Spring 03

UNIVERSITY OF CALIFORNIA

College of Engineering

Department of Electrical Engineering and Computer Sciences

EE 143 Midterm Exam # 2

Family Name ______________________ First Name ____________________________

Signature ______________________

Make sure the exam paper has 9 pages including cover page

This is a 90 minute exam (8 sheet of notes allowed)

DO ALL WORK ON EXAM PAGES

Whenever possible, use sketches to illustarte your explanations,

Numerical answers orders of magnitude off will receive no partial

Credit.

Problem 1 (25 points).

Problem 2 (25 Points).

Problem 3 (20 points).

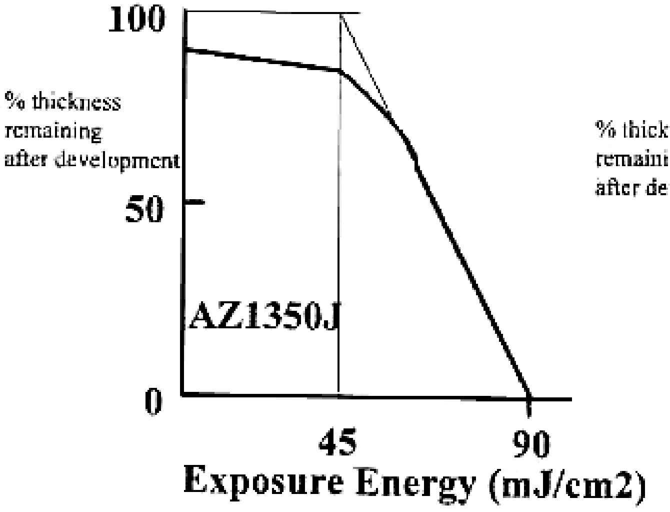
Problem 4 (30 points).

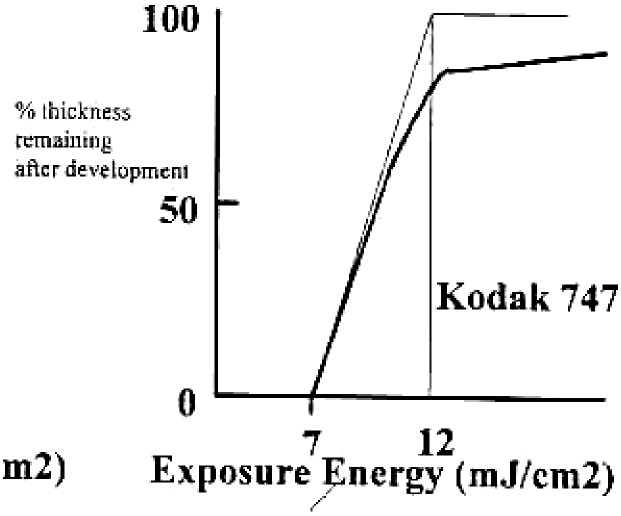
TOTAL (100 points)

Problem 1 Lithography (25 points total)

(a) (4 points) What is the key reason that optical lithography has a throughput advantage over E-beam lithography?

(b) The following plots show percentage of resist remaining after exposure and development versus the exposure energy for Resist AZ1350J and Resist Kodak747.





(i) (2 points) Which resist is a positive resist and which resist is a negative resist?

(ii) (2 points) Which resist has a higher resist contrast?

(iii) (2 points) Which resist has a better sensivity?

Problem 1 continued

(c)(6 points) An optical lithography process can produce a minimum printable feature L_{min} (= $k_1 \cdot \lambda/NA$) and a usable Depth of Focus DOF (= $k_2 \cdot \lambda/(NA)^2$).

A stepper with λ= 365nm and NA=0.7 can produce a L_{min} of 0.3µm with DOF = 0.4 µm. If we change to a new stepper with λ= 248nm and NA=0.5, what are the new values for L_{min} and DOF.

(d) (4 points) Optical steppers have to be maintained at a constant temperature for operation. Why is that?

(e) (5 points) Describe a couple of techniques one can use to minimize the standing wave effect in optical lithography.

