{V_t}$$
$$V_a = V_t \ln \frac{n_p(-x_p)}{n_{p0}} = V_t \ln \frac{0.1N_a}{n_{p0}} = 0.617\,\mathrm{V}$$

(ii)

$n_{p0} > p_{n0}$, po n-region concentration is the factor.

Ex 6.2

(a)

$$J_s = en_i^2 \left(\frac{1}{N_a} \sqrt{\frac{D_n}{\tau_{n0}}} + \frac{1}{N_d} \sqrt{\frac{D_p}{\tau_{p0}}} \right) = 5.145 \times 10^{-11}\,\mathrm{A/cm^2}$$

$$I_s = AJ_s = 2 \times 10^{-4}\,\mathrm{cm^2} \cdot 5.145 \times 10^{-11}\,\mathrm{A/cm^2} = 1.029 \times 10^{-14}\,\mathrm{A}$$

(b)

(i)

$$I = I_s \exp \frac{V_a}{V_t} = 1.029 \times 10^{-14}\,\mathrm{A} \exp \frac{0.45\,\mathrm{V}}{0.0259\,\mathrm{V}} = 3.615 \times 10^{-7}\,\mathrm{A}$$

(ii)

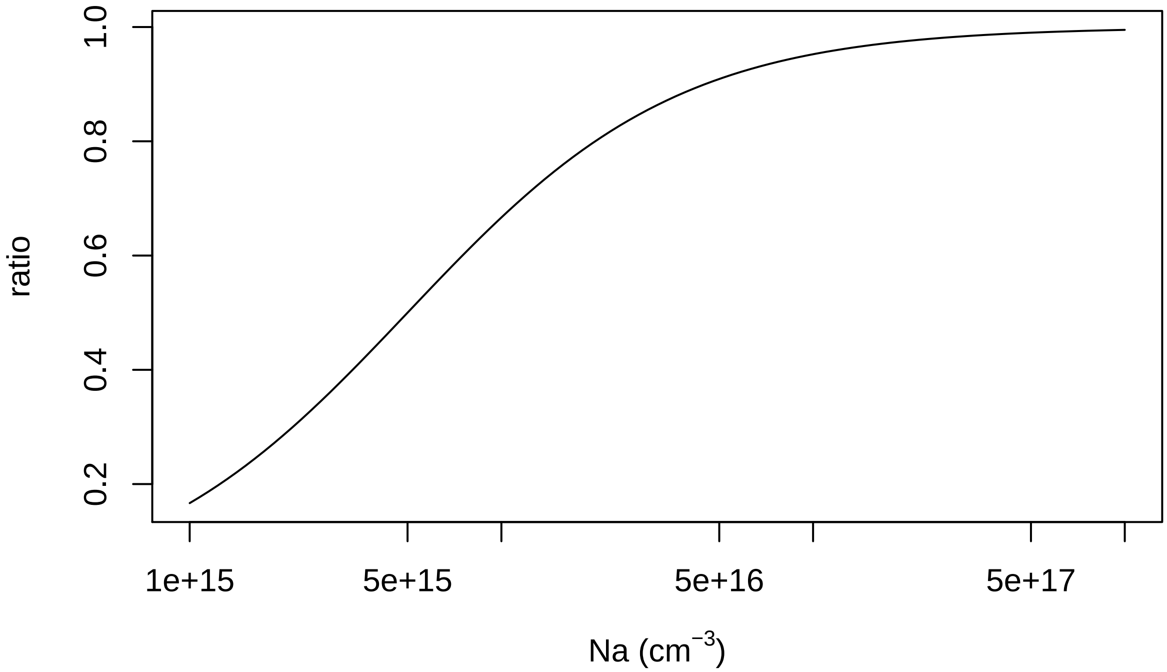
$$I = I_s \exp \frac{V_a}{V_t} = 1.029 \times 10^{-14}\,\mathrm{A} \exp \frac{0.55\,\mathrm{V}}{0.0259\,\mathrm{V}} = 1.717 \times 10^{-5}\,\mathrm{A}$$

(iii)

$$I = I_s \exp \frac{V_a}{V_t} = 1.029 \times 10^{-14}\,\mathrm{A} \exp \frac{0.65\,\mathrm{V}}{0.0259\,\mathrm{V}} = 8.160 \times 10^{-4}\,\mathrm{A}$$

