ECE 162B
HW #3 SOLUTIONS

① DEGENERATE DOPING, $N_D = 10^{19}\ cm^{-3} \Rightarrow E_F = E_C$

WHY? AT $N_D = 10^{19}\ cm^{-3}$, $n_i = 10^{15}\ cm^{-3}$ IN Si

SINCE $N_D >> n_i$, $n_0 \approx N_D = N_C e^{-(E_C - E_F)/KT}$

$KT \ln\left(\frac{N_D}{N_C}\right) = E_F - E_C$ $\quad N_C = 2.78 \cdot 10^{19}\ cm^{-3}$ @ 300 K IN Si

FROM $N_C = 2\left(\frac{2\pi m_n^* KT}{h^2}\right)^{3/2}$

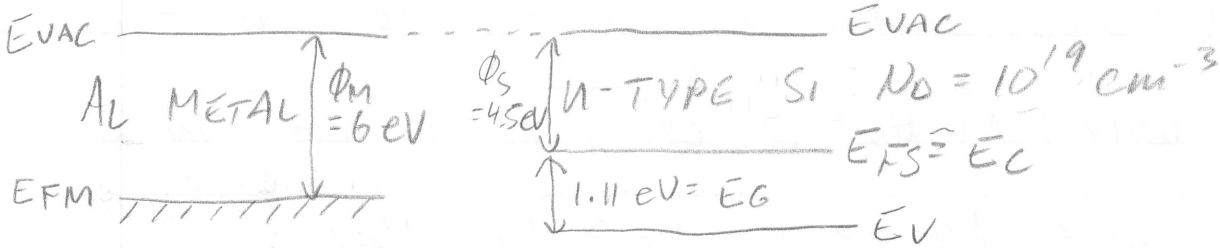
$\Rightarrow E_F = E_C + 26\,meV \cdot \ln\left(\frac{10^{19}}{2.78 \cdot 10^{19}}\right) \cong E_C + 26\,meV \cdot (-1)$

SO E_F IS ONLY $KT = 26$ meV LESS THAN E_C
$\Rightarrow E_F \approx E_C$ IS A GOOD APPROXIMATION

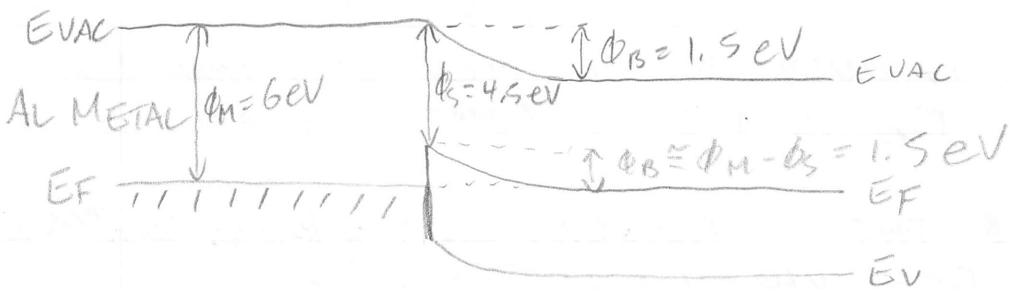
CONSIDER THE Si BANDGAP, $E_G \approx 1.11$ eV @ 300 K
SO $\frac{E_C - E_F}{E_G} = \frac{.026\ eV}{1.11\ eV} = .023 = 2\%$

SEE STREETMAN & BANERJEE, "SOLID STATE ELECTRONIC DEVICES" OR CONSULT ECE 132 COURSE NOTES IF YOU ARE UNCLEAR ON THIS.

THEN, BEFORE CONTACT, THE BAND DIAGRAM OF THE TWO MATERIALS LOOKS LIKE THIS:



AT CONTACT, ELECTRONS WILL MOVE FROM THE SI TO THE AL, SINCE $E_{FS} > E_{FM}$, UNTIL AN EQUILIBRIUM IS REACHED, WITH A CONSTANT E_F ACROSS THE AL AND SI:



(B) SO THE BARRIER HEIGHT = BAND BENDING = $\phi_B = \phi_M - \phi_S$ = 4.5 eV

FOR A GOOD PICTURE OF THIS, SEE SOLYMAR & WALSH, FIG. 9.16, PG 171. THIS PROBLEM IS THE SAME AS THE SITUATION DEPICTED IN FIG. 9.16 WITH $E_{FS} = E_C$.

