UNIVERSITY OF CALIFORNIA, BERKELEY
College of Engineering
Department of Electrical Engineering and Computer Sciences

EE 130/230M — Spring 2013
Integrated Circuit Devices — Prof. Liu & Dr. Xu

QUIZ #2
Time allotted: 25 minutes

NAME: SOLUTIONS ______ ______
(print) Last First Signature

STUDENT ID#: ____________

1. **Use the values of physical constants provided below.**
2. **SHOW YOUR WORK, and write legibly!**
3. **Underline or box numerical answers, and specify units where appropriate.**

Physical Constants

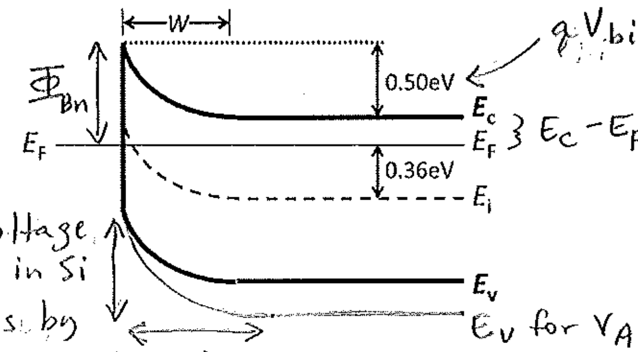
Description	Symbol	Value
Electronic charge	q	1.6×10^{-19} C
Thermal voltage at 300K	kT/q	0.026 V

Properties of silicon (Si) at 300K

Description	Symbol	Value
Energy band gap	E_G	1.12 eV
Intrinsic carrier concentration	n_i	10^{10} cm^{-3}
Permittivity	ε_{Si}	1.0×10^{-12} F/cm

Problem 1 [11 points]

The equilibrium energy band diagram for a rectifying metal-Si contact is shown below. $T = 300$K.
$kT\,ln(10) = 0.06$ eV



$E_c - E_F = \frac{E_G}{2} - 0.36\,eV = 0.56\,eV - 0.36\,eV = 0.2\,eV$

Total voltage dropped in Si increases by $0.25V \rightarrow 0.25eV$. W increases; more band bending (by a factor $\sqrt{0.75/0.5}$)

a) What is the value of the Schottky barrier height, Φ_B? **Indicate it on the band diagram above.** [3 pts]

$\Phi_{Bn} = qV_{bi} + (E_c - E_F) = 0.50\,eV + 0.2\,eV = \underline{0.7\,eV}$

b) What is the width of the depleted region, W? [4 pts]

$\sqrt{\frac{10}{1.6}} = 2.5$

$\sqrt{\frac{1}{1.6}} = 0.8$

$W = \sqrt{\frac{2\varepsilon_s V_{bi}}{qN_D}} = \left[\frac{2\times10^{-12}\times0.5}{1.6\times10^{-19}\times10^{16}}\right]^{1/2} = \left[\frac{10^{-12}}{1.6\times10^{-3}}\right]^{1/2}$

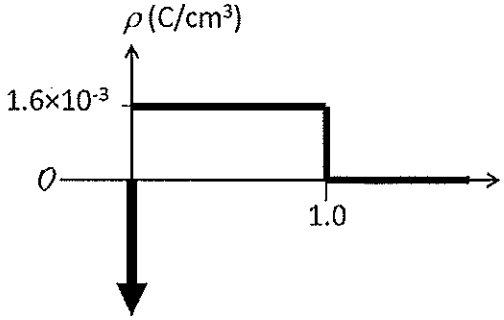
$= \left[\frac{10}{1.6}\times10^{-10}\right]^{1/2} = 2.5\times10^{-5}\,cm = \underline{0.25\,\mu m}$

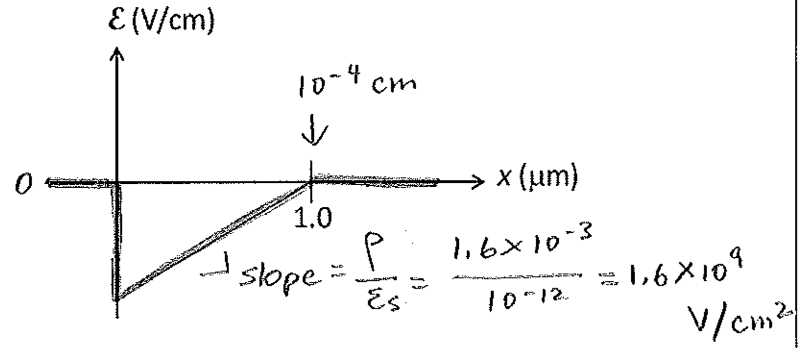
d) Carefully sketch E_v corresponding to a reverse bias of 0.25 V on the band diagram above. [2 pts]

e) Explain how this contact can be made to be practically ohmic. [2 pts]

Increase the dopant concentration to decrease W (to ≤10 nm) so that electrons can easily tunnel through the potential barrier.

