Assignment3

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1. (a) For intrinsic semiconductor, $n = p = n_i$

$$\rho = \frac{1}{q(\mu_n n + \mu_p p)} = \frac{1}{q(\mu_n + \mu_p)n_i}$$

$$\rho(Ge) = \frac{1}{(1.6 \times 10^{-19})(4000 + 1900)(2.5 \times 10^{13})} = 42.4(\Omega \cdot cm)$$

$$\rho(Si) = \frac{1}{(1.6 \times 10^{-19})(1358 + 461)(1.0 \times 10^{10})} = 3.44 \times 10^5(\Omega \cdot cm)$$

$$\rho(GaAs) = \frac{1}{(1.6 \times 10^{-19})(8000 + 400)(2.25 \times 10^6)} = 331 \times 10^8(\Omega \cdot cm)$$

(b) $$\rho = \frac{1}{q(\mu_n n + \mu_p p)} = \frac{1}{q(\mu_n n + \mu_p n_i^2/n)}$$

$$\leq \frac{1}{q2\sqrt{(\mu_n n)(\mu_p n_i^2/n)}} = \frac{1}{2q\sqrt{\mu_n \mu_p} n_i}$$

So when $\mu_n n = \mu_p n_i^2/n$, which implies $n = \sqrt{\mu_n \mu_p} n_i$

$$\rho_{max} = \frac{1}{2q\sqrt{\mu_n \mu_p} n_i}$$

$$\rho_{max}(Ge) = \frac{1}{2(1.6 \times 10^{-19})\sqrt{4000 \times 1900}(2.5 \times 10^{13})} = 45.3(\Omega \cdot cm)$$

$$\rho_{max}(Si) = \frac{1}{2(1.6 \times 10^{-19})\sqrt{1358 \times 461}(1.0 \times 10^{10})} = 3.95 \times 10^5(\Omega \cdot cm)$$

$$\rho_{max}(GaAs) = \frac{1}{2(1.6 \times 10^{-19})\sqrt{8000 \times 400}(2.25 \times 10^6)} = 7.76 \times 10^8(\Omega \cdot cm)$$

2. (a) For p-type semiconductor, $N_A = p$

Then $N_0 e^{-x/x_0} + N_A B = n_i e^{(E_i(x) - E_F)/kT}$

Then $E_i(x) - E_F = kTln[\frac{1}{n_i}(N_0 e^{-x/x_0} + N_{AB})] = 0.0259ln(10^8 e^{-x/10^4} + 10^5)$

(Plot is on the attached paper.)

(b) When $x \gg x_0$,

$e^{-x/x_0} \to 0$

$$E_i(x) - E_F = \text{constant}$$

$$E = \frac{1}{q}\frac{dE_i(x)}{dx} = 0$$

When $x < x_0$,

$$E = \frac{1}{q}\frac{dE_i(x)}{dx} = 0.00259(\frac{1}{e^{-x/10^4}+1} - 1)(V/m)$$

3. (a) Yes. The semiconductor is in equilibrium because the Fermi level has the same energy at different positions.

(e) $n = n_i e^{(E_F - E_i)/kT}$

$$p = n_i e^{(E_i - E_F)/kT}$$

(Plots are on the attached paper.)

4. At equilibrium and 1-Dimensional case,

For electron,

$$J_N = J_{N|drift} + J_{N|diff} = q\mu_n nE + qD_N\frac{dn}{dx} = 0$$

However,

$$E = \frac{1}{q}\frac{dE_i}{dx}, \quad n = n_i e^{(E_F - E_i)/kT}$$

Then $\frac{dn}{dx} = \frac{d}{dx}n_i e^{(E_F - E_i)/kT} = -\frac{n_i}{kT}e^{(E_F - E_i)/kT}\frac{dE_i}{dx} = -\frac{n}{kT}qE$

$$\Rightarrow q\mu_n nE - qD_N\frac{n}{kT}qE = 0$$

$$\Rightarrow \frac{D_N}{\mu_n} = \frac{kT}{q}$$

Similarly, for holes,

$$\frac{D_P}{\mu_p} = \frac{kT}{q}$$

5. $\dfrac{\partial \Delta n_p}{\partial t} = D_N \dfrac{\partial^2 \Delta n_p}{\partial x^2} - \dfrac{\Delta n_p}{\tau_n} + G_L$

$\Rightarrow \dfrac{d\Delta n_p}{dt} = -\dfrac{\Delta n_p}{\tau_n} + \dfrac{G_{L0}}{2}$

$\Rightarrow \Delta n_p(t) = \dfrac{G_{L0}\tau_n}{2} + Ae^{-t/\tau_n}$

Boundary condition, $n_p(0) = G_{L0}\tau_n = 10^{16} \times 10^{-6} = 10^{10}(cm^{-3})$

Then $A = \dfrac{G_{L0}\tau_n}{2}$

So $\Delta n_p(t) = \dfrac{G_{L0}\tau_n}{2}(1 + e^{-t/\tau_n}) = 5 \times 10^9(1 + e^{-10^6 t})(cm^{-3})$

6. (a) $n_0 = n_i e^{(E_F - E_i)/kT} = 10^{10} e^{0.3/0.00259} = 1.07 \times 10^{15}(cm^{-3})$

$p_0 = n_i e^{(E_i - E_F)/kT} = 10^{10} e^{-0.3/0.00259} = 9.32 \times 10^4(cm^{-3})$

(b) $n = n_i e^{(E_N - E_i)/kT} = 10^{10} e^{0.318/0.00259} = 2.15 \times 10^{15}(cm^{-3})$

$p = n_i e^{(E_i - E_P)/kT} = 10^{10} e^{0.3/0.00259} = 1.07 \times 10^{15}(cm^{-3})$

(c) $N_D \cong n_0 = 1.07 \times 10^{15}(cm^{-3})$

(d) No. Because for low level injection, $\Delta p \ll n_0$ must be satisfied. However, in this case, $\Delta p = p - p_0 \cong n_0$.

(e) Before illumination,

$$\rho = \frac{1}{q(\mu_n n + \mu_p p)} \cong \frac{1}{q\mu_n N_D}$$
$$= \frac{1}{(1.6 \times 10^{-19})(1345)(1.07 \times 10^{15})} = 4.34(\Omega \cdot cm)$$

After illumination,

$$\rho = \frac{1}{q(\mu_n n + \mu_p p)}$$
$$= \frac{1}{(1.6 \times 10^{-19})[(1345)(2.15 \times 10^{15}) + (458)(1.07 \times 10^{15})]} = 1.85(\Omega \cdot cm)$$