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

EE143 Midterm Exam #2

Family Name ______________________  First name_________________SID___________________

Signature______________________________________________________________

Make sure the exam paper has 7 pages total (including cover page)

Instructions: DO ALL WORK ON EXAM PAGES  
This is a 90-minute exam (8 sheets of HANDWRITTEN notes allowed)

Grading:

• The reader can only assess what you put down on the exam paper, not what is inside your brain. Please be concise with your answers. For answers requiring explanation, adding sketches can be very effective.

• To obtain full credit, show correct units and algebraic sign. Numerical answers orders of magnitude off will receive no partial credit.

Problem 1 (25 points)________________

Problem 2 (25 points)_______________

Problem 3 (25 points) ________________

Problem 4 (25 points) ________________

TOTAL (100 points) __________________
Problem 1 Lithography (25 points total)

(a) An optical stepper using G-line illumination (λ = 436 nm) and NA = 0.7 can produce a minimum printable feature \( l_m \) of 0.5 \( \mu \)m with a Depth of Focus of 1 \( \mu \)m.

The stepper is modified by changing the light source wavelength to 365 nm (I-line) and by placing an aperture before the lens to reduce NA to 0.5.

<table>
<thead>
<tr>
<th></th>
<th>( \lambda )</th>
<th>NA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Old Stepper</td>
<td>436 nm</td>
<td>0.7</td>
</tr>
<tr>
<td>Modified stepper</td>
<td>365 nm</td>
<td>0.5</td>
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With the lithography technology factors being the same,

(i) (4 points) Calculate the new \( l_m \)

(ii) (4 points) Calculate the new DOF

(b) (8 points) With an 1X optical stepper, at lithography step #1, alignment marks are transferred to edge of the 100mm-diameter wafer with mask temperature at 22°C and wafer temperature at 24°C. At lithography steps #2, mask temperature is at 24°C and wafer temperature is at 22°C.

<table>
<thead>
<tr>
<th>Lithography Step #1</th>
<th>Lithography Step #2</th>
</tr>
</thead>
<tbody>
<tr>
<td>mask</td>
<td>22°C</td>
</tr>
<tr>
<td>wafer</td>
<td>24°C</td>
</tr>
</tbody>
</table>

Calculate the thermal run-out (or run-in) error in microns for the alignment marks at lithography Step #2.

Given: Linear coefficients of expansion of mask material = \( 6 \times 10^{-6} \) /°C

Linear coefficients of expansion of Si wafer = \( 2.3 \times 10^{-6} \) /°C
Problem 1 continued

(c) The following schematic illustrates how one can GRADUALLY reduce the height of an array of microfluidic channels in a substrate with one single lithography exposure. The channel patterns are defined by a photomask with contact printing. An additional blocking mask is used to modulate the lateral light intensity with edge diffraction.

(i) (5 points) For this special application, do you prefer a high or low photoresist contrast (γ)? Explain briefly.

(ii) (4 points) After photoresist development, describe the steps you will use to transfer the resist pattern to the substrate. Specifically mention the selectivity and anisotropy of the etching processes.
Problem 2 Thin Film Deposition (25 points total)

(A) Evaporation is used to deposit a thin film onto a substrate with trench structures. The following three sketches show time development of thin film (grey layers) topography. Describe the deposition conditions which can explain the features for cases (a), (b) and (c). Illustrate with sketches if necessary.

Case (a) (3 points) Deposition condition

Case (b) (3 points) Deposition condition

Case (c) (3 points) Deposition condition:

(B) Consider the two control variables of CVD: temperature T, and gas flow velocity U.

(i) (6 points) If high growth rate is the only consideration, choose conditions for T (high or low) and U (high or low). Briefly explain you rationale.

(ii) (5 points) If film thickness uniformity is the only consideration, choose conditions for T (high or low) and U (high or low). Briefly explain you rationale.

(i) (5 points) If conformal coverage over steps is the only consideration, choose conditions for T (high or low) and U (high or low). Briefly explain you rationale.
**Problem 3 Etching (25 points total)**

(a) Aluminum film of thickness $t_{Al}$ is deposited on a substrate. Line patterns of photoresist is used as the etching mask with width $W_{PR}$ and thickness $t_{PR}$. A reactive ion etching recipe is used to etch the Aluminum with the following characteristics (including variation):

- Photoresist thickness $t_{PR} = 1.0 \pm 0.1 \, \mu m$
- Aluminum thickness $t_{Al} = 1.1 \pm 0.3 \, \mu m$
- Degree of anisotropy of Al etching = 1
- Vertical etching rate of Al = 1 \, \mu m/min (no variation)
- Selectivity of Al over photoresist: $S$ varies from 2:1 to 4:1 (vertical etching rates)
- Degree of anisotropy of photoresist etching = 0
- Etching does not attack substrate

![Cross-section diagram]

(i) (3 points) What is the etching time (in minutes) that the thickest aluminum lines are just cleared?

(ii) (4 points) What is the minimum photoresist thickness remaining when the thickest aluminum lines are just cleared?

(iii) (5 points) Use worst-case design consideration: If the top width of aluminum lines ($W_{Al}$) has to exceed 1 \, \mu m, what is the required minimum initial photoresist width $W_{PR}$?

(b) (4 points) With all etching parameters in part(a) being the same, except degree of anisotropy of Al etching is now < 1, re-sketch qualitatively the cross-section when Al is just cleared. Write down description of the major differences with part(a).
Problem 3 continued

(b) The Si etching rate in a CF\(_4\) + O\(_2\) plasma is plotted as a function of [ F\(^*\) ] concentration for various oxygen content. F\(^*\) is the excited F atoms.

(i) (3 points) With O\(_2\) percentage below a certain value (i.e. 16.3%), explain why the Si etching rate increases with oxygen content in the plasma.

(ii) (3 points) With O\(_2\) percentage increase 0 to 16%, do you expected the Si etching profile will become more isotropic or anisotropic. Explain your answer.

(iii) (3 points) With O\(_2\) percentage above a certain value (i.e. 16.3%), explain why the Si etching rate decreases with oxygen content in the plasma.
Problem 4 Metallization (25 points total)
The following schematic shows the cross-section of a Copper Dual Damascene multilevel metallization.

(i) (3 points) How many copper deposition steps are used?

(ii) (3 points) List the Chemical-Mechanical Polishing (CMP) steps used and the purpose?

(iii) (4 points) Describe the purpose(s) of using the TiN liner.

(iv) (3 points) Why do we use shallow trench oxide isolation (instead of conventional local oxidation)?

(v) (3 points) Why do we use plasma enhanced CVD oxide instead of thermal CVD oxide?

(vi) (6 points) Your textbook (Jaeger) describes a thin silicon nitride layer is used between the PECVD oxide layers as etch stops [not shown in above schematic]. Use sketches to illustrate the advantage of using these etch stops.

(vii) (3 points) Copper has a larger activation energy $E_A$ for interconnect electromigration failure than aluminum. Is this good or bad? Explain.