c) [8 pts] Roughly estimate the resistivity of this sample.

For an n-type sample, $n = N_D = 10^{15}$ cm^{-3}
From the mobility plot provided, μ_n = 1400cm^2/Vs for $N_D + N_A = 10^{15}$ cm^{-3}
Resistivity $\rho \cong 1/qn\mu_n = 1/[(1.6\times10^{-19})(10^{15})(1400)]$ = 5ohm-cm

d) [6 pts] If this sample were to be subjected to an electric field of strength 1000V/cm, what would be the electron drift velocity?

$v_{dn} = \mu_n \cdot \mathcal{E} = 1400 \times 1000 = 1.4 \times 10^6$ cm/s

e) [4 pts] **Qualitatively**, how would your answer to **(d)** change if this sample were to be additionally doped with boron atoms to a concentration of $10^{18} cm^{-3}$. Briefly, justify your answer.

More doping ->Degraded □$_n$ (increased ionic impurity scattering)->lower v_{dn}

Question 3) [30 pts]

Sketch the energy-band diagrams indicating the Schottky barrier height (Φ_B) and the width of the depletion region (W), for each of the following cases: (**Φ_{Bn}=0.65eV, Φ_{Bp}=0.47eV, N_c = 3.2x10^{19} and N_v = 1.8x10^{19}**)

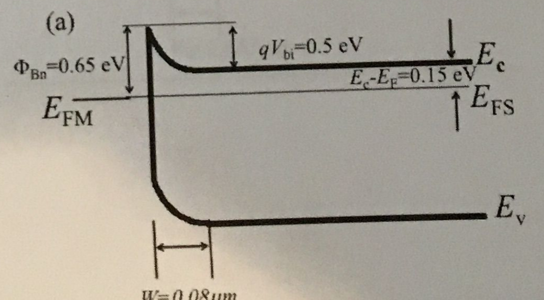
a) [10 pts] A contact between NiSi and uniformly doped n-type silicon with $N_D = 10^{17}$ cm^{-3}, $V_A = 0$ V

E_c–E_F=kT ln(N_c/N_D) = 0.026·ln(3.2x10^{19}/10^{17})=0.15eV

qV_{bi}= Φ_{Bn} – (E_c–E_F)

qV_{bi} = 0.65-0.15=0.5eV

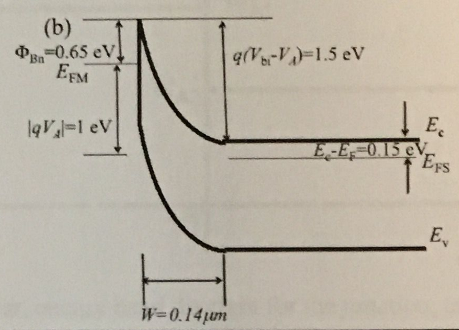
$$W = \sqrt{\frac{2\varepsilon_s (V_{bi} - V_A)}{qN}} \quad W = \sqrt{\frac{2\times12\times8.85\times10^{-14}(0.5)}{1.6\times10^{-19}\times10^{17}}}$$ **= 8.14 ×10^{-6} cm= 0.0814µm.**



b) [10 pts] A contact between NiSi and uniformly doped n-type silicon with $N_D = 10^{17}\ \text{cm}^{-3}$, $V_A = -1$ V

Φ_{Bn}, E_c–E_F and V_{bi} are unchanged from (a) since the contacting materials are the same.

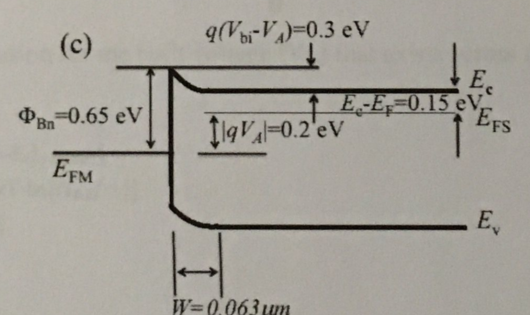
$$W = \sqrt{\frac{2 \times 12 \times 8.85 \times 10^{-14}(0.5+1)}{1.6 \times 10^{-19} \times 10^{17}}}$$ **= 1.4 x 10^{-5} cm= 0.14µm.**



c) [10 pts] A contact between NiSi and uniformly doped n-type silicon with $N_D = 10^{17}\ \text{cm}^{-3}$, $V_A = 0.2$ V

