ECE 3030 Spring 2025 HW8

1. *Under the given parameters for a piece of Ge, find its conductivity, work function difference. Explain whether it is a Schottky barrier or an ohmic contact.*

(a) $n + N_a = p + N_d = n_i^2/n + N_d$

$n^2 + (N_a – N_d)n - n_i^2 = 0 \rightarrow$ *Use binomial theorem.*

$n + 2.5 \times 10^{13} = (2.5 \times 10^{13})^2/n + 5 \times 10^{13}$, solve for n : $n = 4.04 \times 10^{13} cm^{-3}$, $p = 1.54 \times 10^{13} cm^{-3}$

$D_n/\mu_n = kT/q$ and $D_p/\mu_p = kT/q$ so $\mu_n = Dn·q/kT$ and $\mu_p= Dp·q/kT$

$\sigma = q(n\mu_n + p\mu_p) = (q/(kT/q)) (nD_n + pD_p)$

$= (1.6 \times 10^{-19}/0.0259) (4.04 \times 10^{13} \times 100 + 1.54 \times 10^{13} \times 50) = 0.0297 (\Omega \cdot cm)^{-1}$

(b) $\Phi_F = E_F – E_i = kT\ln(n/n_i) = 0.0259 \ln[4.04 \times 10^{13}/2.5 \times 10^{13}] = 0.0124eV$

For n – type semiconductor, the Fermi level is above the intrinsic Ge Fermi level by the Fermi potential Φ_F.

$\Phi_{ms} = \Phi_m – (\chi + E_g/2 – \Phi_F) = 4.5 – (4.0 + 0.67/2 – 0.012) = 4.5 – 4.323 = 0.177eV$

Electrons move from Ge to the metal. Therefore, we lose majority carriers in the semiconductors, making this a Schottky barrier.

2. *Electrostatic potentials of a heterojunction.*

$V_{01}/V_{02} = \varepsilon_2N_2/\varepsilon_1N_1$

$V_{01} + V_{02} = V_0$

$V_{01} = V_{02}\ \varepsilon_2N_2/\varepsilon_1N_1$

$V_{02}\ \varepsilon_2N_2/\varepsilon_1N_1 + V_{02} = V_0$

$V_{02}\ (\varepsilon_2N_2/\varepsilon_1N_1 + 1) = V_0$

$V_{02} = V_0\ \varepsilon_1N_1 / (\varepsilon_1N_1 + \varepsilon_2N_2)$

$V_{01} = V_0\ \varepsilon_2N_2 / (\varepsilon_1N_1 + \varepsilon_2N_2)$

$V_{01} = 13x(3x10^{19}) \cdot 1.6/[12x(1x10^{16}) + 13x(3x10^{19})] = 1.6\ V$

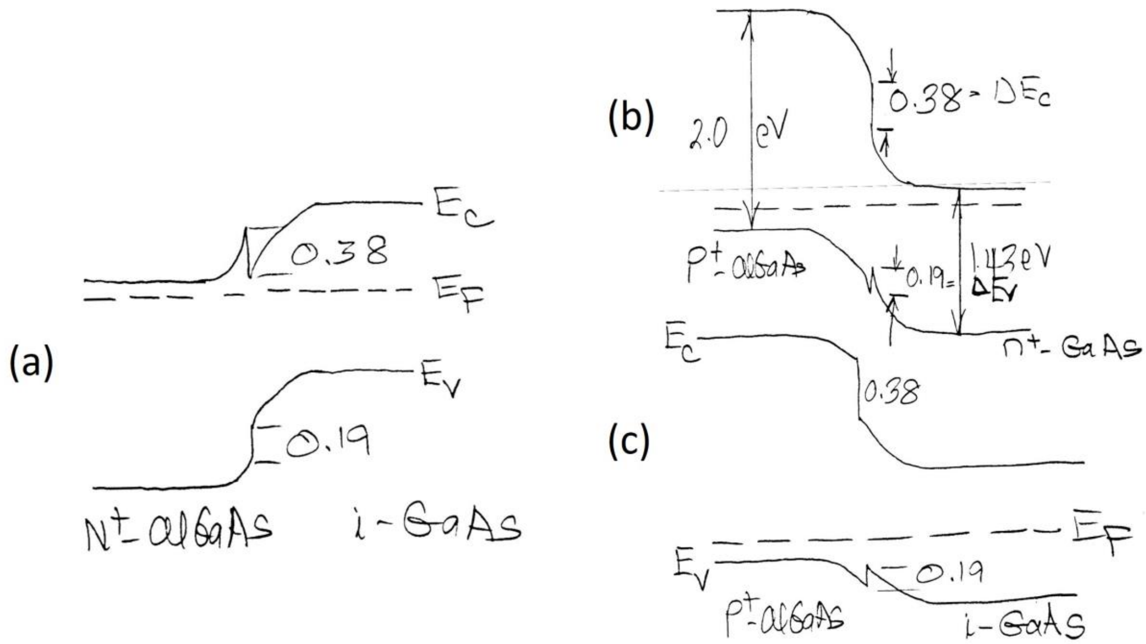
$V_{02} = 12x(3x10^{16}) \cdot 1.6/[12x(1x10^{16}) + 13x(3x10^{19})] = 4.9 \times 10^{-4}\ V.$

