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

EE 105: Microelectronic Devices and Circuits
MIDTERM EXAMINATION #1
Time allotted: 45 minutes

NAME: ________________________________

STUDENT ID#: _______________________

INSTRUCTIONS:

1. Unless otherwise stated, assume
   a. temperature is 300 K
   b. material is Si

2. SHOW YOUR WORK. (Make your methods clear to the grader!)
   Specially, while using chart, make sure that you indicate how you
   have got your numbers. For example, if reading off mobility, clearly
   write down what doping density that corresponds to.

3. Clearly mark (underline or box) your answers.

4. Specify the units on answers whenever appropriate.

SCORE: 1 ________ / 15

2 ________ / 15

Total ________ / 30
PHYSICAL CONSTANTS

<table>
<thead>
<tr>
<th>Description</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electronic charge</td>
<td>q</td>
<td>$1.6 \times 10^{19}$ C</td>
</tr>
<tr>
<td>Boltzmann's constant</td>
<td>k</td>
<td>$8.62 \times 10^{-5}$ eV/K</td>
</tr>
<tr>
<td>Thermal voltage at 300K</td>
<td>$V_T$</td>
<td>$0.026$ V</td>
</tr>
<tr>
<td></td>
<td>$kT/q$</td>
<td>$V_T \ln(10) = 0.060$ V at $T = 300$K</td>
</tr>
</tbody>
</table>

PROPERTIES OF SILICON AT 300K

<table>
<thead>
<tr>
<th>Description</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Band gap energy</td>
<td>$E_G$</td>
<td>1.12 eV</td>
</tr>
<tr>
<td>Intrinsic carrier</td>
<td>$n_i$</td>
<td>$10^{10}$ cm$^{-3}$</td>
</tr>
<tr>
<td>Dielectric permittivity</td>
<td>$\varepsilon_{Si}$</td>
<td>$1.0 \times 10^{12}$ F/cm</td>
</tr>
</tbody>
</table>

Electrostatics:

$$\frac{dE}{dx} = \frac{\rho}{\varepsilon}, \quad E = -\frac{dV}{dx}$$

Depletion region Width:

$$W = \sqrt{\frac{2\varepsilon}{q} \left( \frac{1}{N_a} + \frac{1}{N_d} \right) (V_{bi} - V_{\text{Applied}})}$$

Reverse saturation current of a diode,

$$J_S = qn_i^2 \left( \frac{D_n}{N_A L_n} + \frac{D_p}{N_D L_p} \right)$$

**Electron and Hole Mobilities in Silicon at 300K**

![Graph showing mobilities](image-url)
Prob 1. [15]

(a) [12 pts] A Si sample is doped first with B to $10^{17}$ /cm$^3$.
(i) [2 pts] Find out the number of electrons and holes.

$$n = \frac{n_i^2}{N_A}$$

$$= \frac{10^{20}}{10^{17}}$$

$$n = 10^3 / \text{cm}^3$$

$$p = 10^{17} / \text{cm}^3$$

Boron is an acceptor.

(b) [10 pts] Now the Si sample is further doped with As to $2 \times 10^{17}$ /cm$^3$ and a voltage of 1 Volt is applied across the sample. Find out the amplitude of the current that will flow due to this voltage. Assume that the sample has the following dimensions: Length=10 µm, Width=1µm and thickness=1µm.

As is a donor.

$$N_A + N_D = (2+1) \times 10^{17} = 3 \times 10^{17} / \text{cm}^3$$

$$n = (2-1) \times 10^{17} = 10^{17} / \text{cm}^3$$

$$\mu = 500 \text{ cm}^2/\text{V-s}$$

$$\sigma = q n \mu = 1.6 \times 10^{-19} \times 10^{17} \times 500$$

$$= 8 \ \Omega^{-1} \text{ cm}^{-1}$$

$$l = \frac{1}{8} = \frac{1}{8} \ \Omega \cdot \text{cm}$$

$$R = \frac{\sigma l}{A} = \frac{105}{8 \times 10^{4} \times \frac{105}{8}} \times \frac{1}{10^{4} \times 10^{4}}$$

$$= \frac{105}{8} \ \Omega$$

$$I = \frac{V}{R} = \frac{1}{105/8} = 8 \times 10^{-5} \ A$$

$$l = 80 \ \mu \text{A}$$
(c) [3 pts] What is the mechanism of current flow in a p-n junction diode under (i) forward and (ii) reverse bias. Simply mention the mechanisms.

(i) forward bias $\rightarrow$ diffusion
(ii) reverse bias $\rightarrow$ drift
Prob 2: [15 pts]

(a) [3 pts] For the following p-n junction diode, roughly sketch the

(i) charge density profile

(ii) electric field profile

(iii) energy band diagram

across the junction.

\[ N_A = 10^{18} / \text{cm}^3 \quad \text{and} \quad N_D = 10^{18} / \text{cm}^3 \]
(b) [8 pts] A p-n junction has to be designed such that the width of the depletion region on the N side is 0.212 μm, the built-in potential is 0.72 V and the maximum electric field at the junction is 3.4x10⁶ V/cm. What doping density on the p and n side will have to be used to design such a diode? What is the capacitance of this diode?

\[
\frac{\partial E}{\partial x} = \frac{q}{\varepsilon} \quad ; \quad E = -\frac{2V}{\partial x}
\]

\[
\varepsilon E_{\text{max}} = qN_D W_n \quad \left[ \text{area under the charge density profile} \right]
\]

\[
N_D = \frac{\varepsilon E_{\text{max}}}{qW_n} = \frac{10^{-12} \times 3.9 \times 10^{19}}{1.6 \times 10^{-19} \times 0.212 \times 10^{-9}} = \frac{3.9 \times 10^{-8}}{0.339 \times 10^{-23}} \approx 16 \text{ cm}^{-3}
\]

\[
V_d = \frac{1}{2} E_{\text{max}} W_n + \frac{1}{2} E_{\text{max}} W_p \quad \left[ \text{from area under } \varepsilon \text{ field plot} \right]
\]

\[
V_d = \frac{1}{2} E_{\text{max}} (W_n + W_p) = \frac{1}{2} E_{\text{max}} W
\]

\[
W = \frac{2V_d}{E_{\text{max}}} = \frac{2 \times 0.72}{3.9 \times 10^{19}} = 0.4235 \text{ μm}
\]

\[
W_p = W - W_n = 0.4235 - 0.212 \approx 0.212 \text{ μm} = W_n
\]

\[
N_A = \frac{\varepsilon E_{\text{max}}}{W_p} \approx 10^{16} / \text{cm}^3 = N_D
\]

\[
C = \frac{\varepsilon}{N} = \frac{10^{-12}}{0.4235 \times 10^{-4}} = 2.36 \times 10^8 \text{ F/cm}^2 = 23.6 \text{ nF/cm}^2
\]

at and around \( V_d = 0 \text{ V} \).
(c) [4 pts] What are the different mechanisms of reverse bias breakdown in a p-n junction diode? What are the main physical mechanisms responsible for each of these breakdown mechanisms?

Two main mechanisms:

(i) 
**Zener:** happens due to tunneling when the diode is heavily doped.

(ii) 
**Avalanche:** happens in a lightly doped junction at high reverse bias when the electrons can gain enough kinetic energy to generate additional electrons through avalanche.