Fall 2004

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

EE143 Midterm Exam #2

Family Name

Signature____

Make sure the exam paper has 7 pages including cover page (+ 2 pages of data for reference)

This is a 90-minute exam (8 sheets of HANDWRITTEN notes allowed)

DO ALL WORK ON EXAM PAGES
Whenever possible, use sketches to illustrate your explanations.
Numerical answers orders of magnitude off will receive no partial credit.

Problem 1 (25 points)_

Problem 2 (25 points)_

Problem 3 (25 points)

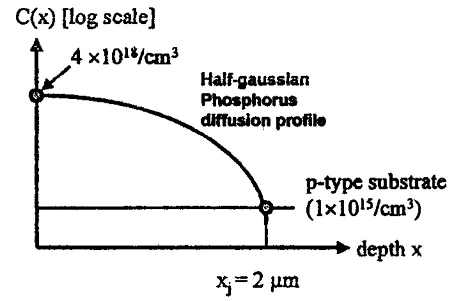
Problem 4 (25 points)

TOTAL (100 points) _

Problem 1 Dopant Diffusion (25 points)

(a) A Phosphorus half-gaussian drive-in profile has surface concentration = $4 \times 10^{18}/cm^3$. With a p-type substrate with background concentration of $10^{15}/cm^3$, it forms a pn junction at a depth of 2µm.

(i) (3 points) Calculate the Dt-product of the diffusion profile.



(ii) (3 points) Calculate the Phosphorus dose in #/cm^2.

(iii) (4 points) Use the Irvins Curves to find out the sheet resistance R_S of the diffused layer.

(b) Boron is diffused into a Si substrate having a background phosphorus concentration of $10^{16}/cm^3$. The measured junction depth (x_j) is 0.7 µm and measured sheet resistance is 5 Ω/square.

Because of high-concentration diffusion effects, we will not know the exact shape of the boron depth profile. Instead, we make up two hypothetical approximations:

Profile 1: The profile is an erfc function with $(Dt)^{1/2} = 0.1\mu m$

Profile 2: The profile is a rectangular profile with constant boron concentration from surface to x_j.

(i) (6 points) Calculate the surface concentration of boron for both profiles. For Profile 2, the hole mobility can be taken as constant (= 60 cm^2/V-s) for all depths.

(ii) (3 points) Examine the surface concentration values of part(i) carefully. Which profile is a better approximation ? Justify your reasoning.

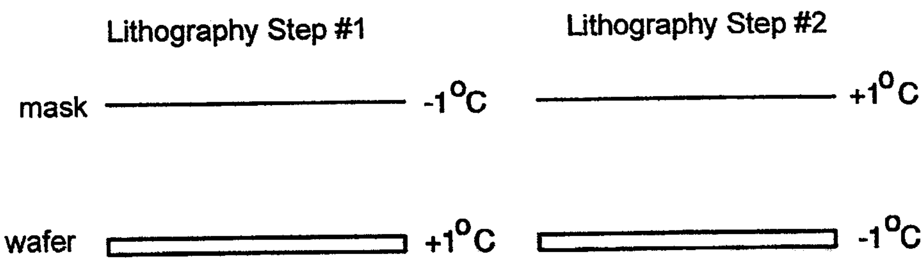
(c) The source/drain of a MOSFET is fabricated by dopant implantation followed by an annealing step around 950°C.

(i) (3 points) Do you expect to see transient enhanced diffusion ? Briefly explain why.

(ii) (3 points) Do you expect to see high-concentration diffusion effects ? Briefly explain why.

Problem 2 Lithography (25 points total)

(a) (5 points) For a 1X projection printer, the mask temperature can vary by ±1°C. The wafer temperature is independent of the mask temperature and can also vary by ± 1°C. The linear coefficients of expansion of the photolithography mask material and Si wafers are 8×10^{-6} /°C and 2.3×10^{-6} /°C respectively. For alignment error, the worst scenario for temperature differences is illustrated below.



Calculate the corresponding thermal run-out error of two alignment marks near the edge of the wafer (wafer diameter =200mm).

