Name: ___________________________     Student ID ____________

Guidelines

1. Closed book and notes; one 8.5” x 11” page (both sides) of your own notes is allowed.
2. You may use a calculator.
3. Do not unstaple the exam.
4. Show all your work and reasoning on the exam in order to receive full or partial credit.

Score

<table>
<thead>
<tr>
<th>Problem</th>
<th>Points Possible</th>
<th>Score</th>
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<tbody>
<tr>
<td>1</td>
<td>20</td>
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<td>2</td>
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<td>3</td>
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</table>
1. Micromirror Structure [20 points]

![Micromirror Structure Diagram]

- Poly1 Mask (clear field)
- Oxide1 Mask (clear field)
- Oxide2 Mask (dark field)
- Metal Mask (clear field)
- Poly2 Mask (clear field)
**Process Sequence:**

1. Starting material: phosphorus-doped silicon, concentration $5 \times 10^{16}$ cm$^{-3}$
2. Deposit 200 nm of silicon nitride (see properties below)
3. Deposit 200 nm of n-type polysilicon and pattern using **poly1 mask** (clear field)
4. Deposit 400 nm of silicon dioxide and pattern using the **oxide1 mask** (clear field).
5. Deposit 250 nm of n-type polysilicon and pattern using the **poly2 mask** (clear field)
6. Spin photoresist, expose with the **oxide2 mask** (dark field), develop, and etch 400 nm of oxide, strip photoresist.
7. Deposit 250 nm of gold and pattern using the **metal mask** (clear field)
8. Etch in hydrofluoric acid long enough to remove all remaining oxide; rinse, and dry.

**Silicon nitride:** $\varepsilon_n = 7.5 \varepsilon_o$ where $\varepsilon_o$ is the permittivity of air or vacuum ($8.85 \times 10^{-14}$ F/cm). It is not etched in any of the processes used to etch oxide, polysilicon, or gold.

(a) [7 pts.] Sketch the cross section $A-A'$ on the graph below. Identify all layers clearly.

(b) [7 pts.] Sketch the cross section $B-B'$ on the graph below. Identify all layers clearly.
(c) [3 pts.] Find the numerical value of the capacitance between terminals 1 and 2 in femtoFarads (fF). Use the layout on p. 2 to estimate the area of the capacitor. Note that the substrate is grounded, so it has no contribution to the answer to this part. Hint: terminal 1 is connected to a poly2 structure, whereas terminal 2 is connected to a poly1 structure. The capacitance is between the two polysilicon structures.

(d) [3 pts.] Find the numerical value of the capacitance between terminal 3 and the substrate. Neglect the contribution from the metal layer. Hint: you are not expected to consider capacitors in series to find the answer.
2. Integrated Circuit Resistor Structure [20 points]

Doping concentrations and thicknesses of regions a, b, and c:

- a $3 \times 10^{17} \text{ cm}^{-3}$ boron, $2.5 \times 10^{17} \text{ cm}^{-3}$ phosphorus (0.5 µm thick)
- b $10^{17} \text{ cm}^{-3}$ boron, $2.5 \times 10^{17} \text{ cm}^{-3}$ phosphorus (1 µm thick)
- c $10^{17} \text{ cm}^{-3}$ boron (substrate)

Given

- Electron mobility: $\mu_n = 1000 \text{ cm}^2/(\text{Vs})$
- Hole mobility: $\mu_p = 400 \text{ cm}^2/(\text{Vs})$
- Unit charge: $q = 1.6 \times 10^{-19} \text{ C}$

(a) [2 pts.] What is the type (n or p) and the sheet resistance of layer a in the IC structure whose layout and cross section is shown in the figure?
(b) [2 pts.] What is the type (n or p) and the sheet resistance of layer b in the IC structure whose layout and cross section is shown in the figure?

(c) [16 pts.] Fill in the table with the numerical value of the currents $I_0$, $I_1$, $I_2$, and $I_3$ in $\mu$A for the two sets of voltages. If you couldn’t solve parts (a) and (b), you can assume for this part that $R_{a} = 250 \Omega$ for layer a and $R_{b} = 100 \Omega$. Needless to say, these are not the correct answers to parts (a) and (b). Hint: some of the answers are zero.

<table>
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<tr>
<th>(Volts)</th>
<th>(MicroAmps)</th>
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<tr>
<td>$V_0$</td>
<td>$V_1$</td>
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<tr>
<td>0</td>
<td>2</td>
</tr>
<tr>
<td>3</td>
<td>7</td>
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3. Switched capacitor circuit [10 points]

\[
V_{\text{in}} = 1 \text{ V}
\]

\[V_{\text{out}}\]

Switch operation

(a) [3 pts.] Find the charge stored on each capacitor at the time \( t = 0.5 \mu\text{s} \), given that \( C = 50 \text{ fF} \) and \( V_{\text{in}} = 1 \text{ V} \). Hint: draw the circuit at that time, using the switch states given above.

HINT: This problem is MUCH SIMPLER than it looks!
(b) [3 pts.] Find the charge stored on each capacitor at the time $t = 1.5 \, \mu s$, given that $C = 50 \, \text{fF}$ and $V_{in} = 1 \, \text{V}$. The same hint from part (a) applies.

(c) [4 pts.] Find the output voltage $V_{out}$ at the time $t = 1.5 \, \mu s$, given that $C = 50 \, \text{fF}$ and $V_{in} = 1 \, \text{V}$. The same hint from part (a) applies.