Ex 6.3

```r
func <- function(Na) {
  Jn <- 1 / Na * sqrt(25 / 1e-6)
  Jp <- 1 / 1e16 * sqrt(10 / 1e-7)
  return(Jp / (Jn + Jp))
}
curve(func, from = 1e15, to = 1e18, xlab = TeX('Na (cm^{-3})'), ylab = 'ratio', log = 'x')
```



Ex 6.4

$$\frac{I_f}{I_s} = \exp\frac{V_a}{V_t}$$

$$V_t = \frac{V_a}{\ln(I_f/I_s)} = \frac{0.5\,\mathrm{V}}{\ln 2^4} = 5.049 \times 10^{-2}\,\mathrm{V}$$

$$T = \frac{300V_T}{0.0259} = 5.848 \times 10^2\,\mathrm{K}$$

$$\tau_{n0} = \tau_{p0} = 5 \times 10^{-7}\,\mathrm{s}$$

$$I_s = Aen_i^2\left(\frac{1}{N_a}\sqrt{\frac{D_n}{\tau_{n0}}} + \frac{1}{N_d}\sqrt{\frac{D_p}{\tau_{p0}}}\right)$$

$$1.2 \times 10^{-6} = 1.432 \times 10^{-34} n_i^2$$

$$n_i^2 = N_c N_v \exp\frac{-E_g}{kT}$$

$$n_i^2 = 8.379 \times 10^{27} = 2.8 \times 10^{19} \cdot 1.04 \times 10^{19} \cdot \left(\frac{T}{300}\right)^3 \cdot \exp\frac{-1.12}{0.0259 \cdot T/300}$$

$$T \approx 502.46\,\mathrm{K}$$

So the maximum temperature is $502.46\,\mathrm{K}$, J_s is the limiting factor.

Ex 6.5

(a)

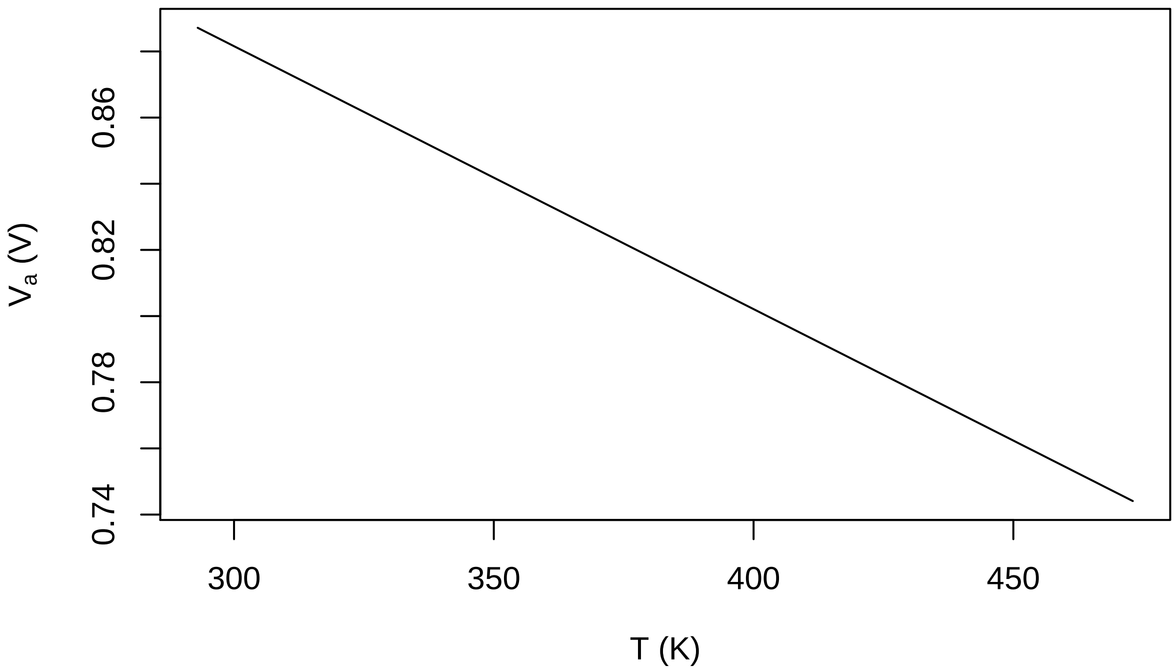
$$I_D = Cn_i^2 \exp\frac{eV_a}{kT} = C\exp\frac{-E_g + eV_a}{kT}$$