(b) Two optical steppers have with the following specifications:

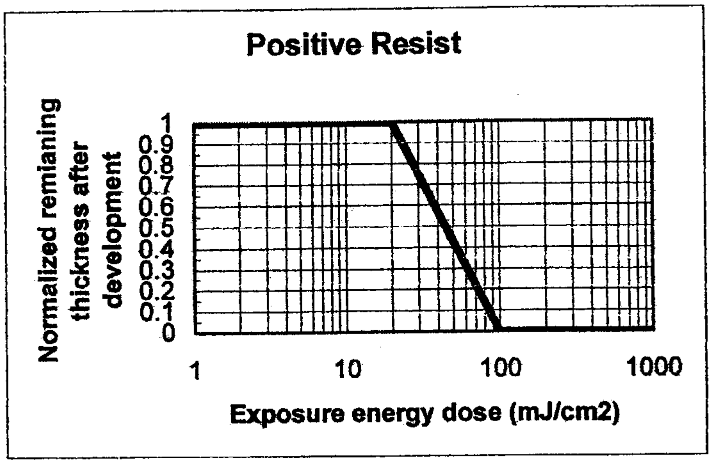
	λ	NA
Stepper A	365 nm (I-line)	0.7
Stepper B	248 nm (excimer laser)	0.5

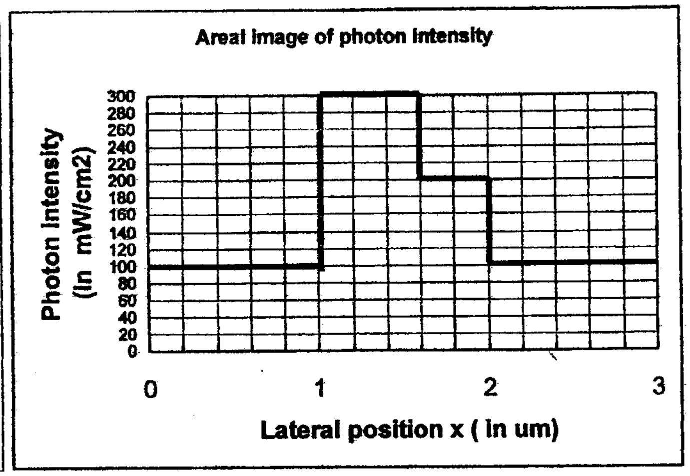
(i) (5 points) Stepper A can print a smallest feature of 0.28 μm. Using the same technology factor k_1,what is the smallest feature Stepper B can print ?

(ii) (5 points) For Depth of Focus (DOF) consideration, which stepper is more desirable if the technology factors k_2 are the same ?