② **6.3** $\lambda = 2\cdot 10^{-7}\,m \Rightarrow E_\gamma = h\nu = \frac{hc}{\lambda} = \frac{(6.6\cdot 10^{-34}\,J\cdot s)(3\cdot 10^{8}\,m/s)}{(2\cdot 10^{-7}\,m)}$

$= 9.9\cdot 10^{-19}\,J = \underline{6.19\ eV}$

SINCE THIS IS LARGER THAN EACH OF THE WORK FUNCTIONS IN TABLE 6.2, LIGHT OF THIS WAVELENGTH WILL DRIVE A PHOTOELECTRIC CURRENT IN ALL OF THE TABLE 6.2 METALS.

③ **6.4** $N = Z(E)F(E) = \frac{CE^{1/2}}{1+e^{\frac{E-E_F}{KT}}}$ (6.10) $E = E_F + KT$

$\Rightarrow N = \frac{C(E_F+KT)^{1/2}}{1+e^{\frac{E_F+KT-E_F}{KT}}} = \boxed{\frac{C(E_F+KT)^{1/2}}{1+e}} = N(E_F+KT)$

FIND ΔE ST $N(E_F - \Delta E) = N(E_F + KT)$

$\frac{\not{C}(E_F-\Delta E)^{1/2}}{1+e^{\frac{E_F-\Delta E-E_F}{KT}}} = \frac{\not{C}(E_F+KT)^{1/2}}{1+e}$ FOR $\frac{\Delta E}{KT} \gg 1$, $\frac{E_F}{KT} \gg 1$

OR $(E_F-\Delta E)^{1/2} \cong \frac{(E_F)^{1/2}}{1+e} \Rightarrow \Delta E = E_F\left(1 - \frac{1}{(1+e)^2}\right)$

$\Delta E = E_F\frac{e(2+e)}{(1+e)^2} = .928\,E_F$

④ **6.8** # γ'S IN LASER BEAM = $\frac{\text{POWER OF BEAM, } P}{\text{ENERGY OF } \gamma,\ E_\gamma}$ $[s^{-1}]$

$$E_\gamma = h\nu = \frac{hc}{\lambda} \Rightarrow \# = \frac{P\lambda}{hc} = \frac{(.002\ W)(632.8\cdot10^{-9}\ m)}{(6.62\cdot10^{-34}\ J\cdot s)(3\cdot10^{8}\ m/s)}$$

$\# = 6.373\cdot10^{15}\ \frac{\gamma's}{s}$ EACH PHOTON INDUCES $10^{-4}\ e^-$

SO PHOTOELECTRIC CURRENT, $I = 6.373\cdot10^{15}\frac{\gamma's}{s}\cdot\frac{1e}{10^4\gamma's}\cdot1.6\cdot10^{-19}\frac{C}{e}$

$= 1.02\cdot10^{-7}\ A = \boxed{102\ nA}$

ASSUME ALL e^- COME FROM THE FERMI LEVEL, THEN EMITTED ELECTRONS HAVE $KE = h\nu - \phi$. ELECTRON FLOW STOPS WITH A VOLTAGE ON THE ANODE ST $-eV_a = KE$

$$\Rightarrow \phi = h\nu - |eV_a|$$

⑤ **6.9** $n = \frac{9.4\cdot10^3\ kg/m^3}{63.5\ g/mol}\cdot\frac{1000\ g}{kg} / \frac{1\ mol}{6.02\cdot10^{23}}\cdot\left(\frac{1\ m}{100\ cm}\right)^3 = 8.91\cdot10^{22}\ cm^{-3}$

$= 8.91\cdot10^{28}\ m^{-3}$

$= N_e$

$$E_F = \frac{h^2}{2m}\left(\frac{3N_e}{8\pi}\right)^{2/3} = 7.27\ eV$$

$C_e = \frac{\pi^2 k^2 T}{2E_F} N_e/\rho_{cu}$ (EQN 6.25) $= 2.24\ \frac{J}{kg\,K}$ @ $T = 293\ K$

$C_{LATTICE} = 3N_a k/\rho_{cu} = 392\ \frac{J}{kg\,K} \Rightarrow C_{TOTAL} = C_e + C_L = 394.2\ \frac{J}{kg\,K}$

SO $\frac{C_e}{C_T} = \frac{2.2}{394.2} \simeq .005 = \boxed{.5\%}$ CONTRIBUTED BY e^-

BOOKS SAY $C_{cu} = 398\ J/kg\,K$, CLOSE TO ESTIMATE