$$-E_g + eV_a = kT \ln \frac{I_D}{C}$$

$$V_a = \frac{E_g}{e} + \frac{kT}{e} \ln \frac{I_D}{C}$$

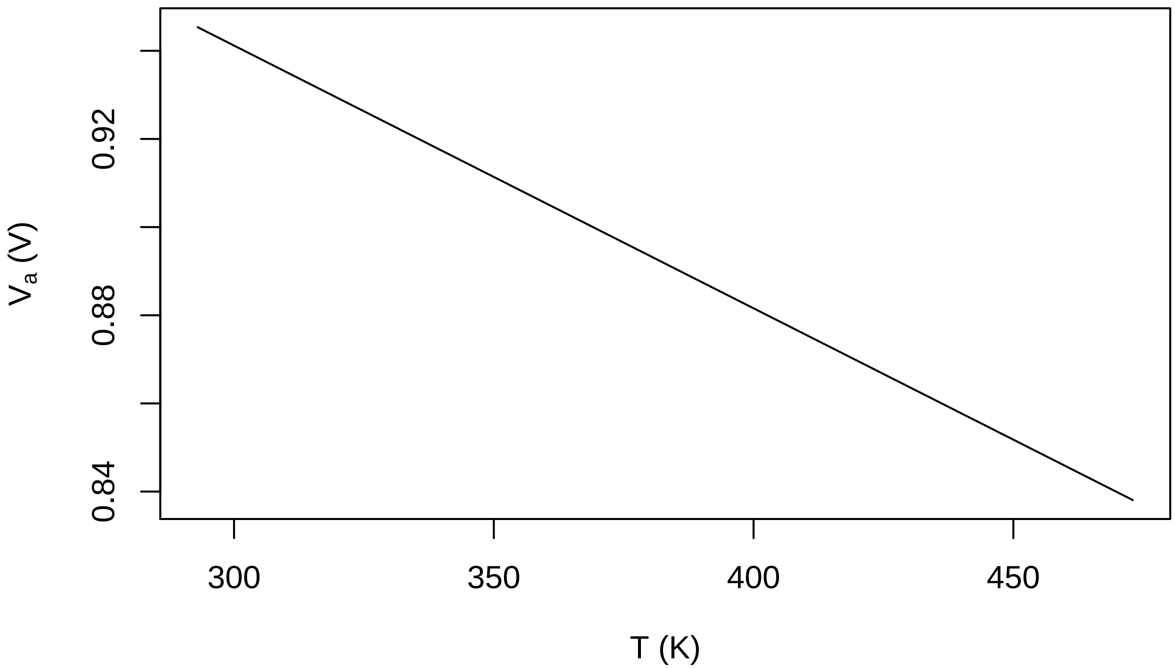
(b)

```r
func <- function(t) {
  Eg <- 1.12
  k <- 1.3806e-23
  e <- 1.6e-19
  ID <- 1e-4
  return(Eg + k * t / e * log(ID))
}
curve(func, from = 20+273, to = 200+273, xlab = TeX('T (K)'), ylab = TeX('V_a (V)'))
```



(c)

```r
func <- function(t) {
  Eg <- 1.12
  k <- 1.3806e-23
  e <- 1.6e-19
  ID <- 1e-3
  return(Eg + k * t / e * log(ID))
}
curve(func, from = 20+273, to = 200+273, xlab = TeX('T (K)'), ylab = TeX('V_a (V)'))
```



(d)

When T becomes larger, E_g of silicon becomes smaller, so the result will not be a straight line, the curve will be below the origin line.

Ex 6.6

(a)

(b)

(c)

Ex 6.7

(a)

(b)

(c)

(d)

Ex 6.8

(a)

$$
\begin{aligned}
n_{E0} &= \frac{n_i^2}{N_E} = \frac{(1.5 \times 10^{10}\,\mathrm{cm}^{-3})^2}{5 \times 10^{17}\,\mathrm{cm}^{-3}} = 4.5 \times 10^2\,\mathrm{cm}^{-3} \\
p_{B0} &= \frac{n_i^2}{N_B} = \frac{(1.5 \times 10^{10}\,\mathrm{cm}^{-3})^2}{10^{16}\,\mathrm{cm}^{-3}} = 2.25 \times 10^4\,\mathrm{cm}^{-3} \\
n_{C0} &= \frac{n_i^2}{N_C} = \frac{(1.5 \times 10^{10}\,\mathrm{cm}^{-3})^2}{10^{15}\,\mathrm{cm}^{-3}} = 2.25 \times 10^5\,\mathrm{cm}^{-3}
\end{aligned}
$$

