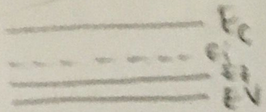


$1000\,Å \times \frac{0.1\,nm}{1\,Å} \times \frac{10^{-9}\,m}{1\,nm} \times \frac{100\,cm}{1\,m} = 10^{-5}\,cm$

Question 2) [25 points]

A MOS Capacitor is fabricated with an Al gate ($\Phi_M = 4$ eV) on 1000 Å of SiO_2 on p-type Si with a minority carrier lifetime of 10^{-5} sec and doped at $p = 1 \times 10^{17}\ cm^{-3}$.

a) Sketch the C-V curves for a slow voltage scan with measurement frequencies of 1 Hz. What is the flat band voltage? What is the threshold voltage?

$V_{FB} = \Phi_M - \Phi_S$

$= 4 - 5.03$

$V_{FB} = -1.03\,V$

$\Phi_S = \chi + (E_c - E_F) = \chi + \frac{E_g}{2} + (E_i - E_F)$

$= 4.05 + \frac{1.12}{2} + .42$

$\Phi_S = 5.03\ eV$

$p = n_i\, e^{(E_i - E_F)/KT}$

$E_i - E_F = KT \ln\left(\frac{p}{n_i}\right)$

$= 0.026 \ln\left(\frac{10^{17}}{10^{10}}\right)$

$E_i - E_F = 0.42\ eV$

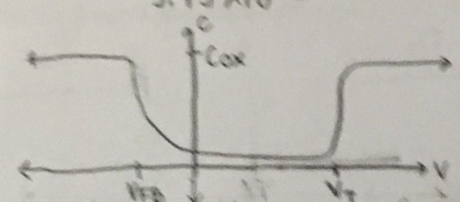
$V_T = V_{FB} + 2\phi_F + \frac{\sqrt{2q N_A \varepsilon_{Si} (2\phi_F)}}{C_{ox}}$

$C_{ox} = \frac{\varepsilon_{ox}}{X_{ox}} = \frac{3.9 \times 8.85 \times 10^{-14}}{10^{-5}} = 3.45 \times 10^{-8}$

$= -1.03 + 2(0.42) + \frac{\sqrt{2q(10^{17})(10^{-12})(2 \times 0.42)}}{3.45 \times 10^{-8}}$

$\phi_F = \frac{KT}{q} \ln\left(\frac{10^{17}}{10}\right) = 0.42\,V$

$V_T = 4.56\ V$



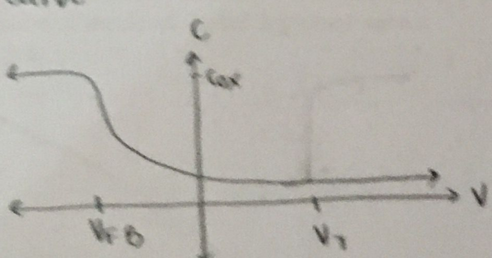
b) Sketch the C-V curves for a slow voltage scan with measurement frequencies of 1MHz. What is the flat band voltage? What is the threshold voltage?

the V_{FB} and the V_T stay the same as in part a

$V_{FB} = -1.03V$

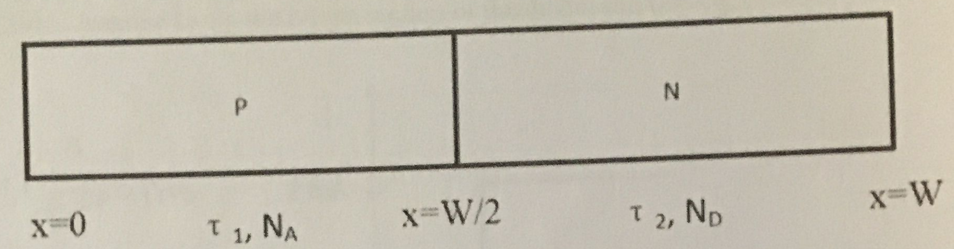
$V_T = 4.56\ V$

the C-V curve



Question 3) [30 points]

