Name Solutions

Quiz #2 — EE 482
Winter 2010

The test is open book/open notes. Show all work. Be sure to state all assumptions made and **check** them when possible. The number of points per problem are indicated in parentheses.

1. In a piece of Si doped with $N_d = 10^{16}\text{cm}^{-3}$, $\tau_n = 55\mu s$ and $\tau_p = 25\mu s$ due to midgap traps. If light generates 10^{14} carriers/cm^{3}s, what are the steady-state hole and electron concentrations. (8)

Assuming low level injection,
Trap level is @ midgap.

$U = \dfrac{pn - n_i^2}{\tau_p n} \Rightarrow \simeq \dfrac{\Delta p}{\tau_p}$. (2)

$N_A = 10^{16}\text{cm}^{-3}$ -> full ionization.
$n_0 = 10^{16}\text{cm}^{-3}$.
$p_0 = \dfrac{n_i^2}{N_A} = 10^4\text{cm}^{-3}$.

$10^{14}\text{cm}^{-3}\text{s}^{-1} = \dfrac{\Delta p}{25\mu s}$.

$\Delta p = 2.5\times10^9\text{cm}^{-3}$ (2)

$\Delta p \ll n_0 \rightarrow$ low level injection ok.

Steady state holes: $p = p_0 + \Delta p \simeq \Delta p = \underline{\underline{2.5\times10^9\text{cm}^{-3}}}$. (2)

" electrons: $n = n_0 + \Delta n$

since $\Delta n = \Delta p = 2.5\times10^9\text{cm}^{-3}$

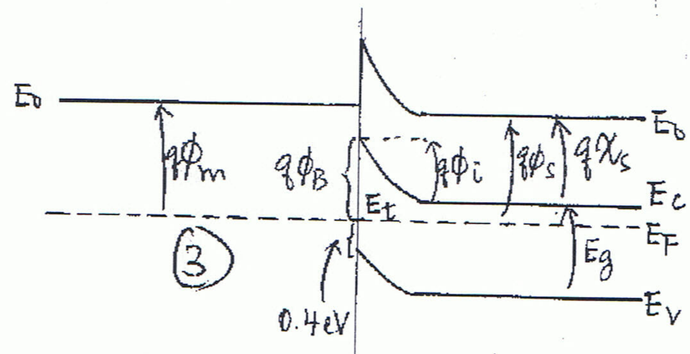
$n \simeq n_0 = \underline{\underline{10^{16}\text{ cm}^{-3}}}$ (2)

2. A contact is made between silicon ($\chi_s = 4.05$eV) doped with $N_d = 10^{17}\text{cm}^{-3}$ and aluminum ($\phi_m = 4.1$eV). A high density of surface states pins the Fermi level at 0.4eV above the valence band maxima. Sketch the band diagram and the charge density versus position for the contact in equilibrium. Calculate and indicate on plot the heights of barriers for majority carrier flow between semiconductor and metal (ignoring any narrow tunnelable barrier associated with interface dipole layer). (14)

Majority carrier is electron.

Barrier for electrons from M → S is $q\phi_B$.

Barrier for holes from S → M is $q\phi_i$.



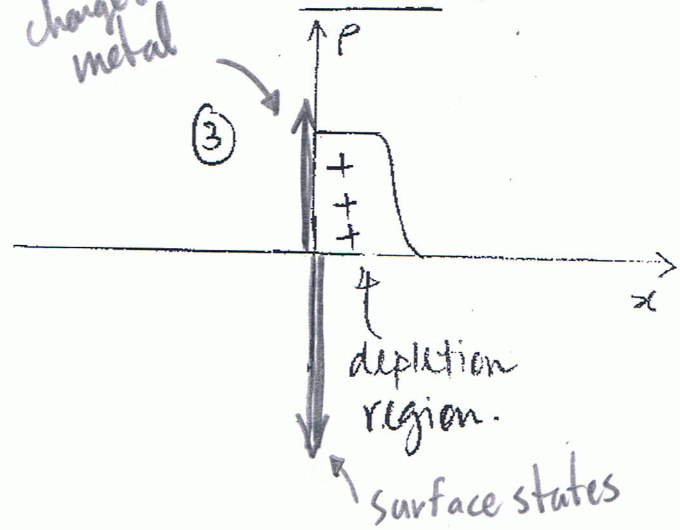
★ Band diagram.

$$q\phi_B = E_g - 0.4\text{eV} = 1.12 - 0.4\text{ eV}$$
$$= \underline{\underline{0.72\text{eV}}} \quad 3$$

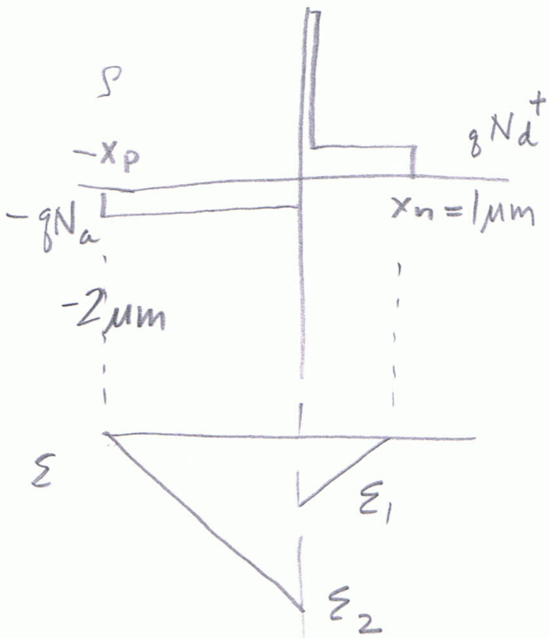
$$q\phi_i = q\phi_B - (E_c - E_F) = 0.72 - 0.141$$
$$= \underline{\underline{0.579\text{eV}}} \quad 3$$