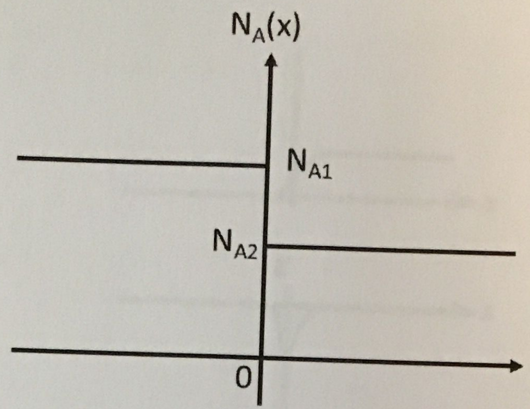
Φ_{Bn}, E_c–E_F and V_{bi} are unchanged from (a) since the contacting materials are the same.

$$W = \sqrt{\frac{2 \times 12 \times 8.85 \times 10^{-14}(0.5-0.2)}{1.6 \times 10^{-19} \times 10^{17}}}$$ **= 6.3 x 10^{-6} cm= 0.063µm.**

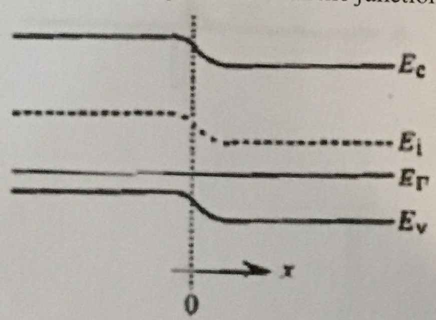


Question 4) [30 pts]

Consider the $p1$-$p2$ "isotype" step junction shown in the following figure.



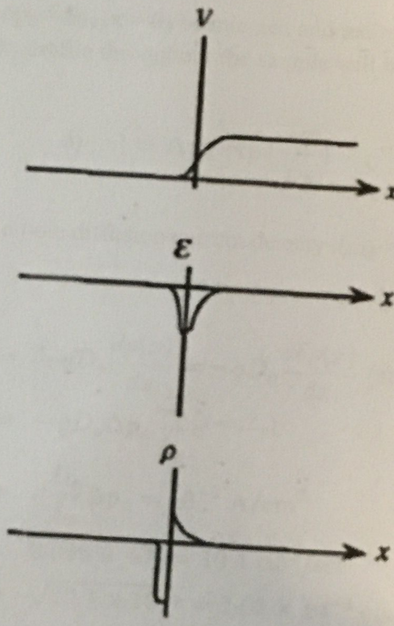
a) [10 pts] Draw the equilibrium energy band diagram for the junction, taking the doping to be nondegenerate and $N_{A1} > N_{A2}$. (Hint: A good starting point may be to consider the relative position of E_v (or equivalently E_i) with respect to E_F in the regions far from the junction on either side.)



b) [10 pts] Derive an expression for the built voltage (V_{bi}) that exists across the junction under equilibrium conditions.

$$V_{bi} = 1/q[(E_i\text{-}E_f)_{p1\text{-side}} - (E_i\text{-}E_f)_{p2\text{-side}}]$$
$$= 1/q[kT\cdot\ln(N_{A1}/n_i)\text{-}\ kT\cdot\ln(N_{A2}/n_i)]$$
$$= 1/q[kT\cdot\ln(N_{A1}/N_{A2})]$$

c) [10 pts] Make rough sketches of the voltage, electric field, and charge density inside the junction.



Question 5) [10pts]

A uniformly-doped n-type silicon sample has $N_D = 10^{18}$ /cm^3. At room temperature. Use μ_n = 1200cm^2/V.s, μ_p = 400cm^2/V.s. The carrier lifetimes are $\tau_n = \tau_p = 10^{-7}$ sec.

