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 #4
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

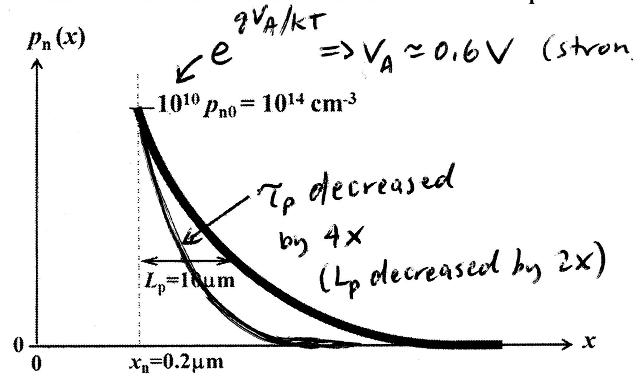
Description	Symbol	Value
Electronic charge	q	1.6×10^{-19} C
Thermal voltage at 300K	kT/q	0.026 V

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 [13 points] One-sided pn Junction

The excess hole concentration within the quasi-neutral n-type region of a silicon p^+n step junction of area A = **1mm** × **1mm** maintained at T = 300K is plotted on a linear scale below. The hole lifetime τ_p = **10^{-6}** s.



(a) Calculate the minority-carrier charge stored in this diode, Q_P. [3 pts]

$$Q_P = qA\,\Delta p_n(x_n)\,L_p$$
$$= 1.6\times10^{-19} \times 10^{-2} \times 10^{14} \times 10\times10^{-4}$$
$$= 1.6\times10^{-10}\,C$$

(b) Calculate the diode current, I. [3 pts]

$$I = \frac{Q_P}{\tau_p} = \frac{1.6\times10^{-10}}{10^{-6}} = 1.6\times10^{-4}\,A = 0.16\,mA$$

(c) Estimate the small-signal capacitance, C, of this junction. [3 pts]

$$\frac{1}{0.026} \cong 40$$

$C \simeq C_D$ under strong forward bias

$$C = \frac{\tau_p I}{(kT/q)} = \frac{10^{-6}\times1.6\times10^{-4}}{0.026} = 64\times10^{-10} = 6.4\,nF$$

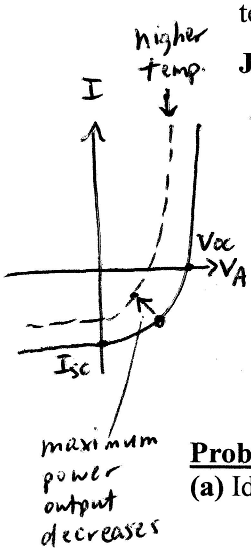
(d) Show on the plot above how $p_n(x)$ would change if τ_p were to be decreased by a factor of 4. [2 pts]
Qualitatively, how would the diode turn-off transient response change? Explain briefly. [2 pts]

The storage delay time would be reduced (hence the diode would turn off more quickly) because there are fewer holes stored and they die out more rapidly due to recombination.

Problem 2 [5 points] Optoelectronic Diodes
Circle the correct choices in the sentences below.

(a) Light is generated in a [**light-emitting diode** *or* photodiode] when it is operated under [**forward** *or* reverse] bias due to [generation *or* **recombination**] within the [depletion region *or* **quasi-neutral regions**]. [2 pts]

(b) The amount of electric power generated by a solar cell [increases *or* **decreases**] with an increase in temperature (*e.g.* in the range from 300K to 400K). [1 pt]



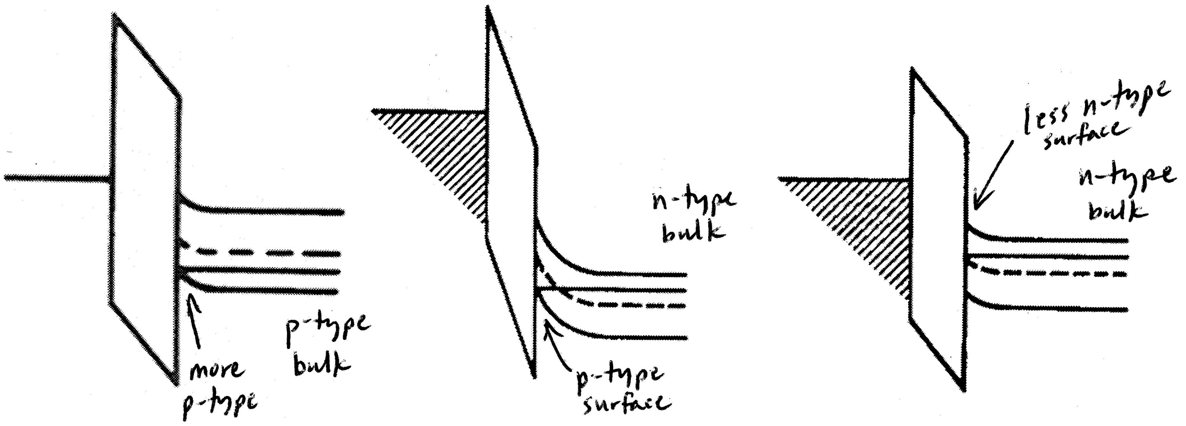
Justify your answer. [2 pts]

The open-circuit voltage (V_{oc}) decreases with increasing temperature, due to an increase in n_i.

The short-circuit current (I_{sc}) decreases with increasing temperature, due to reductions in L_p and L_n since D_p and D_n are degraded. (μ_p and μ_n decrease with increasing T.)

Problem 3 [7 points] MOS Capacitor

(a) Identify the bias condition (accumulation, depletion, or inversion) for the MOS energy-band diagrams below [3 pts]



Bias Condition: ACCUMULATION | INVERSION | DEPLETION

(b) Consider a MOS capacitor with 3.45 nm = 3.45×10^{-7} cm SiO_2 and p-type Si with $N_A = 10^{17}$ cm^{-3} maintained at 300K. The flatband voltage V_{FB} = -0.8V. **Calculate the threshold voltage, V_T.** [4 pts]
(Note: The permittivity of SiO_2 is 3.45×10^{-13} F/cm.)

$$C_{ox} = \frac{\varepsilon_{ox}}{x_{ox}} = \frac{3.45\times10^{-13}}{3.45\times10^{-7}} = 10^{-6}\ \mathrm{F/cm^2}$$

$$\phi_F = \frac{kT}{q}\ln\left(\frac{N_A}{n_i}\right) = \frac{kT}{q}\ln\left(\frac{10^{17}}{10^{10}}\right) = 7\times0.026\ln(10) = 7\times60\mathrm{mV} = 0.42\mathrm{V}$$

$$Q_{dep} = qN_AW_T = \sqrt{qN_A2\varepsilon_{Si}(2\phi_F)} = \sqrt{(1.6\times10^{-19})(10^{17})(2\times10^{-12})(2\times0.42)}$$

$$\simeq \sqrt{1.6^2\times10^{-14}} = 1.6\times10^{-7}\ \mathrm{C/cm^2}$$

$$V_T = V_{FB} + 2\phi_F + \frac{Q_{dep}}{C_{ox}} = -0.8 + 2(0.42) + \frac{1.6\times10^{-7}}{10^{-6}}$$

$$= -0.8 + 0.84 + 0.16 = \underline{\underline{0.2\mathrm{V}}}$$