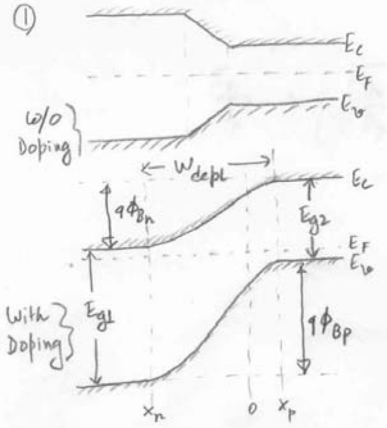
EE 566 SOLID STATE DEVICES
SPRING 2004
ASSIGNMENT 5: SOLUTIONS

PROBLEM 1

①



Band Diagrams

$\epsilon_{S1}(\text{AlGaAs}) = 13.1\,\epsilon_0$
$\epsilon_{S2}(\text{GaAs}) = 11.9\,\epsilon_0$ } Safe to assume $\epsilon_{S1} \approx \epsilon_{S2} = \epsilon_S$

$$\boxed{qV_{bi} \simeq kT \ln \frac{N_A N_D}{n_i^2} + \Delta E_C} \quad \text{if } \underline{N_{C1} \approx N_{C2},\ N_{V1} \approx N_{V2}}$$

$$W_{depl} \approx \left[\frac{2\epsilon_S}{q}\left(\frac{1}{N_A}+\frac{1}{N_D}\right)\left(\underset{\uparrow\ \boxed{(1.51V)}}{V_{bi}} - 2\frac{kT}{q}\right)\right]^{1/2}$$

$$= \boxed{480\,nm}$$

② **Barrier for electrons**

$$q\phi_{Bn} = qV_{bi} - \Delta E_C$$
$$= \underbrace{\boxed{1.21\,eV}}_{\text{lower than homojunction!}}$$

} Since graded region is n-doped, CB is flat + VB has a field

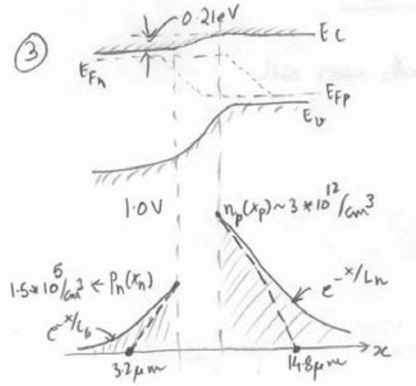
Barrier for holes

$$E_{g2} + q\phi_{Bp} = E_{g1} + q\phi_{Bn} \quad \text{(see figure)}$$

$$q\phi_{Bp} = q\phi_{Bn} + (E_{g1} - E_{g2})$$
$$= 1.21\,eV + 0.5\,eV = \underbrace{\boxed{1.71\,eV}}_{\text{larger than homojunction!}}$$

$$\boxed{\Rightarrow J_n \uparrow,\ J_p \downarrow\ !!}$$

③

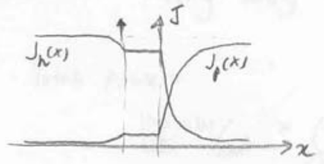


$$n_p(x) = n_p(x_p)\, e^{-x/L_n}$$
$$= \frac{n_{i2}^2}{N_A} \exp\left(\frac{qV_A}{kT}\right) \approx \boxed{3 * 10^{12}/cm^3}$$

$$P_n(x_n) = \frac{n_{i1}^2}{N_D} \exp\left(\frac{qV_A}{kT}\right) = \frac{n_{i2}^2}{N_D} \exp\left(-\frac{\Delta E_g}{kT}\right) \exp\left(\frac{qV_A}{kT}\right)$$
$$\approx \boxed{1.5 * 10^5/cm^3}$$

Problem 1 contd...

④



$$J_n(x_p) = \frac{-qD_n n_{p0}}{L_n}\left(e^{\frac{qV_A}{kT}}-1\right) \approx -66\ mA/cm^2$$

$$J_p(x_n) = \frac{-qD_p p_{n0}}{L_p}\left(e^{\frac{qV_A}{kT}}-1\right) \approx -0.6\ nA/cm^2$$

$$J_n(x_p) >> J_p(x_n).$$

$$\frac{J_n}{J_p} = \underbrace{\left\{\sqrt{\frac{D_n}{D_p}} \cdot \sqrt{\frac{\tau_p}{\tau_n}} \cdot \frac{N_D}{N_A}\right\}}_{\text{Homojunction}} * \underset{\substack{\uparrow \\ \text{Heterojunction term.}}}{\exp\left(\frac{\Delta E_g}{kT}\right)}$$

Homojunction ↓ $\frac{J_n}{J_p} \approx \boxed{0.46}$

Heterojunction term. ↓ leads to $\frac{J_n}{J_p} \approx \boxed{10^8}$

↖ ↗ Huge difference!!

⑤ If $t_{6x} > x_n$, only that part of the bandgap difference that lies in the depletion region contributes to $\exp\left(\frac{\Delta E_g}{kT}\right)$.

$\therefore$ Effective ΔE_g is

$$\boxed{\Delta E_g^{eff} = E_{g_1}(x_n) - E_{g_2}}.$$

This can lead to substantial drop in the ratio $\frac{J_n}{J_p}$

PROBLEM 2

(Very Easy Problem)

⑥ Total power:

$$100\,\mathrm{mW}/_{\mathrm{cm}^2} * (4*1\,\mathrm{cm}^2) * 5\% = \boxed{20\,\mathrm{mW}}$$

⑦ EHP^s/second -

$$\frac{20\,\mathrm{mW} * 10\%}{\underbrace{1.424}_{E_g} * \underbrace{1.6*10^{-19}}_{e}} = \boxed{8.8*10^{15}\ \mathrm{EHP}^s/s}$$

$$\therefore\ G_L = \frac{8.8*10^{15}\ \mathrm{EHP}^s/s}{4*10^{-4}\,\mathrm{cm}^3} = \boxed{2.2*10^{19}/\mathrm{cm}^3\text{-}s}$$

⑧ Short-circuit current is

$$I_L = q G_L (L_p + L_n)\cdot S$$

$$= \boxed{0.28\,\mathrm{mA}}$$