55:072 Electrical Engineering Materials and Devices
Exam II

Name: ________________________________ April 9, 1998

You have until the end of class (10:45 am) to complete this exam. It is closed book, but you may have a calculator and two 8-1/2” x 11” sheets with notes on both sides. **Show your work** to get partial credit.

**Useful numbers:**

For silicon at room temperature:
- \( n_i = 1 \times 10^{10} \text{ cm}^{-3} \)
- \( N_v = 2 \times 10^{19} \text{ cm}^{-3} \)
- \( N_c = 3 \times 10^{19} \text{ cm}^{-3} \)
- \( E_g = 1.12 \text{ eV} \)
- \( k_B = 8.62 \times 10^{-5} \text{ eV/°K} \)
- \( q = 1.60 \times 10^{-19} \text{ C} \)

\( 1. \) (31% total, 4% for (a), 3% for other parts)
(a) For each of the four ideal silicon diodes listed in the table, calculate \( V_{bi} \) at room temperature.

<table>
<thead>
<tr>
<th>diode</th>
<th>( N_A ) (cm(^{-3}))</th>
<th>( N_D ) (cm(^{-3}))</th>
<th>( V_{bi} ) (V)</th>
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<tr>
<td>( p^+ - n^+ )</td>
<td>( 10^{17} )</td>
<td>( 10^{17} )</td>
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<td>( p^+ - n )</td>
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Assuming that material properties are independent of doping type and doping level, state which of the above diodes would satisfy the following requirements (if there are more than one diode satisfying the requirement, list them all):

(b) the largest current at 0.5 V forward bias?
(c) the smallest current at -2 V reverse bias?
(d) the largest \(|\varphi_{max}|\) at zero bias?
(e) the largest ratio of electron current to hole current under forward bias?

(f) the largest ratio of electron current to hole current under reverse bias?

(g) the largest low frequency capacitance under forward bias?

(h) the largest breakdown voltage?

(i) most of the depletion region on the p-side?

(j) smallest capacitance under reverse bias?

2. (12% total, 4% each) A varactor is a voltage tunable capacitor that is made with a p-n junction. Assume an ideal p-n junction.

(a) Why should the varactor be a reverse biased rather than a forward biased p-n junction?

(b) Give an expression for the varactor capacitance $C$ as a function of the bias voltage $V_A$.

(c) The term $dC/dV_A$ is useful for the small signal analysis. Derive an expression for $dC/dV_A$.

3. (27% total, 3% each) Consider an abrupt p-n junction with a doping of $N_A$ on the p-side of the junction and $N_D$ on the n-side. Assume the depletion approximation except in part (c) and label key points on your graphs.

(a) Sketch (and label which is which) the spatial distribution of the ionized donors and ionized acceptors in the vicinity of the junction at equilibrium. Do not confuse this with the net charge.
(b) Sketch the spatial distribution of the majority carriers (state whether they are electrons or holes) in the vicinity of the junction at equilibrium.

(c) How would the majority carrier distribution differ from part (b) if we do not use the depletion approximation? Either explain the difference in words or show the difference in a graph.

(d) Sketch the spatial distribution of the net charge in the vicinity of the junction at equilibrium.

(e) Sketch the electric field in the vicinity of the junction at equilibrium.

(f) Sketch the potential in the vicinity of the junction at equilibrium.
(g) Sketch the band diagram in the vicinity of the junction at equilibrium.

(h) Sketch the distribution of minority carriers near the junction at equilibrium.

(i) Sketch the distribution of minority carriers near the junction under forward bias.

4. (12% total, 4% each) An ideal p-n junction is used to rectify a square wave with a frequency low enough that any switching transients are gone before the wave changes sign.

(a) Sketch the diode current $i(t)$ as a function of time over one full cycle.

(b) Sketch the diode voltage $v(t)$ as a function of time over one full cycle.
(c) Without changing the circuit, how could the diode be modified to decrease the negative going current?

5. (12% total, 3% each) The forward bias current of a diode is 100 µA at 0.5 V.
   (a) At what voltage will the current be 1 mA if the diode current is dominated by diffusion current and the diode has negligible series resistance?

   (b) At what voltage will the current be 1 mA if the diode current is dominated by recombination current and the diode has negligible series resistance?

   (c) At what voltage will the current be 1 mA if the diode current is dominated by diffusion current and the diode has a series resistance of 1 kΩ?

   (d) If the diode is ideal with no series resistance, what is the value of the saturated current $I_o$?

6. (a) (3%) What is the largest value that $V_{bi}$ can have for a nondegenerate semiconductor?

6. (b) (3%) What is the smallest value that $V_{bi}$ can have?

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| Total | 100   |