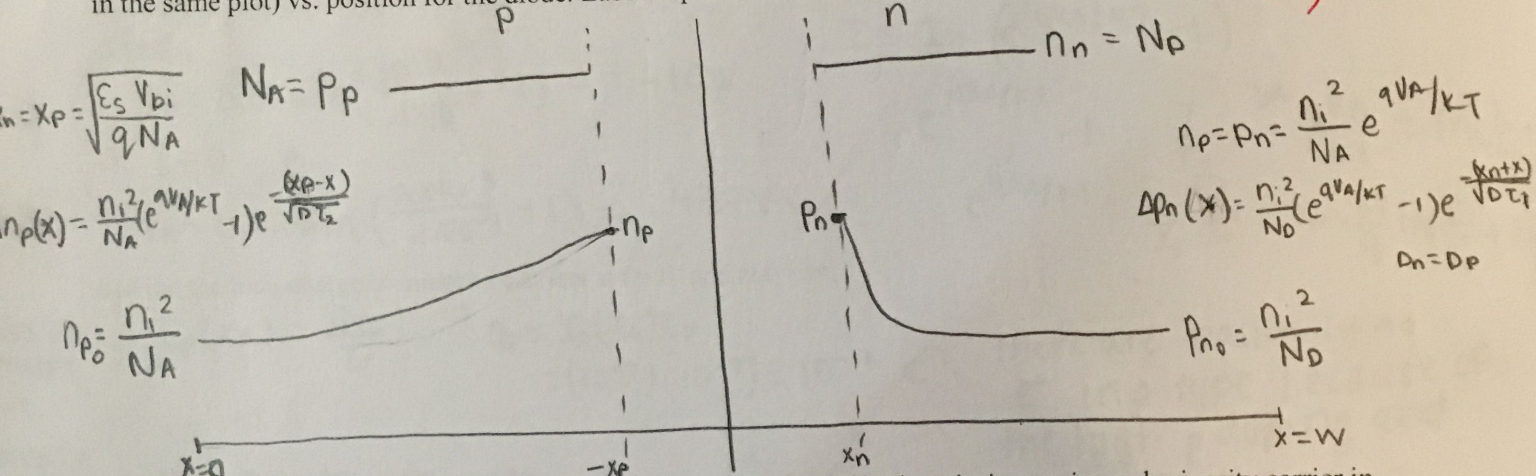
Consider a semiconductor PN diode as below:



The length of the diode is much larger than the electron and hole diffusion lengths (long diode). Assume the mobility of electrons is equal to the mobility of holes. Also, we have $N_A = N_D$. Due the device fabrication process, the lifetime of carrier in P side is 100 times larger than the lifetime in N side, $\tau_n = 0.01\ \tau_p$. Assume W>> L_n or L_p .

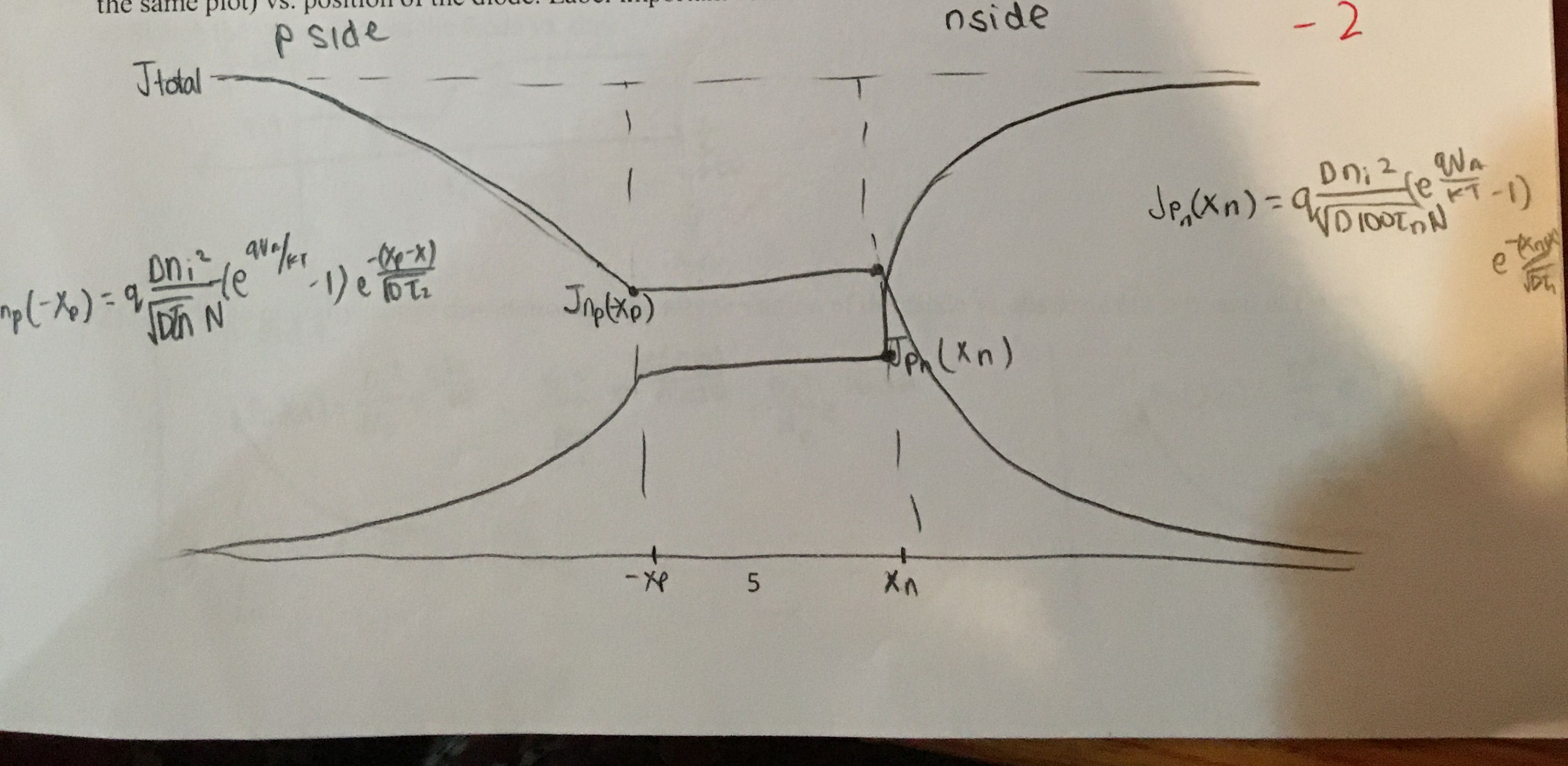
a) When the diode is forward biased, sketch the carrier concentration (of both ~~majority~~ majority carrier and minority carrier in the same plot) vs. position for the diode. Label important values.