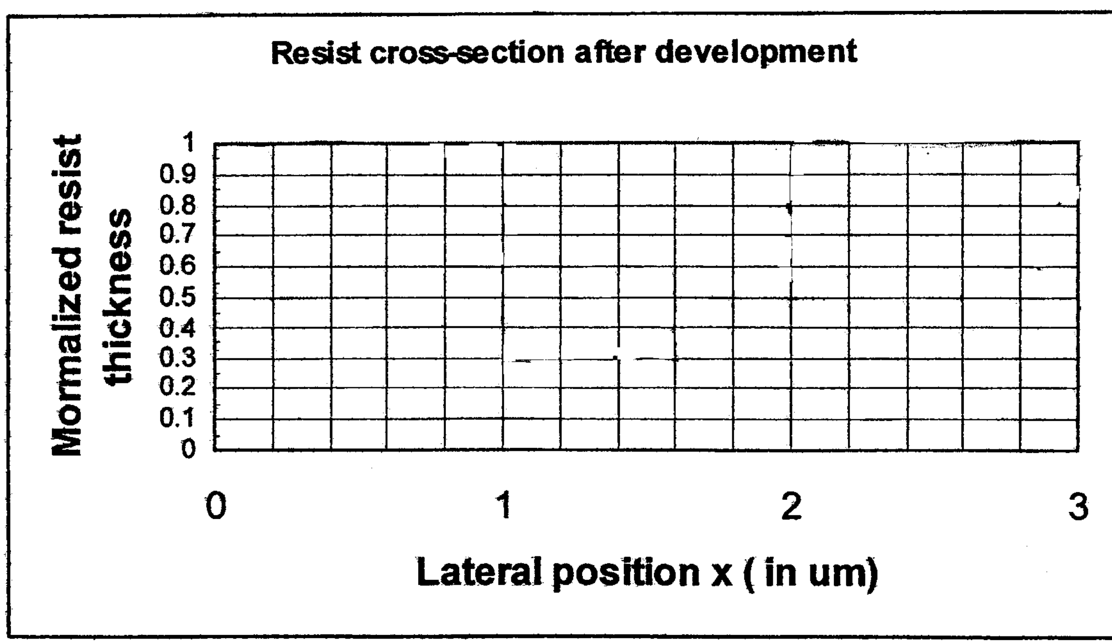
Problem 2 Lithography continued

(b) (10 points) Normalized remaining thickness of a photoresist after development versus photon exposure energy density is plotted below at left. The resist is exposed to an optical image shown below at right.





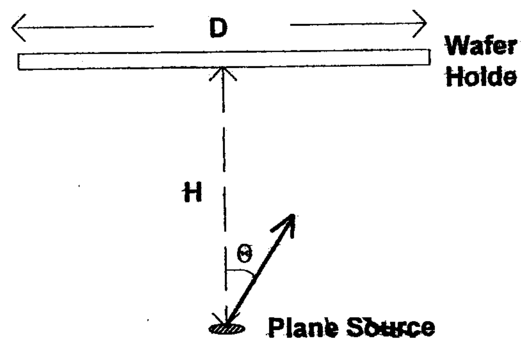
If we ignore lateral development effects, sketch the developed resist cross-section using an exposure time of 0.2 second. [Hint: 1 mW × 1 second = 1 mJ]



Bonus points (3 points) : Can you think of a good usage of this resist profile for microfabrication ?

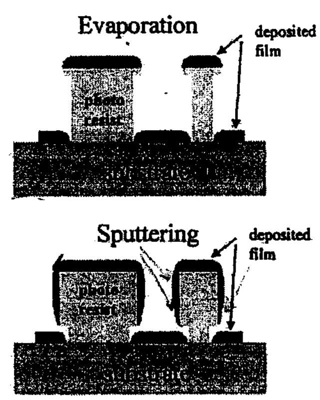
Problem 3 Thin Film Deposition (25 points total)

(a) (5 points) E-beam evaporation of aluminum is modeled as a *small planar source* (i.e., emission flux is proportional to cos θ). For a 300-mm-diameter wafer, the center of wafer receives a 0.5 μm thick aluminum. If the aluminum thickness difference between center of wafer and edge of wafer has to be less than 0.05 μm, what will be the required minimum source-wafer distance (i.e., distance H shown in figure)?



(b) We would like to pattern an array of thin-film lines by the ***Liftoff Process***. The morphologies of the deposited film and photoresist are shown in the following figures using evaporation and sputtering as deposition methods.

(i) (4 points) Why are films deposited on the sidewalls of the photoresist if one uses sputtering deposition?



(ii) (3 points) To make the liftoff process successful, is it advantageous to tilt and rotate the substrate during sputtering deposition? Explain your answer.

(iii) (3 points) If we require the line patterns to be as identical as possible across the whole substrate (e.g. a 300-mm Si wafer). Will you choose evaporation or sputtering ? Explain your answer.