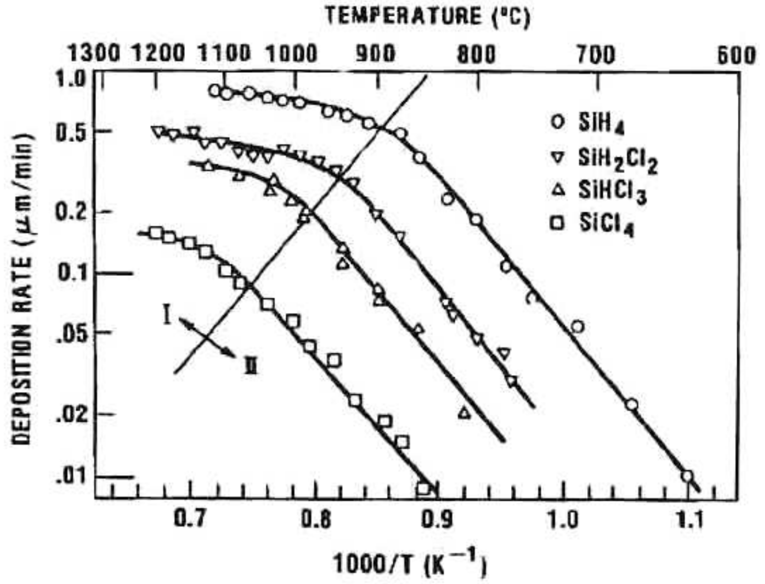
Problem 2 Thin Film Deposition (20 points total)

(a) (5 points) The following reaction is used to deposit poly-Si by chemical vapor deposition (CVD):

$$SiCl_4 \rightarrow Si + 2Cl_2$$

It is known that the $SiCl_4$ concentration in the gas stream is 9.6×10^{16} molecules/cm^3 and the gas transfer coefficient h_G is 2.62 cm/sec. Estimate the poly-Si film deposition rate (in angstroms /sec), assuming the growth process is ***mass-transfer limited***. [Atomic density of poly-Si is 5×10^{22} atoms/cm^3]

(b) The following figure shows the deposition rates of Si (log scale) from 4 different gas sources versus 1000/T where T is the deposition temperature in K.

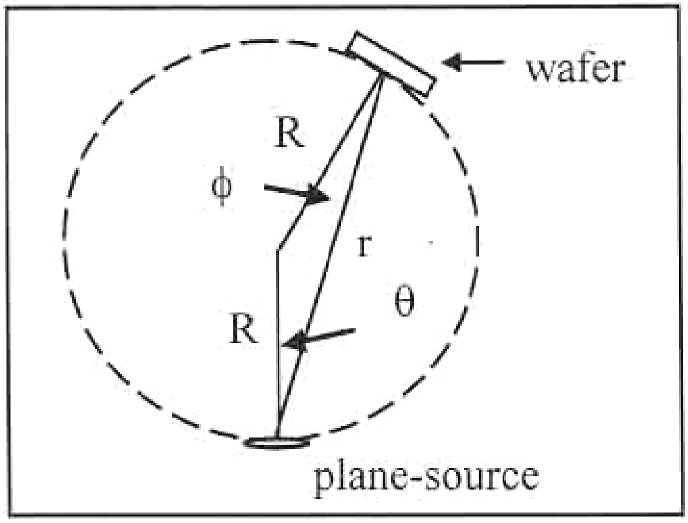


(i) (5 points) From the SiH4 curve, find the activation energy E_a (in eV) for the surface-reaction rate constant k_s

(ii) (5 points) Suppose we dilute the SiH4 with an inert gas (e.g. helium) but maintaining the same **total gas pressure**. The inert gas is known not perturbing the k_s term but the partial pressure of SiH_4 is lower with the dilution. Sketch a new deposition rate curve versus 1/T in the above figure. [No credit will be given without showing your reasoning]

Problem 2 continued

(b) In the textbook and lecture notes, we derive that for a small plane-like source (e.g. sputtering) and a spherical receiving surface (see figure below), the thickness deposited on all wafers is independent of the distance **r** from the plane source.



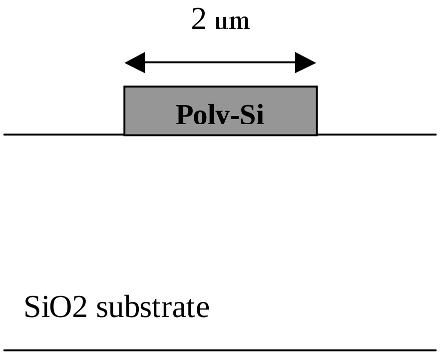
(i) (4 points) Using the above geometry to deposit thin films over contact holes or across steps on the wafers, do you expect to see step coverage problems. Explain.

(ii) (6 points) Suppose the small-plane source actually have a $(\cos\theta)^2$ flux emission dependence instead of a $\cos\theta$ dependence. How will the thickness deposited depnd on **r**? Show your derivation.

