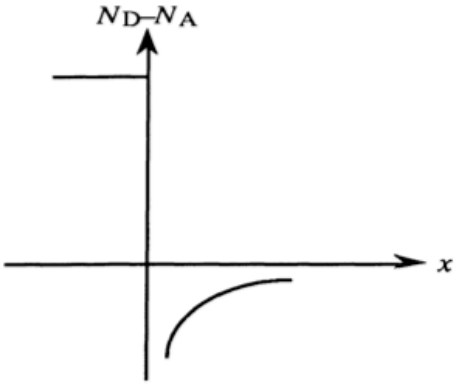
2022 Spring ECE606 - Homework 8 Solutions

Problem 1

(Please note that the solutions are taken from the solutions manual of Semiconductor Device Fundamentals.)

(a) The in and out movement of the majority carriers about the steady-state depletion width in response to the applied a.c. signal.

(b)



(c) *Quasistatically* is an adverb used to describe a situation where carriers or a device subject to non-steady-state conditions responds as if steady-state conditions applied at each instant of time.

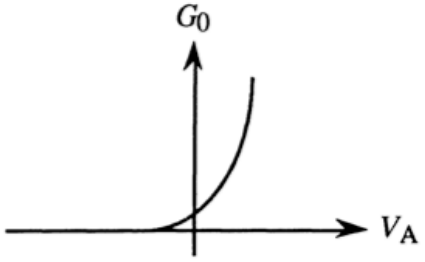
(d) *Varactor*—a contraction of *var*iable re*actor*. A commercial device, such as a reverse-biased *pn* junction diode, where the reactance = $1/j\omega C$ varies as a function of the applied voltage.

(e) *Profiling*—the process of determining the doping concentration inside a device as a function of position.

(f) The low-frequency conductance of an ideal diode was noted to be (Eq. 7.15),

$$G_0 = \frac{q}{kT}(I + I_0)$$

$G_0 \propto I$ when the diode is forward biased and vanishes for reverse biases greater than a few kT/q. Also note that $G_0 = qI_0/kT$ when $V_A = 0$. We conclude



(g) The diffusion admittance arises from fluctuations in the number and position of minority carriers stored in the quasineutral regions adjacent to the depletion region.

(h) At signal frequencies where $\omega\tau_p \gtrsim 1$, the minority carriers have trouble following the a.c. signal and the resulting out-of-phase oscillations enhance the diffusion conductance at the expense of the diffusion capacitance.

i) Thermionic emission current — majority carrier injection over the surface potential-energy barrier.
j) Since I_M->S(VA)=I_M->S(0)=I_S->M(0), the M->S component is obtained by evaluating the S->M component at zero bias.
k) The diffusion capacitance and conductance arise from the fluctuation of the minority carriers stored in a quasineutral region adjacent to the depletion region. The minority carrier storage is large in a forward-biased pn junction diode and leads to a significant diffusion admittance. In an MS diode there is minimal minority carrier storage for operational forward biases.

Problem 2

l) There is a minimal number of stored minority carriers to be removed in going from the forward-bias "on" condition to the reverse-bias "off" condition.

(Please note that the solutions are taken from the solutions manual of Semiconductor Device Fundamentals.)

8.2

(a) Reverse biased. $\Delta p_n(x_n,t) = p_n(x_n,t) - p_{n0} < 0$. A carrier deficit at the edge of the depletion region indicates the junction is reverse biased.