Problem 3 continued

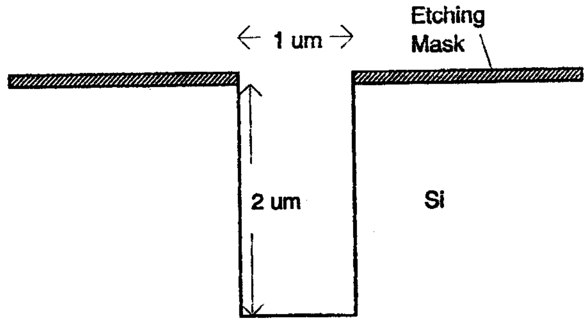
(c) (i) (6 points) For chemical vapor deposition of poly-Si using $SiCl_4$ as a gaseous source, the vapor-phase mass-transfer coefficient $h_g = 1$ cm/sec, the surface-reaction rate constant $k_s = 2\times10^6 \exp(-1.9\text{eV}/kT)$ cm/sec, and the concentration of Si atoms in the gas stream $C_g = 1\times10^{16}$ atoms/cm^3. The atomic concentration of solid Si is 5×10^{22} atoms/cm^3. Calculate the deposition rate at 1153 °C.

(ii) (2 points) Do you expect the deposition rate to increase or decrease **when the gas flow rate increases?** Justify your answer.

(iii) (2 points) Do you expect the deposition rate to increase or decrease **when the temperature increases?** Justify your answer.

Problem 4 Etching (25 points total)

(a) (10 points) The cross-section of a Si trench with vertical sidewalls is shown at the right. Assume the etching mask is not attacked by the following etching processes.



(i) (3 points) The structure is first subjected to a ***completely isotropic wet-etch process.*** The etching rate is 1 μm/min and etching time is 1 minute. Sketch proportionally the etched Si cross-section **with dashed lines** in the same figure.

(ii) (4 points) The structure in part (i) is followed by a ***completely anisotropic plasma - etch process.*** The etching rate is 1 μm/min and etching time is 1 minute. Sketch proportionally the etched Si cross-section **with dotted lines** in the same figure.

(b) 5000Å of poly-Si over SiO_2 is to be patterned using RIE with an etching rate of 500 Å/min.

- poly-Si thickness has a variation of ±10%
- poly-Si etching rate has a variation of ±5%.
- poly-Si is running over steps. Over-etch time fraction = 10%.

(i) (4 points) Use worst-case consideration to find the difference between maximum time to clear poly-Si and minimum time to clear poly-Si.

(ii) (4 points) If process requirement allows less than 100 Å of SiO_2 being removed during the poly etching step, what is the **minimum selectivity** required for poly-Si : SiO_2 (i.e., vertical poly etching rate / vertical SiO_2 etching rate) ?

(c) (5 points) Make a list of mechanisms which affect the degree of anisotropy for reactive ion etching.

(d) (5 points) Describe the strategy to control etching selectivity with reactive ion etching. Quote one example.

Information for reference

$0°C = 273K$

Electron charge $q = 1.6 \times 10^{-19}$ coulombs;

