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

MIDTERM EXAMINATION  
EE 130/230A: Spring 2016  
Time allotted: 60 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!)  
   o 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.  
   o Clearly write down any assumption that you have made.
   • Clearly mark (underline or box) your answers.

3. Specify the units on answers whenever appropriate.

SCORE: 1 _________ / 20

2 _________ / 20

Total _________ / 40
**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>$V_T = kT/q$</td>
<td>0.026 V</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 concentration</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>

**USEFUL NUMBERS**

$V_T \ln(10) = 0.060$ V at $T=300$K

Depletion region Width:

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

$$n_i = \sqrt{\frac{N_a N_d}{kT}} \exp(-\frac{E_G}{2kT})$$

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

[Graph showing mobility vs. total dopant concentration]
Prob 1 [20 pts].

(a) [8 pt]
(i) What kind of dopant would one use to dope an III-V semiconductor like GaAs. What determines whether or not it is a donor or acceptor? [4 pt]

(ii) After doping a Si by donors it is found that the carrier concentration does not change appreciably from 0K-400K. How can this happen? Explain by drawing Ec, Ev and the energy level for the dopants, Ed. [4pt]
(b) [6 pt] A compensated Si sample was measured and it was found that the conductivity is \( \sigma = 16 \text{ (ohm-cm)}^{-1} \) and mobility of \( 375 \text{ cm}^2/\text{V-sec} \). Find out the doping concentration of the sample.
(c) [6 pts] Please indicate ‘True’ or ‘False’

<table>
<thead>
<tr>
<th>Phenomenon</th>
<th>True/False</th>
</tr>
</thead>
<tbody>
<tr>
<td>Impurity scattering goes up at higher temperature</td>
<td></td>
</tr>
<tr>
<td>In a solid electrons and holes see same electrostatic potential</td>
<td></td>
</tr>
<tr>
<td>At equilibrium flows of electrons and holes balance each other to give zero current</td>
<td></td>
</tr>
<tr>
<td>In Si electron velocity saturates at high electric field due to impurities</td>
<td></td>
</tr>
<tr>
<td>When low level injection holds, ( np = n_i^2 ) also holds</td>
<td></td>
</tr>
<tr>
<td>Diffusion depends on the total number of carriers and not only on the excess carriers</td>
<td></td>
</tr>
</tbody>
</table>

Prob 2: [20 pts] For the P-N junction diode shown below, answer the following questions. Note that the picture shown below only shows the amplitude (and not ‘sign’) of the doping concentrations.

While drawing the diagrams,

- please be careful to indicate relative quantities (such as the amplitude of charge densities, the curvature of potential profiles, the width of the depletion region etc)
- For each diagram you need to draw quantities at both the P and N sides
- If you are using the same diagram to answer multiple questions, please mark the answers clearly.

\[ N_A = 5 \times 10^{16} / \text{cm}^3 \]
\[ N_D = 10^{16} / \text{cm}^3 \]
(i) [2 pt] Draw energy band profile at zero bias
(ii) [3 pt] Calculate the built in potential
(iii) [3 pt] Draw the electric field and potential profile
(iv) [3 pt] Calculate the depletion region width
(v) [3 pt] Draw the energy band profile if a reverse bias of $|V_d|$ is applied.
(vi) [6 pt] Draw the energy band profile at zero bias if the temperature is increased from 300K to 400K. Clearly mention all the approximations.