UNIVERSITY OF CALIFORNIA  
College of Engineering  
Department of Electrical Engineering and Computer Sciences  
EECS130 Midterm 1  

Last Name ________________ First Name ________________ SOLUTIONS

Instructions:
Print your name on the cover page CLEARLY now
Show major intermediate steps on exam pages to facilitate grading
Make sure your copy of the exam paper has 7 pages (including cover page)

Information that may be useful
q = 1.6 \times 10^{-19} \text{ coulombs}
Boltzmann constant \( k = 8.62 \times 10^{-5} \text{ eV/ K} \)
\( n_{i\text{f Si}} = 10^{10} \text{ cm}^{-3} \) at 300K

Problem 1 (14 points) ________________  
Problem 2 (28 points) ________________  
Problem 3 (17 points) ________________  
Problem 4 (41 points) ________________  

TOTAL (100 points) ________________
Problem 1 (14 points)

A donor-doped silicon sample at 300K has resistivity of 0.1 Ω-cm.

a) What is the doping density? (3 points)

Given \( \rho = 0.1 \ \Omega \text{-cm} \)

From Resitivity versus Doping chart,

\[ N_D = 7 \times 10^{16} \ \text{cm}^{-3} \]

b) What is the hole concentration? (2 points)

\[ p = \frac{n^2}{n} = \frac{10^{20}}{7 \times 10^{16}} \]

\[ = 1.42 \times 10^3 \ \text{cm}^{-3} \]

\[ n_i = 1.45 \times 10^{10} \ \text{cm}^{-2} \ \text{OK} \]

c) What is electron diffusion constant? (4 points)

\[ D_n = \frac{kT}{q} \mu_n \]

\[ \mu_n = 8.3 \times 10^{-5} \ \text{cm}^2/\text{V-s} \]

\[ D_n = \frac{kT}{q} \mu_n = \frac{8.62 \times 10^{-5} \ \text{eV}}{300} \times \frac{8.3 \times 10^{-5} \ \text{cm}^2}{\text{V-s}} = 2.46 \ \text{cm}^2/\text{s} \]

On hand from the chart.

d) Now acceptor density, \( N_A = 3 \times 10^{16} \ \text{cm}^{-3} \) is added to above sample. What is conductivity of the sample? (5 points)

\[ N_A = 3 \times 10^{16} \], \[ N_D = 7 \times 10^{16} \]

\[ N_A + N_D = 10^{17} \ \text{cm}^{-3} \]

\[ \eta = N_D - N_A = 4 \times 10^{16} \ \text{cm}^{-3} \]

\[ p = \frac{n^2}{n} = \frac{10^{20}}{4 \times 10^{16}} = 2.5 \times 10^3 \ \text{cm}^{-3} \]

\[ \sigma = \frac{q \mu_h n + q \mu_p p}{\mu_n} \rightarrow \text{small contribution} \]

\[ \sigma = q \mu_n n \]

\[ \mu_n @ 10^7 \ \text{cm}^{-3} = 720 \ \text{cm}^2/\text{V-s} \]

\[ \sigma = 4.6 \times 10^{-19} \ \text{GPa} \times 720 \ \text{cm}^2/\text{V-s} \times 4 \times 10^{16} \]

\[ = 4.6 \ \frac{1}{\text{ohm-cm}} \]

\[ \sigma = 4.6 \ \text{[ohm-cm]}^{-1} \]
Problem 2 (14 x 2 = 28 points)

Answer each with one or two sentences, or phrases or define with an equation. Unless otherwise specified answer the questions for Si at 300K. You may assume that commonly used parameters are given.

a) What is the electron concentration given $N_d = N_p = 5 \times 10^{15}$ cm$^{-3}$?

\[ n = n_i \]

b) Is silicon a donor or an acceptor in GaAs? (Ga is group III and As is Group V).

both Acceptor and Donor (Si is IVth Group)

c) What is the recombination rate, given $n'$?

\[ \frac{n'}{\tau} \] where $\tau$ is recombination time

d) Give an expression for Einstein relationship.

\[ \frac{D}{\mu} = \frac{kT}{q} \]

e) What is the “excess carrier concentration”?

\[ n' \equiv n - n_0 \]

or Difference between carrier concentration and the equilibrium value.

f) What is wet lithography technology?

use liquid to reduce the light wavelength in lithography process.

or Add water to the space between the lens and the water.

or Use liquid to improve lithography resolution.

g) What is ‘end-point detection’ in etching process?