Boltzmann constant $k = 8.62 \times 10^{-5}$ eV/K

n_i of Si $= 3.69 \times 10^{16} \times T^{3/2} \exp[-0.605eV/kT]$ cm^{-3}

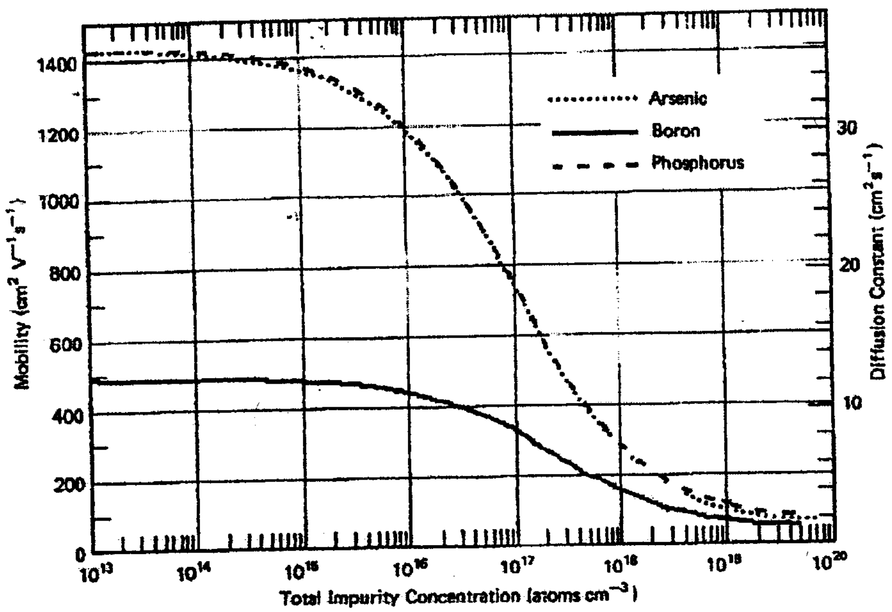
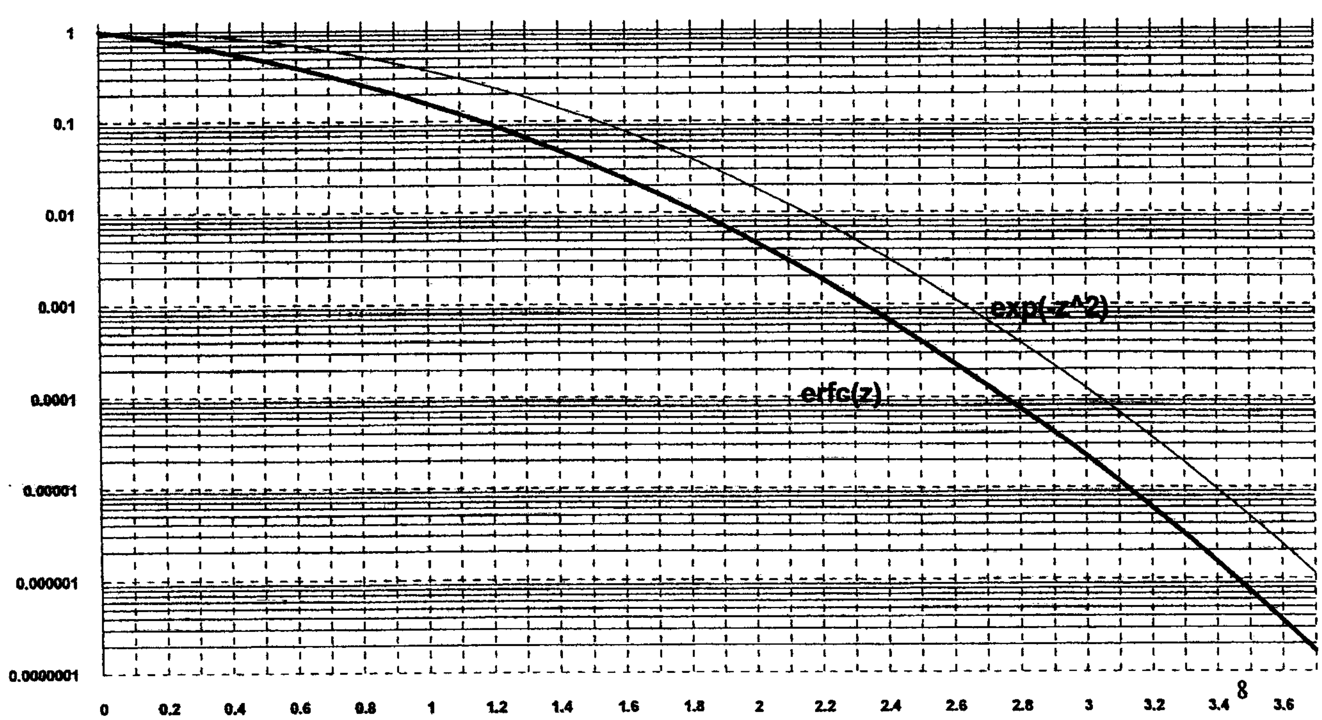


Figure 1.15 Electron and hole mobilities in silicon at 300 K as functions of the total dopant concentration. The values plotted are the results of curve fitting measurements from several sources. The mobility curves can be generated using Equation 1.2.10 with the following parameter values:[3]



Irvin Curves