**ECE 340** **Fall 2015**

# Homework Assignment #9

DUE: FRIDAY, NOVEMBER 13, 2015

Print your **name** and **NetID** legibly. Follow the guidelines and format given in the syllabus. Staple multiple pages. Show all units. Homework must be turned in at the **beginning** of class and any late homework assignments will not be accepted. Please contact the course director, Professor Dallesasse, should any issues with late homework arise.

## 1. SCHOTTKY BARRIERS

A Schottky barrier is formed by attaching a metal with a work function of 5 eV to a wafer of n-type Si ($q\chi$=4.05 eV). The donor doping of the silicon is $1\times10^{18}$ cm$^{-3}$ and T=300 K.

(A). What is the potential barrier? The contact potential? Draw out the equilibrium band diagram of the junction, labeling the potential barrier, contact potential, and depletion width.

(B). Repeat part (a) with an applied bias of 0.4 V and again for -1 V.

(C). Qualitatively explain why we'd expect charge separation into three regions across the Schottky diode. Do these change when we apply a positive or negative bias?

## 2. P-N DIODE

A Silicon p-n diode with reverse saturation current 4 nA is used as a solar cell. When illuminated, the diode produces a photocurrent of 150 mA.

(A). Show that when the power extracted from the photodiode is maximized, the following expression holds:

$$(1+\frac{q}{k_BT}V_{max})\cdot e^{\frac{qV_{max}}{k_BT}} = 1+\frac{I_{op}}{I_{th}} \tag{2.1}$$

(B). Find the voltage and current values corresponding to the maximum power ($P_{max}$) power that can be extracted from the diode at room temperature (300 K).

(C). What is the fill factor of this diode?

(D). If your diode's quantum efficiency is 31%, what is the incident photon rate?

(E). Suppose you have a metal with work function $q\Phi_M$=3.0eV. Is it a rectifying or ohmic contact when you attach onto the diode's p-side? What about onto the n-side? Justify your answers based on a band diagram description.

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## 3. MOS-Capacitor

Consider a MOS-capacitor at room temperature with an Al gate ($q\Phi_m \approx 4.05$ eV) on top of an oxide made of $SiO_2$ with thickness $t_{ox}$=1.5nm and electron affinity $q\chi_{ox}$=0.9 eV. The Si semiconductor has a donor concentration of $N_D = 1\times10^{19}$ cm$^{-3}$.

(A). What is the maximum value for the depletion width into the semiconductor?

(B). Find $V_{FB}$ and $V_T$ for the MOS-Capacitor.

(C). If you wanted to use $HfO_2$ ($\varepsilon_{HfO_2}/\varepsilon_0 \approx 20$) for the oxide instead, what thickness would you need to match the same capacitance?

(D). From your answer in (C), explain why higher permittivities are increasingly preferred in fabricating integrated circuitry.

(E). Explain what happens qualitatively to capacitance as you change gate voltage, $V_G$, from negative to positive values. Note all unique regions and when they change.

## 4. Laser Design

Suppose you want to design a semiconductor laser cavity to emit light at a free-space wavelength $\lambda_0$=980nm at room temperature. You choose to use $In_{0.11}Ga_{0.89}As$ as your cavity material and you assume the material has a dispersionless refractive index of 3.63.

(A). Calculate the cavity length required for an adjacent mode spacing of 30nm in wavelength.

(B). Derive an equation for the spacing between adjacent modes in frequency space. What is the biggest difference between this equation and the equation for wavelength spacing between adjacent modes? Using the calculated cavity length from part (a), what is the **frequency spacing** between adjacent modes? (NOTE: The derivation of frequency spacing is not the same as for wavelength spacing)

(C). To construct your laser junction, you dope each side of your wafer separately, creating a p-n junction of p-$In_{0.11}Ga_{0.89}As$ and n-$In_{0.11}Ga_{0.89}As$. Across this junction, what is the applied voltage needed for population inversion? Should you forward bias or reverse bias the diode?

(D). Draw out the band diagram of this laser under bias and indicate all energy labels and inversion regions. Specify the span along the junction where stimulated emission would occur for your depiction.

(E). Given Eq. (8-8b), what can be done to increase stimulated emission rate compared to the spontaneous emission rate?

(F). Given Eq. (8-9), what can be done to increase the stimulated emission rate relative to the absorption rate?