### UNIVERSITY OF CALIFORNIA College of Engineering Department of Electrical Engineering and Computer Sciences

EE 130/230A Fall 2013 Prof. Liu

# Homework Assignment #8

Due at the beginning of class on Thursday, 10/24/13

## Problem 1: P-I-N Photodiode

P-i-n diodes are used for photodetectors as well as fast switches and high-voltage power electronics applications. A p-i-n diode has a wide (1-50  $\mu$ m), intrinsic (very lightly doped) region between a heavily doped p-type region and a heavily doped n-type region. Consider a silicon p-i-n diode with a doping profile as shown below. Assume T = 300K.



- a) Applying the depletion approximation (*i.e.* assuming that the electron and hole concentrations have negligible impact on electrostatics within the depletion region), sketch the charge density distribution, electric field distribution, and potential distribution as a function of position *x*, for zero bias.
- **b**) Find the built-in potential,  $V_{\rm bi}$ , and the lengths of the depletion regions in the n-type region and the p-type region.
- c) How does the maximum electric field in this p-i-n diode compare to that for a pn diode which contains no intrinsic region but has the same dopant concentrations in the n-type and p-type regions?
- **d**) How does the small-signal capacitance of the p-i-n diode compare to that of a pn diode which contains no intrinsic region but has the same dopant concentrations in the n-type and p-type regions?

#### **Problem 2: Light-Emitting Diodes**

When a LED is turned on (*i.e.* forward biased), minority carriers are injected into the quasi-neutral regions, where they subsequently recombine with majority carriers. Because the LED is made using a direct band-gap semiconductor material, a photon is emitted whenever an electron and hole recombine. The wavelength of the emitted photon,  $\lambda$  (in  $\mu$ m), is dependent on the band-gap energy  $E_{\rm G}$  (in eV):

$$\lambda \cong \frac{1.24}{E_G}$$

In words: the larger the energy band gap, the larger the energy of the emitted photon and hence the shorter the wavelength of the emitted light. Recall that the visible spectrum spans the wavelength range from  $\sim 0.45 \ \mu m$  (blue) to  $\sim 0.65 \ \mu m$  (red). How would you expect the LED bias voltage for a given forward current (e.g. 1 mA) to change with the LED color? Explain briefly.

### **Problem 3: Solar Cell Design**

In order to maximize the amount of power that can be generated by a pn-junction solar cell:

(a) Would you design the quasi-neutral regions to be "long" or "short"?

(b) Should the quasi-neutral regions be lightly doped, or heavily doped?

Provide qualitative explanations for your answers (without using any equations or formulas).

## **Problem 4: MOS Capacitor Energy Band Diagrams**

Consider an ideal MOS capacitor maintained at T = 300K with the following parameters:

- Gate material is n+ polycrystalline-silicon (work function  $\Phi_M = 4.05 \text{ eV}$ ) Substrate is p-type Si, with doping concentration  $10^{17} \text{ cm}^{-3}$  (assume that this is non-degenerate)
- Oxide thickness  $x_0 = 3 \text{ nm}$
- (a) What is the flat-band voltage,  $V_{\rm FB}$ , of this capacitor?
- (b) Sketch the energy-band diagrams, labeling  $qV_{\rm G}$ ,  $q\phi_{\rm S}$ ,  $qV_{\rm ox}$  (no numerical values required), for the following bias conditions:
  - (i) flat band
  - (ii) equilibrium
  - (iii) accumulation
  - (iv) strong inversion