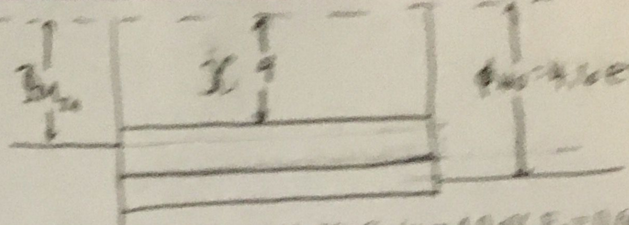
-3



b) When the diode is forward biased, sketch the current density (of both majority carrier and minority carrier in the same plot) vs. position of the diode. Label important values.

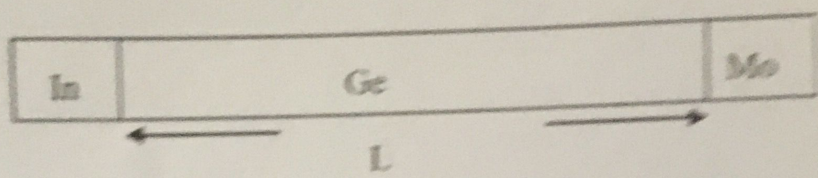
-2





Question 5) [15 points]

A Metal-Semiconductor-Metal structure is formed using In ($\Phi = 4.12$ eV), Ge ($\chi = 4.0$ eV, $E_g = 0.66$ eV, $\Phi = 4.33$ eV) and Mo ($\Phi = 4.6$ eV). Assume that there are no traps at the interface.



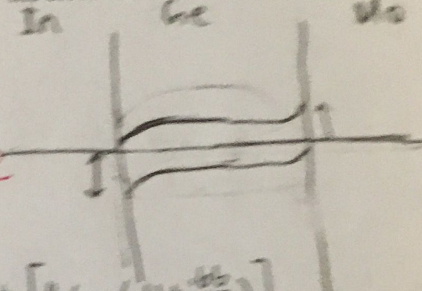
a) What is the barrier height seen by holes at the In side, and that seen by the electrons at the Mo side?

holes at the In side:

$(\Phi_S - \Phi_{M_{In}}) + \frac{E_g}{2} = (\chi + \frac{E_g}{2} - \Phi_{M_{In}}) + \frac{E_g}{2}$

$= (4 + \frac{.66}{2} - 4.12) + \frac{.66}{2} = 0.46V$ ✗ 0.54

−2



electrons at the Mo side

$\frac{E_g}{2} + (\Phi_{Mo} - \Phi_S) = \frac{E_g}{2} + (\Phi_{Mo} - (\chi + \frac{E_g}{2})) = \frac{.66}{2} + [4.6 - (4 + \frac{.66}{2})]$

$= 0.6V$

b) What is the built-in potential?