Problem 2 [8 points]
Consider the following charge density distribution for a Schottky diode under reverse bias:





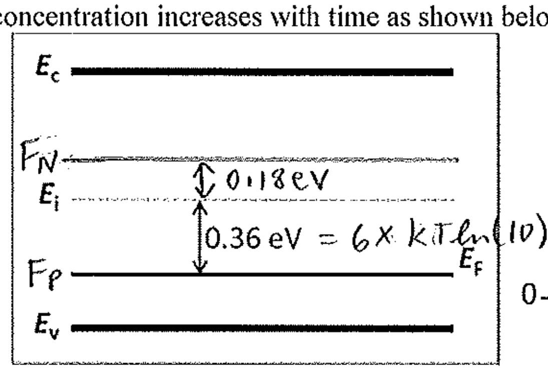
a) Sketch the electric field distribution on the axes provided. Indicate the numerical value of $\mathcal{E}$ at $x = 0$. [5 pts]

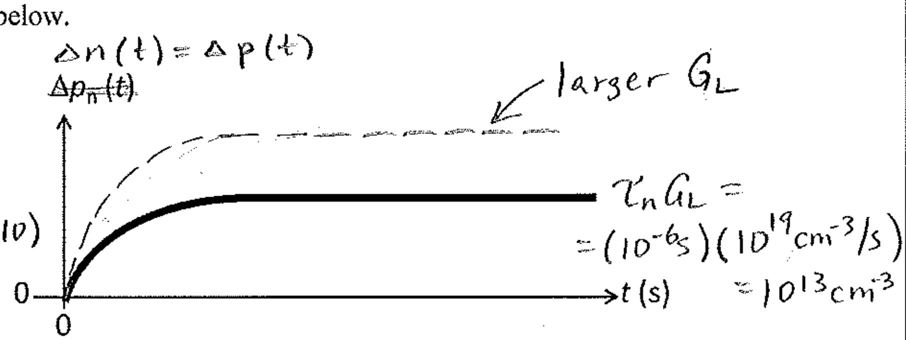
$$|\mathcal{E}(0)| = (1.6\times10^{9}\ V/cm^2)(10^{-4}\ cm) = 1.6\times10^{5}\ V/cm$$

b) If the cross-sectional area of this diode is 1 mm × 1 mm ($10^{-2}\ cm^2$), what is its small-signal capacitance? [3 pts]

$$C = \frac{A\varepsilon_s}{W} = \frac{(10^{-2})(10^{-12})}{10^{-4}} = 10^{-10}\ F = 100\ pF$$

Problem 3 [6 points]
The equilibrium energy band diagram for a uniformly doped Si sample with minority-carrier lifetime $\tau_n = 10^{-6}$ s is shown below. Suppose this sample is illuminated uniformly with light beginning at time $t = 0$, generating electron-hole pairs at a rate $G_L = 10^{19}/cm^3/s$ throughout the sample, so that the excess carrier concentration increases with time as shown below.





a) Indicate the final positions of the electron and hole quasi-Fermi levels (F_N and F_P, respectively) in this sample (*i.e.* at $t = \infty$). [4 pts]

In steady state, $\frac{\partial \Delta n}{\partial t} = \frac{-\Delta n}{\tau_n} + G_L = 0 \Rightarrow \Delta n = \tau_n G_L = 10^{13}\ cm^{-3}$

Equilibrium carrier concentrations $p_o = 10^{16}\ cm^{-3}$, $n_o = \frac{n_i^2}{p_o} = 10^{4}\ cm^{-3}$

$p = p_o + \Delta p = 10^{16} + 10^{13} \approx 10^{16}\ cm^{-3} \Rightarrow F_P$ same as E_F

$n = n_o + \Delta n = 10^{4} + 10^{13} \approx 10^{13}\ cm^{-3} \Rightarrow F_N = E_i + kT\ln\left(\frac{n}{n_i}\right)$

$= E_i + kT\left(\frac{10^{13}}{10^{10}}\right)$

$= E_i + 3kT\ln(10)$

$= E_i + 0.18\ eV$

b) Indicate on the plot above how $\Delta p_n(t)$ would change if ~~τ_n~~ G_L were to be increased. [2 pts]

- Final value would be higher
- Time to reach final value would be the same.