Aside:

$$E_c - E_F = KT\ln\left(\frac{N_c}{N_d}\right)$$
$$= 25\text{meV} \; \frac{2.8\times10^{19}}{10^{17}}$$
$$= \underline{0.141\text{eV}} \quad 2$$



3. A pn junction with doping of 10^{17} cm^{-3} on both sides has an additional very narrow heavily donor-doped region in the middle (at metallurgical junction) with dose of 10^{13} cm^{-2} (e.g., doping of 10^{20} cm^{-3} for width of 1 nm). If the depletion region width on the n-side is 1um, what is the depletion region width on the p-side? What is the applied voltage? What is the capacitance of the junction? (14)



$$x_p = \frac{(1\,\mu m)(10^{17}\,cm^{-3}) + 10^{13}\,cm^{-2}}{10^{17}\,cm^{-3}}$$

$$= 2\times10^{-4}\,cm = \underline{\underline{2\,\mu m}}$$

$$\mathcal{E}_1 = \frac{-qN_d x_n}{K_s\epsilon_0} = -\frac{(1.6\times10^{-19}\,C)(10^{17}\,cm^{-3})(10^{-4}\,cm)}{(11.7)(8.854\times10^{-14}\,\frac{F}{cm})}$$

$$= 1.54\times10^{6}\,V/cm$$

$$\mathcal{E}_2 = 2\mathcal{E}_1$$

$$\phi_i - V_A = -\frac{1}{2}\left[\mathcal{E}_2 x_p + \mathcal{E}_1 x_n\right] = -\frac{1}{2}\left[5\left(1.54\times10^{6}\,\frac{V}{cm}\right)(10^{-4}\,cm)\right]$$

$$= 385\,V$$

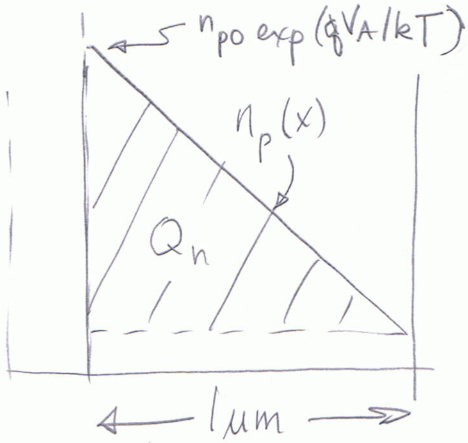
$$\phi_i = \frac{kT}{q}\ln\left(\frac{N_a(-x_p)\,N_d(x_n)}{n_i^2}\right) = .0259V\ln\left(\frac{10^{34}}{10^{20}}\right) = 0.83V$$

$$\underline{\underline{V_A = -386V}}$$

$$C_d = \frac{K_s\epsilon_0}{x_d} = \frac{(11.7)(8.854\times10^{-14}\,F/cm)}{3\times10^{-4}\,cm} = \underline{\underline{3.45\times10^{-9}\,\frac{F}{cm^2}}}$$

4. In a one-sided n^+p-junction, the doping is $N_d = 10^{19}\text{cm}^{-3}$ and $N_a = 10^{17}\text{cm}^{-3}$. If the width of the undepleted neutral p-region is 1um, calculate the diode current and stored minority charge for $V_A = 0.7\,\text{V}$.

Assume $\tau_n = 0.25\mu\text{s}$, $\tau_p = 0.16\mu\text{s}$, $D_n = 4\,\text{cm}^2/\text{s}$ and $D_p = 2\,\text{cm}^2/\text{s}$ in the n-region and $\tau_n = 0.25\mu\text{s}$, $\tau_p = 0.16\mu\text{s}$, $D_n = 25\,\text{cm}^2/\text{s}$ and $D_p = 9\,\text{cm}^2/\text{s}$ in the p-region, Assume recombination in depletion region can be neglected. (14)



$$L_{np} = \left[D_{np}\,\tau_{np}\right]^{1/2} = \left[25\,\frac{\text{cm}^2}{\text{s}}\,0.25\times10^{-6}\,\text{s}\right]^{1/2} = 2.5\times10^{-3}\,\text{cm} = 25\,\mu\text{m} \gg W_p$$

One-sided, so $J_{diode} \cong J_{n_p} + \cancel{J_{GR}}$

$$J_{n_p} = q\frac{D_{n_p}}{W_p}\,n_{po}\left(e^{qV_A/kT} - 1\right) = (1.6\times10^{-19}\,\text{C})\left(\frac{25\,\text{cm}^2/\text{s}}{10^{-4}\,\text{cm}}\right)\left(\frac{10^{20}\,\text{cm}^{-6}}{10^{17}\,\text{cm}^{-3}}\right)e^{0.7\text{V}/.0259}$$

$$J_{diode} = 21.9\,\frac{\text{A}}{\text{cm}^2}$$

$$Q_n = \frac{q}{2}W_p\,n_{po}\left(e^{qV_A/kT} - 1\right) = \left(\frac{1.6\times10^{-19}\,\text{C}}{2}\right)(10^{-4}\,\text{cm})\left(\frac{10^{20}\,\text{cm}^{-6}}{10^{17}\,\text{cm}^{-3}}\right)\left(e^{0.7/0.0259}\right)$$

$$= 4.37\times10^{-9}\,\text{C}/\text{cm}^2 = J_{np}\underbrace{\left(\frac{D_{np}}{2W_p^2}\right)}_{\text{transit time}}$$

End Of Exam