$.46 + .6 = 1.06V$ ✗

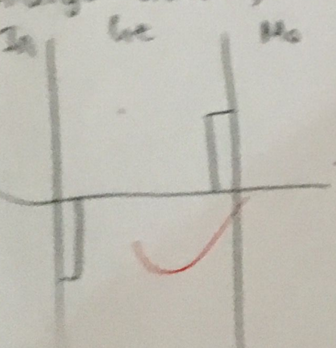
$\Phi_{M_{In}} - \Phi_S = 4.12 - (4 + \frac{.66}{2}) = .21$ −3

$\Phi_{M_{Mo}} - \Phi_S = 4.6 - (4 + \frac{.66}{2}) = .27$

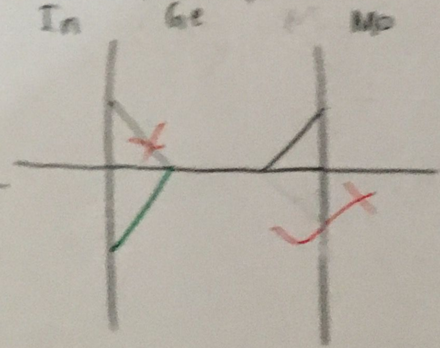
$V_{bi} = .27 + .21 = .48$

c) Sketch the charge density, electric field and band diagram of the structure at equilibrium. You may assume that the length of the Ge layer is much larger than the depletion width at the two contacts.

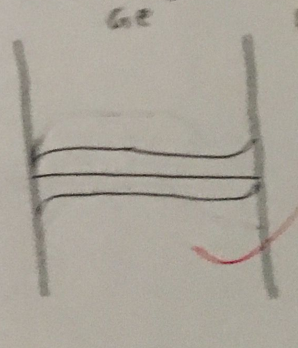
charge density



E field



band diagram



−1

UCLA Department of Electrical & Computer Engineering
EE121B – Principles of Semiconductor Device Design
Winter 2018
Midterm 2, Feb 27 2018, (100 minutes)

Properties of silicon (Si at 300K).

Symbol	Value
E_G	1.12 eV
N_c	$3\times10^{19}\,cm^{-3}$
N_v	$2\times10^{19}\,cm^{-3}$
n_i	$10^{10}\,cm^{-3}$
ε_S	11.8
ε_{SiO2}	3.9
τ_0	10^{-6} s
χ	4.01 eV
$\varepsilon_S = \varepsilon_0\varepsilon_S$	10^{-12} F/cm

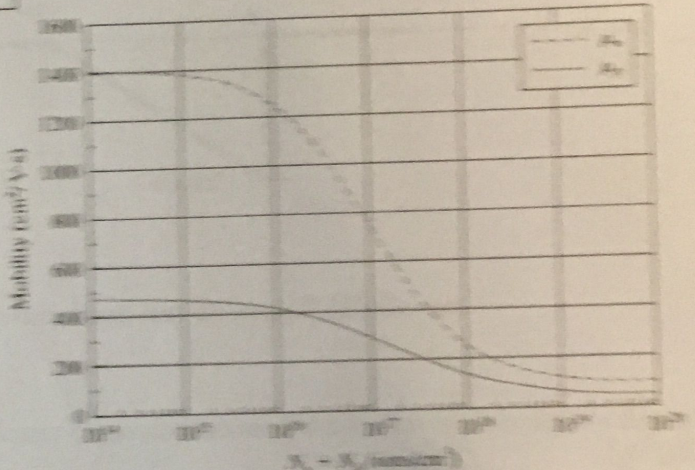
Properties of GaAs (Si at 300K).