3. Band diagrams for for $Al_{0.35}Ga_{0.65}As$ on GaAs for (a) p^+-AlGaAs, n^+-GaAs, (b) p^+-AlGaAs, intrinsic GaAs, (c) n^+-AlGaAs, intrinsic GaAs

$Al_{0.35}Ga_{0.65}As$ has a band gap of E_g – 2.0 eV

$\Delta E_g = Eg(Al_{0.35}Ga_{0.65}As) – Eg(GaAs) = 2.0 – 1.43 = 0.57$ eV

$2/3 \cdot(\Delta E_g) = 0.38$ eV = $\Delta E_C = 1/3 \cdot(\Delta E_g) = 0.19$ eV



4. **Prob. 8.9** *Find I_{sc} and V_{oc} for the solar cell. $I_{thermal} = 32$ nA.*

From Equation 8-1,

$I_{SC} = I_{OP} = q \cdot A \cdot g\,(L_p + L_n + W) = 1.6 \cdot 10^{-19}\ \mathrm{C} \cdot 4\mathrm{cm}^2 \cdot 10^{18}\ (2\mu\mathrm{m}+2\mu\mathrm{m}+1\mu\mathrm{m}) = 0.32$ mA

From Equation 8-3,

$V_{OC} = (kT/q) \cdot \ln(1 + I_{OP}/I_{TH}) = 0.0259\mathrm{V} \cdot \ln(1 + (0.32 \cdot 10^{-3}\mathrm{A}/32 \cdot 10^{-9}\mathrm{A})) = 0.24\mathrm{V}$

5. **Prob. 8.14** If one makes an LED in a semiconductor with a band gap of 2.5 eV, what wavelength of light will it emit? Can you use it to efficiently detect photons of wavelength 900 nm? 100 nm?

Find the LED emission and tell if it can be used to detect 100nm or 900nm photons.

$\lambda = 1.24\ \mathrm{eV} \cdot \mu\mathrm{m}/E_G = 1.24\ \mathrm{eV} \cdot \mu\mathrm{m}/2.5\ \mathrm{eV} = 0.5\ \mu\mathrm{m} = 500$ nm

100 nm light has $h\nu > E$ and will be detected. 900 nm light has $h\nu < E$ and will not be detected.

6. For the p-i-n photodiode, (a) explain why this photodetector does not have gain.

(a) An e-h pair created within the intrinsic region of width W by absorption of a photon is collected as the e- is swept to the n-region and the h+ is swept to the p-region. Since only one e-h pair is collected per photon, there is no gain. (b) Explain how making the device more sensitive to low light levels degrades its speed.

If W is made wider to absorb more photons, the transit time to collect the e-h pair is longer. Thus the response time is degraded.

(c) If this diode is to be used to detect light with λ = 0.6 μm, what material would you use – GaAs or CdS?

E_{ph} = 1.24 / 0.6 = 2 eV. The band gap of GaAs is 1.42 eV so it will absorb the 2 eV photon. The band gap of CdS is 2.4 eV, so it will not absorb the 2 eV photon. So GaAs will work and CdS will not work. See, for example, the band gaps in S&B Appendix III.

7. Long pn junction solar cell.

$$L_n = \sqrt{D_n \tau_{n0}} = \sqrt{(25)(10^{-6})} = 5\times10^{-3} \text{ cm}$$

$$L_p = \sqrt{D_p \tau_{p0}} = \sqrt{(10)(5\times10^{-7})}$$

$$= 2.236\times10^{-3} \text{ cm}$$

Now $J_S = en_i^2 \left(\dfrac{D_n}{L_n N_a} + \dfrac{D_p}{L_p N_d} \right)$

$$= (1.6\times10^{-19})(1.5\times10^{10})^2 \times \left[\frac{25}{(5\times10^{-3})(10^{16})} + \frac{10}{(2.236\times10^{-3})(10^{15})} \right]$$

$$J_S = 1.790\times10^{-10} \text{ A/cm}^2$$

$$I_S = AJ_S = (5)(1.79\times10^{-10})$$

$$= 8.950\times10^{-10} \text{ A}$$

(a) $I_L = eG_L AW$

We find

$$V_{bi} = (0.0259)\ln\left[\frac{(10^{16})(10^{15})}{(1.5\times10^{10})^2} \right] = 0.6350 \text{ V}$$

$$W = \left\{ \frac{2 \in_s V_{bi}}{e} \left(\frac{N_a + N_d}{N_a N_d} \right) \right\}^{1/2}$$

$$= \left\{ \frac{2(11.7)(8.85\times10^{-14})(0.635)}{1.6\times10^{-19}} \times \left[\frac{10^{16}+10^{15}}{(10^{16})(10^{15})} \right] \right\}^{1/2}$$

$$W = 9.508\times10^{-5} \text{ cm}$$

Then

$$I_L = (1.6\times10^{-19})(5\times10^{21})(5)(9.508\times10^{-5})$$

$$= 0.380 \text{ A} = 380 \text{ mA}$$

(b) $V_{oc} = V_t \ln\left(1 + \dfrac{I_L}{I_S} \right)$

$$= (0.0259)\ln\left(1 + \frac{0.380}{8.95\times10^{-10}} \right)$$

$$V_{oc} = 0.5145 \text{ V}$$

(c) $\dfrac{V_{oc}}{V_{bi}} = \dfrac{0.5145}{0.635} = 0.810$