Detecting the exposed substrate film after the removal of the desired film.

or A way to know when etching is done.

or Detection of completion of the (desired) etch process.
h) What type of CVD process is used to deposit oxide at the lowest temperature?

PECVD

i) What is ‘sputtering’?

Depending a film by kicking atoms of the film material out of a “target” with plasma (or ions).

j) Why is wet oxidation sometimes preferred over dry oxidation?

Wet oxidation is faster than dry oxidation.
Or wet oxidation can be performed at lower temperature.

k) Give two reasons for ‘thermal annealing’ after ion-implantation even when the shallowest possible junction depth is desirable.

1. Damage removal
2. Dopant activation

l) Give two reasons why the industry switched from Al to Cu as interconnect material in advanced silicon technology.

1. Electromigration
2. Low contact resistance
3. Low RC delay
4. Faster circuits
5. Better reliability

m) What is the depletion region approximation?

There is a region in PN junction where electrons and hole concentrations are low.
Or mobile carriers are negligible in the depletion region.
Or N ≈ 0, P ≈ 0 in the depletion region.

n) What is a one-sided junction?

One side of the junction is heavily doped as compared to the other side.
Problem 3 (17 points)

Design a sequence of process steps by using the available process options from the given menu to go from Fig. 1 to Fig. 2.

**Process Menu**
- Annealing
- Gas Source doping
- Wet etching
- Deposition of oxide
- Dry etching
- Ion Implantation
- Sputtering
- Solid source diffusion
- Lithography

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**Fig. 1**

**Starting Wafer (P type)**

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**Fig. 2**

**Starting Wafer (P type)**

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- Deposition of oxide
- Lithography
- Dry etching (for oxide)
- Wet etching (for substrate)
- Ion Implantation
- (Annealing) ≤ optional

OR

- Deposition of oxide
- Lithography
- Dry etching (for oxide)
- Ion Implantation
- Wet etching (for substrate)
- (Annealing) ≤ optional

OR

- Deposition of oxide
- Lithography
- Dry etching
### Problem #4

**1.**

<table>
<thead>
<tr>
<th>Affected Parameter</th>
<th>( n_i )</th>
<th>( n )</th>
<th>( p )</th>
<th>( E_c-E_f )</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Changing Parameter</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>( E_g \uparrow )</td>
<td>From Eqn. 1 w/ ( E_g \uparrow \Rightarrow n_i \uparrow )</td>
<td>( \rightarrow )</td>
<td>( p = \frac{n_i^2}{n^2} )</td>
<td>From Eqn. 4 ( n ) stays same ( N_c ) stays same no change in ( E_c-E_f )</td>
</tr>
<tr>
<td>( m_n \uparrow )</td>
<td>From Eqn. 2 w/ ( m_n \uparrow \Rightarrow N_d \uparrow ) ( n_i \uparrow ) (Eqn. 1)</td>
<td>( \rightarrow )</td>
<td>( \uparrow )</td>
<td>( n ) stays same ( N_c ) stays same no change in ( E_c-E_f )</td>
</tr>
<tr>
<td>( m_p \uparrow )</td>
<td>From Eqn. 3 w/ ( m_p \uparrow \Rightarrow N_v \uparrow ) ( n_i \uparrow ) (Eqn. 1)</td>
<td>( \rightarrow )</td>
<td>( \uparrow )</td>
<td>( n ) stays same ( N_c ) stays same no change in ( E_c-E_f )</td>
</tr>
<tr>
<td>( N_D \uparrow )</td>
<td>No effect on ( n_i ) Sample more heavily doped now.</td>
<td>( \rightarrow )</td>
<td>( \uparrow )</td>
<td>From Eqn. 4 ( E_f ) closer to ( E_c )</td>
</tr>
<tr>
<td>( N_A \uparrow )</td>
<td>No effect on ( n_i ) ( N_d \approx N_v ) (compensated)</td>
<td>( \rightarrow )</td>
<td>( \uparrow )</td>
<td>From Eqn. 4 ( E_f ) moves away from ( E_c )</td>
</tr>
<tr>
<td>( T \uparrow )</td>
<td>From Eqn. 1 ( n_i ) does not change</td>
<td>( \rightarrow )</td>
<td>( \uparrow )</td>
<td>From Eqn. 4 ( E_f ) stays constant ( N_c, n ) remain constant ( T \rightarrow (E_c-E_f)\uparrow )</td>
</tr>
</tbody>
</table>