Symbol	Value
E_G	1.42 eV
N_c	$4\times10^{17}\,cm^{-3}$
N_v	$9\times10^{18}\,cm^{-3}$
n_i	$2\times10^{6}\,cm^{-3}$
ε_{GaAs}	13.2
τ_0	10^{-9} s
χ	4.06 eV

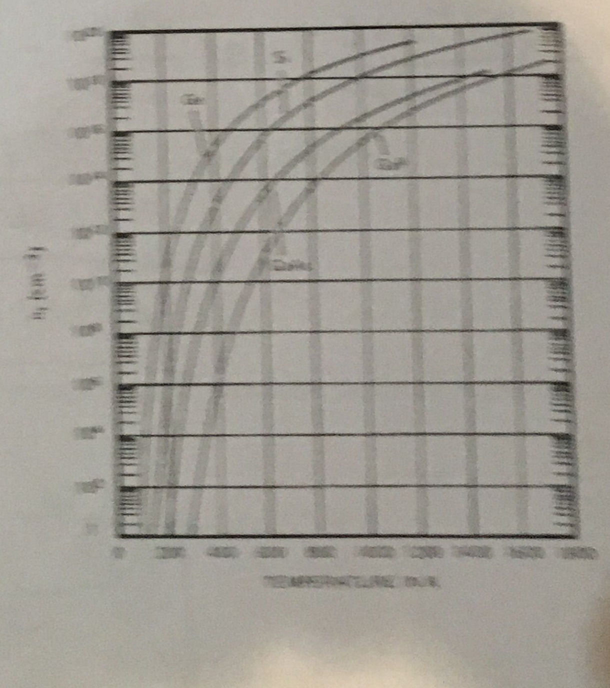
Physical constants

Symbol	Value
q	1.6×10^{-19} C
kT/q	0.026V
ε_0	8.85×10^{-14} Farad/cm

Carrier mobility in silicon



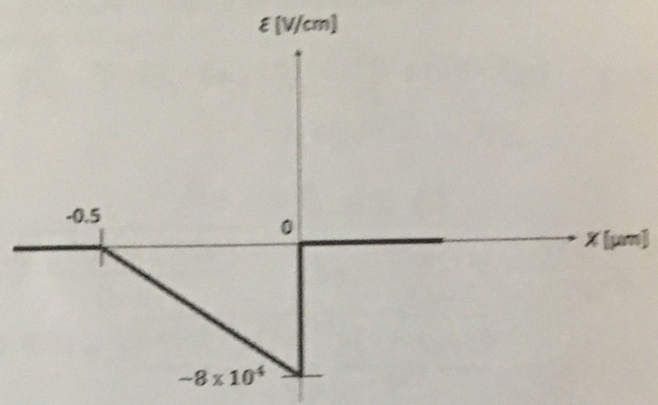
Intrinsic carrier concentration vs. temperature

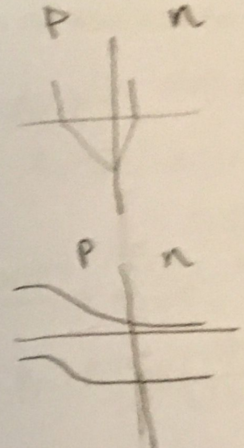


11

Question 1) [15 points]

The electric-field distribution in a Si pn step junction maintained at 300K is shown below.





a) Is the p-type side or n-type side more heavily doped? (Circle one.)

b) What is the value of net dopant concentration on the side that is more lightly doped?

$X_p = 0.5$ (p side)

$E_x = \frac{-qN_A}{\varepsilon_s}(x + X_p)$

$E_x(0) = -8\times10^4 = \frac{-qN_A}{\varepsilon_s} X_p \qquad \frac{(-8\times10^4)\varepsilon_s}{-qX_p} = N_A$

$N_A = \frac{(8\times10^4)(10^{12})}{-(1.6\times10^{-19})(0.05)} = 1\times10^{12}$

$N_A = 10^{12}\ cm^{3}$

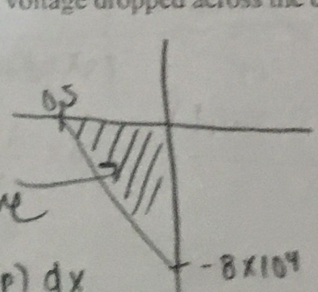
−2

c) What is the value of the total voltage dropped across the depletion region, *i.e.* $q(V_{bi} - V_a)$?

−2

$\frac{1}{2} \cdot 80000 = 20000 \quad V = \int E$

area under curve



$V = \int_{-0.5}^{0} \frac{-qN_A}{\varepsilon_s}(x + X_p)\,dx$

$= \frac{qN_A}{2\varepsilon_s} x^2 + \frac{-qN_A}{\varepsilon_s} X_p x \Big|_{-0.5}^{0} = \frac{qN_A (0.5)^2}{2\varepsilon_s} + \frac{qN_A (0.5)^2}{\varepsilon_s}$

$V(0) = \frac{qN_A}{2\varepsilon} X_p^2 = \frac{q10^{12}(.5)^2}{2\,10^{12}} = 20000\ V$