(b) Invoking the law of the junction,

$$n(x_n)p(x_n) = N_D p_{n0}/2 = n_i^2/2 = n_i^2\, e^{q\upsilon_A/kT}$$

or

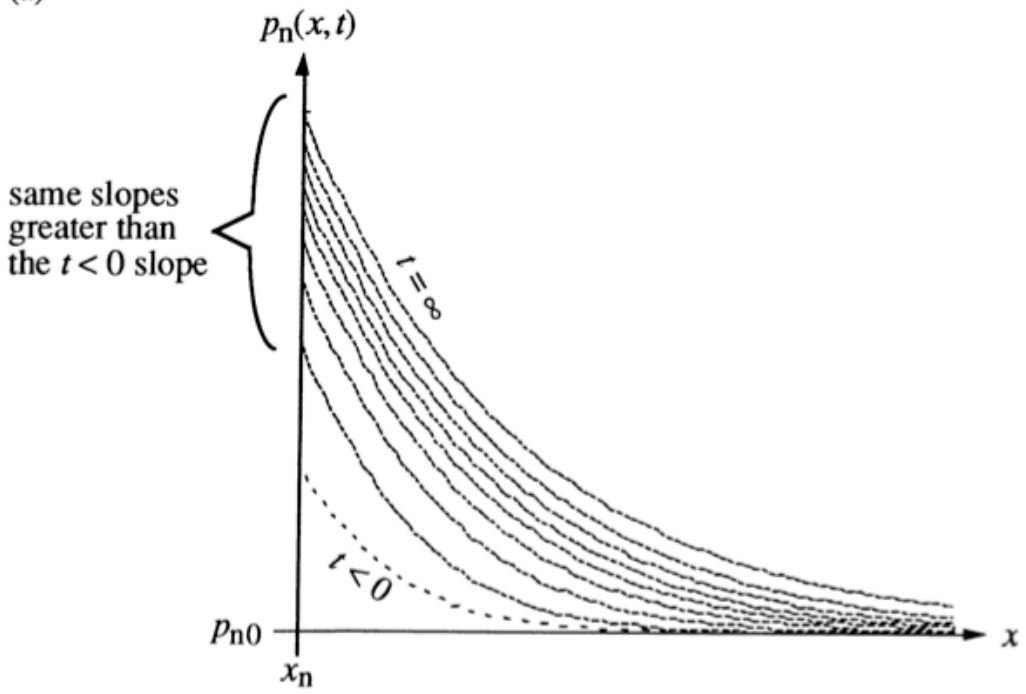
$$\upsilon_A = (kT/q)\ln(1/2) = -0.0259 \ln 2 = \mathbf{-0.018\ V}$$

(c) Reverse. Since $d\Delta p_n/dx\big|_{x=x_n} = dp_n/dx\big|_{x=x_n} > 0$, it follows from Eq. (8.2) that $i < 0$.

Problem 3

(Please note that the solutions are taken from the solutions manual of Semiconductor Device Fundamentals.)

(a)



(b) Here for $t > 0$,

$$\frac{dQ_P}{dt} = I_{F2} - \frac{Q_P}{\tau_p}$$

$$\int_{Q_P(0^+)}^{Q_P(t)} \frac{dQ_P}{I_{F2} - Q_P/\tau_p} = t$$

$$t = -\tau_p \ln\left(I_{F2} - \frac{Q_P}{\tau_p}\right)\Bigg|_{Q_P(0^+)=I_{F1}\tau_p}^{Q_P(t)} = -\tau_p \ln\left(\frac{I_{F2} - Q_P/\tau_p}{I_{F2} - I_{F1}}\right)$$

Thus

$$I_{F2} - \frac{Q_P}{\tau_p} = (I_{F2} - I_{F1})\, e^{-t/\tau_p}$$

and

$$Q_P(t) = I_{F2}\tau_p - (I_{F2} - I_{F1})\tau_p\, e^{-t/\tau_p}$$

Invoking the quasistatic assumption (Eq. 8.15), we can also write

$$Q_P(t) = I_0 \tau_p \left(e^{q v_A/kT} - 1\right)$$

Therefore, equating the $Q_P(t)$ relationships,

$$e^{q v_A/kT} - 1 = \frac{I_{F2}}{I_0} - \frac{(I_{F2} - I_{F1})}{I_0} e^{-t/\tau_p}$$

or

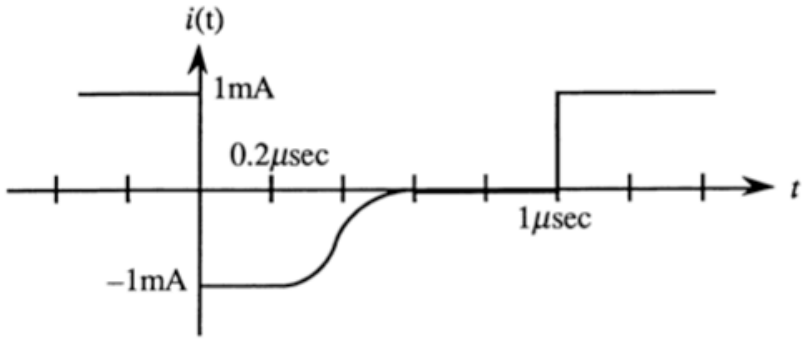
$$\boxed{v_A(t) = \frac{kT}{q} \ln\left[1 + \frac{I_{F2}}{I_0} - \frac{(I_{F2} - I_{F1})}{I_0} e^{-t/\tau_p}\right]}$$

Note as a check that the foregoing expression reduces to Eq. (8.16) if $I_{F1} \to 0$ and $I_{F2} \to I_F$.