Let a fixed excess hole concentration $\Delta p_n = \delta p_n (x = 0)$ be injected and maintained at one edge of the sample, at x = 0. Then the excess hole concentration profile throughout the sample will be given by:

$$\delta p(x) = \Delta p_n \exp\left(\frac{-x}{L_p}\right)$$

Find the Δp_n level required to maintain a hole diffusion current density $J_{p,diff}$ = 10^{-5} A/cm^2 = 10 μA/cm^2 at the edge x = 0 at room temperature.

$$\begin{aligned}
J_{p,diff} &= -qD_p\frac{dp(x)}{dx} = -qD_p\frac{d\delta p(x)}{dx} \text{ (since } p_0 \text{ is uniform.)}\\
&= -qD_p\Delta p_n\frac{-1}{L_p}e^{(-x/L_p)}\\
&= q\frac{D_p}{L_p}\Delta p_n = 10^{-5}\ \mathrm{A/cm^2}\\
D_p = V_{thermal}\mu_p &= 0.026 \times 400 = 10.4\ \mathrm{cm^2/sec}\\
L_p = \sqrt{D_p\tau_p} &= \sqrt{10.4 \times 10^{-6}} = 1.02 \times 10^{-3}\ \mathrm{cm}\\
\Rightarrow J_{p,diff} &= 1.6 \times 10^{-19}\frac{10.4}{0.00102}\Delta p_n = 10^{-5}\\
\Rightarrow \Delta p_n &= \frac{10^{-5} \times 0.00102}{1.6 \times 10^{-19} \times 10.4} = 6.13 \times 10^{9}\ 1/\mathrm{cm^3}
\end{aligned}$$

EE121b winter 2018

Midterm 1 solution

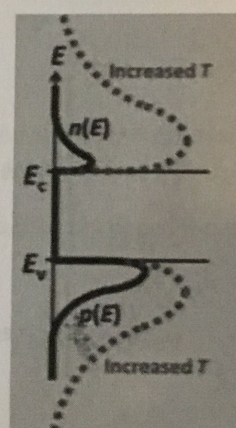
Question 1) [10pts] To the right is a plot of the electron and hole distributions within the conduction and valence bands, respectively, for a lightly doped ($|N_D\text{-}N_A|<10^{17}cm^{-3}$) silicon sample maintained at T = 300K.

a) [3 pts] Is this material ***n-type*** or ***p-type*** (Circle one.) Briefly justify your answer.

P-type

Integral of *p(E)*d*E* over all E within the valence band is greater than integral of *n(E)*d*E* over all E within the conduction band.

b) [7 pts] Show qualitatively (by adding 2 curves to the plot) how *n*(E) and *p*(E) would change if the temperature were to be increased significantly (*e.g* to 1000K).



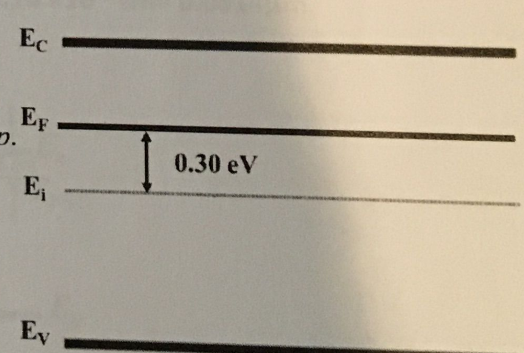
Question 2) [30 pts]

The energy band diagram for a uniformly doped Si sample maintained at T = 300K is shown below.

a) [2 pts] Is this sample ***n-type*** or ***p-type***? (Circle one.)

n-type

b) [10 pts] Calculate the mobile charge carrier concentration, *n* and *p*. (Remember kTln(10) = 0.06eV at 300K)



$E_F - E_i = kT\cdot\ln(n/n_i)$

$E_F - E_i = 5 \times 0.06eV = 5kT\ln(10)$

$n/n_i = 10^5$ $n = 10^{15}$ $p = 10^5$