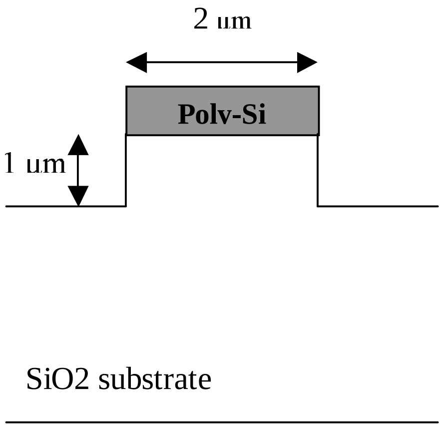
Problem 3 Etching (20 points total)

(a)

(i) (3 points) A poly-Shi is patterned on top of a SiO2 substrate. We will release it from the oxide substrate to form a cantilever beam by etching the oxide underneath with buffered HF solution. The etching recipe has a vertical etching rate of 0.5 micron/minute and the degree of anisotropy is 0 (i.e. complete isotropic). Sketch the cross sections of the oxide after HF etching times = 1 min, 2 min, and 4 min



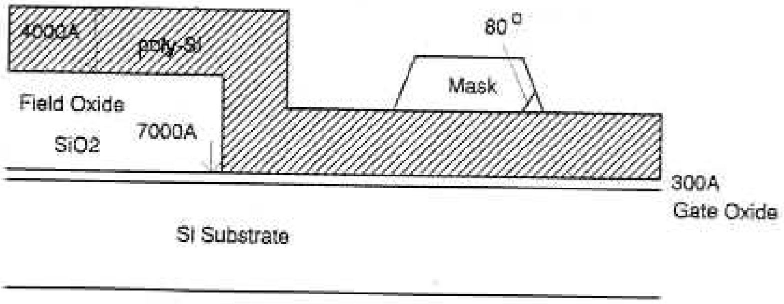
(ii) (3 points) A better way to release the Poly-Si beam is to use an anisotropic RIE process to etch the oxide first to a depth of 1μm. The same buffer HF solution recipe in part(i) is then used to release the poly-Si beam. Sketch the cross sections of the oxide after HF etching times = 1 min, 2 min, and 4 min



(iii) (3 points) Comment on why Method (ii) is better than Method (i)

Problem 3 continued

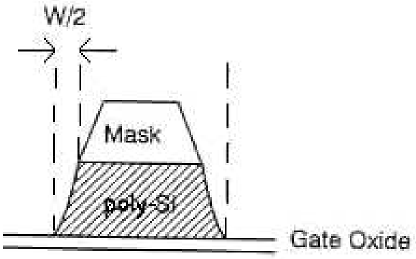
(b) (5 points) The following cross-section shows a 4000 Å-thick poly-Si deposited over a field oxide of step height of 7000 Å which lies on top of a gate oxide with thickness 300 Å.



Given:

Poly etch degree of anisotropy $A_f = 1$
Poly-Si thickness variation factor $\delta = 0.03$
Poly-Si etch rate variabtion factor $\Phi_f = 0.05$

Mask slope angle $\theta = 80°$
Mask etch degree of anisotropy $A_m = 1$



The worse-case design goal is to control the poly-gate linewidth reduction on the top to less than 0.1μm (i.e., $W < 0.1$ μm) when the poly-Si is just cleared. [See schematic figure shown above]
Find the required minimum etching selectivity between the poly and mask (S_{fm})

(c) CF_4 plasma is used to etch Si.

(i) (3 points) By adding O2 to the CF4 gas, the etching is more isotropic. Explain.

(ii) (3 points) By increasing the ion bombardment energy using substrate bias voltage, the etching is more anisotropic. Explain.

Problem 4 Metallization (30 points total)

(a) (10 points) Metal films like Al are usually deposited with sputtering. Step coverage of Al over contact holes etched by directional RIE is a major problem. In terms of step coverage, indicate whether the following process changes will help (by entering a "+"), hurt (by entering a "-") , or have no effect (by entering a "0"). Give a brief explanation for your conclusions.

______ Use a wet chemical etch for the contact holes
Explaination:

______ Increase substrate temperature **during** Al deposition
Explaination:

______ Thicken the oxide around the contact holes while keeping contact size same
Explaination:

______ Develop a CVD Al process
Explaination:

______ Fill the contact hole with CVD tungsten plug before Al deposition
Explaination:

(b) What is the "Aluminum spiking problem" when Al is used as the contact metal to silicon? In particular, describe in your words:

(i) (3 points) Why Al forms spikes instead of uniformly reating with the Si substrate?

(ii) (3 points) Why is the formed spikes larger in size near the perimeter of the contact holes?

(iii) (3 points) Why the spikes are not desirable?

Problem 4 continued

(c)(4 points) To lengthen the median-time-to-failure (MTF) of aluminum interconnects due to electromigration, we added several % copper to aluminum. Describe why the MTF will be improved.

(d) (7 points) Using copper as the metallization material, we can use the dual damascene process to form both the copper plug and the copper interconnect. Describe the dual damascene process flow with sketches and a brief process steps description.