Problem 4

(Please note that the solutions are taken from the solutions manual of Semiconductor Device Fundamentals.)

(a) We note using Fig. 8.6 that $t_s/\tau_p \cong 0.22$ when $I_R/I_F = 1$. Thus $t_s = 0.22\mu$sec, or the diode becomes reverse biased before it is pulsed back to the ON condition. Based on the above information, we conclude



(b) Since pulsing is occurring from reverse bias, we can assume by analogy with the text turn-on development that the pulsing effectively occurs from $i = 0$ with $Q_P(1\mu\text{sec}) = 0$. The situation here is completely analogous—all but identical—to the turn-on situation considered in Section 8.2, except t is replaced by $t - 1\mu$sec. Consequently, the required expression is just Eq. (8.16) with the t in $\exp(-t/\tau_p)$ replaced by $t - 1\mu$sec

Problem 5

(Please note that the solutions are taken from the solutions manual of Semiconductor Device Fundamentals.)

(a) $$\Phi_B = \Phi_M - \chi = 5.10 - 4.03 = \mathbf{1.07\ eV}$$

(b) $$(E_c - E_F)_{FB} \cong E_G/2 - (E_F - E_i)_{FB} = E_G/2 - kT\ln(N_D/n_i)$$
$$= 0.56 - (0.0259)\ln(10^{15}/10^{10})$$
$$= 0.26\ \text{eV}$$

$$V_{bi} = \frac{1}{q}[\Phi_M - (E_c - E_F)_{FB}] = 1.07 - 0.26 = \mathbf{0.81\ V}$$

(c) $V_A = 0$ under equilibrium conditions and

$$W = \left[\frac{2K_S\varepsilon_0}{qN_D}V_{bi}\right]^{1/2} = \left[\frac{2(11.8)(8.85\times10^{-14})(0.81)}{(1.6\times10^{-19})(10^{15})}\right]^{1/2} = \mathbf{1.03\times10^{-4}\ cm}$$

(d) $$|\mathcal{E}_{max}| = |\mathcal{E}_{x=0}| = \frac{qN_D}{K_S\varepsilon_0}W = \frac{(1.6\times10^{-19})(10^{15})(1.03\times10^{-4})}{(11.8)(8.85\times10^{-14})} = \mathbf{1.58\times10^{4}\ V/cm}$$

Problem 7

(Please note that the solutions are taken from the solutions manual of Semiconductor Device Fundamentals.)

For a p^+-n junction...

$$I_{DIFF} = I_0(e^{qV_A/kT} - 1) = qA\frac{D_P}{L_P}\frac{n_i^2}{N_D}(e^{qV_A/kT} - 1)$$

and employing Eqs. (14.24/14.25),

$$I_{TE} = I_s(e^{qV_A/kT} - 1) = A\mathcal{A}^*T^2e^{-\Phi_B/kT}(e^{qV_A/kT} - 1)$$

Thus noting

$$\frac{D_P}{L_P} = \sqrt{\frac{D_P}{\tau_p}} = \sqrt{\frac{(kT/q)\mu_p}{\tau_p}}$$

$$\frac{I_{DIFF}}{I_{TE}} = \frac{I_0}{I_s} = \frac{qA\dfrac{D_P}{L_P}\dfrac{n_i^2}{N_D}}{A\mathcal{A}^*T^2e^{-\Phi_B/kT}} = \frac{q\sqrt{\dfrac{(kT/q)\mu_p}{\tau_p}}\dfrac{n_i^2}{N_D}}{\mathcal{A}^*T^2e^{-\Phi_B/kT}}$$

$$= \frac{(1.6\times10^{-19})\left[\dfrac{(0.0259)(437)}{(10^{-6})}\right]^{1/2}\left(\dfrac{10^{20}}{10^{16}}\right)}{(140)(300)^2e^{-(0.72)/(0.0259)}} = \mathbf{5.05 \times 10^{-7}}$$