**Added condition:**

\( T \) goes up to 400 K
### Problem #4

**Equation 5:**  \( \mu = \frac{qE}{m} \)

- Impurity scattering component \( \propto \frac{1}{N_{A}N_{D}} \)
- Lattice scattering component \( \propto T^{-1/2} \)

**Equation 6:**  \( D = \frac{kT}{\mu} \)

**Equation 7:**  \( \phi_{bi} = \frac{kT}{q} \ln\left( \frac{N_{A}N_{D}}{n_{i}^{2}} \right) \)

**Equation 8:**  \( W_{dep} = \sqrt{2e\phi_{bi} + V} \left( \frac{N_{A} + N_{D}}{2} \right) \)

<table>
<thead>
<tr>
<th>Affected Parameter</th>
<th>( \mu_{n} )</th>
<th>( D_{p} )</th>
<th>( \phi_{bi} ) of PN junction with ( N_{A} = 10^{18} \text{ cm}^{-3} )</th>
<th>( W_{dep} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( E_{g} \uparrow )</td>
<td>( \mu_{n} \uparrow )</td>
<td>( D_{p} ) No change</td>
<td>( n_{i} \downarrow \Rightarrow \phi_{bi} \downarrow )</td>
<td>( \phi_{bi} \uparrow \Rightarrow W_{dep} \uparrow ) (Eqn. 8)</td>
</tr>
<tr>
<td>( m_{n} \uparrow )</td>
<td>( m_{n} \uparrow \Rightarrow \mu_{n} \downarrow ) (Eqn. 5)</td>
<td>( D_{p} ) No change</td>
<td>( n_{i} \downarrow \Rightarrow \phi_{bi} \downarrow )</td>
<td>( \phi_{bi} \uparrow \Rightarrow W_{dep} \downarrow )</td>
</tr>
<tr>
<td>( m_{p} \uparrow )</td>
<td>( m_{p} \uparrow \Rightarrow \mu_{p} \uparrow )</td>
<td>( \mu_{p} ) remains same</td>
<td>( n_{i} \downarrow \Rightarrow \phi_{bi} \downarrow )</td>
<td>( \phi_{bi} \uparrow \Rightarrow W_{dep} \downarrow )</td>
</tr>
<tr>
<td>( N_{D} \uparrow )</td>
<td>( \mu_{n} \downarrow ) More Impurity scattering</td>
<td>( \mu_{p} ) also goes down</td>
<td>( N_{D} \uparrow \Rightarrow \phi_{bi} \uparrow )</td>
<td></td>
</tr>
<tr>
<td>( N_{A} \uparrow )</td>
<td>( \mu_{n} \downarrow ) More Impurity scattering</td>
<td>( \mu_{p} ) also goes down</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( T \uparrow ) (assume ( N_{c} ) and ( N_{v} ) remain constant)</td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

**Notes:**
- \( \phi_{bi} \) increases with \( E_{g} \) and \( m_{n} \) increases with \( m_{n} \).
- \( D_{p} \) remains constant with \( m_{n} \).
- \( n_{i} \) decreases with \( m_{p} \) and \( N_{D} \).
- \( \phi_{bi} \) decreases with \( n_{i} \) and \( D_{p} \).