(b)

$$p_B(0) = p_{B0} \exp \frac{V_{EB}}{V_t} = 2.25 \times 10^4\,\mathrm{cm}^{-3} \exp \frac{0.615\,\mathrm{V}}{0.0259\,\mathrm{V}} = 4.619 \times 10^{14}\,\mathrm{cm}^{-3}$$
$$n_E(0) = n_{E0} \exp \frac{V_{EB}}{V_t} = 4.5 \times 10^2\,\mathrm{cm}^{-3} \exp \frac{0.615\,\mathrm{V}}{0.0259\,\mathrm{V}} = 9.239 \times 10^{12}\,\mathrm{cm}^{-3}$$

(c)

Ex 6.9

$$i_C = \frac{-eD_n A_{BE}}{x_B} \cdot n_{B0} \exp \frac{v_{BE}}{V_t}$$
$$A_{BE} = \frac{|i_C| x_B}{eD_n n_{B0} \exp \frac{v_{BE}}{V_t}} = 9.877 \times 10^{-2} \cdot |i_C|$$

(a)

$$A_{BE} = 9.877 \times 10^{-2} \cdot 2 \times 10^{-3} = 1.975 \times 10^{-4}\,\mathrm{cm}^2$$

(b)

$$A_{BE} = 9.877 \times 10^{-2} \cdot 5 \times 10^{-3} = 4.939 \times 10^{-4}\,\mathrm{cm}^2$$

Ex 6.10

(a)

$$\gamma = \frac{1}{1 + \frac{N_B}{N_E} \cdot \frac{D_E}{D_B} \cdot \frac{x_B}{x_E}}$$
$$k = \frac{N_{B0}}{N_E} \cdot \frac{D_E}{D_B} \cdot \frac{x_{B0}}{x_E}$$
$$\gamma_A = \frac{1}{1+k}$$
$$\gamma_B = \frac{1}{1+2k}$$
$$\gamma_C = \frac{1}{1+k/2}$$

(i)

$$\frac{\gamma_B}{\gamma_A} = \frac{1+k}{1+2k}$$

(ii)

$$\frac{\gamma_C}{\gamma_A} = \frac{1+k}{1+k/2}$$

(b)

$$\alpha_T = \frac{1}{1 + \frac{1}{2}\left(\frac{x_B}{L_B}\right)^2}$$

$$m = \frac{1}{2}\left(\frac{x_{B0}}{L_B}\right)^2$$

$$\alpha_{TA} = \frac{1}{1+m}$$
$$\alpha_{TB} = \frac{1}{1+m}$$
$$\alpha_{TC} = \frac{1}{1+m/4}$$

(i)

$$\frac{\alpha_{TB}}{\alpha_{TA}} = 1$$

(ii)

$$\frac{\alpha_{TC}}{\alpha_{TA}} = \frac{1+m}{1+m/4}$$

(c)

$$\delta = \frac{1}{1 + \frac{J_{r0}}{J_{s0}} \exp\frac{-eV_{BE}}{2kT}}$$
$$n = \frac{J_{r0}}{J_{s0}} \exp\frac{-eV_{BE}}{2kT} \propto N_B$$
$$\delta_A = \frac{1}{1+n}$$
$$\delta_B = \frac{1}{1+2n}$$
$$\delta_C = \frac{1}{1+n}$$

(i)

$$\frac{\delta_B}{\delta_A} = \frac{1+2n}{1+n}$$

(ii)

$$\frac{\delta_C}{\delta_A} = 1$$

(d)

$$\beta = \frac{1}{\frac{N_B}{N_E} \cdot \frac{D_E}{D_B} \cdot \frac{x_B}{x_E} + \frac{1}{2}\left(\frac{x_B}{L_B}\right)^2 + \frac{J_{r0}}{J_{s0}} \exp \frac{-eV_{BE}}{2kT}}$$

According to the expression, can can find that N_B and x_B should be smaller so that β will become larger. So Device C should be chosen.