Chemical Vapor Deposition

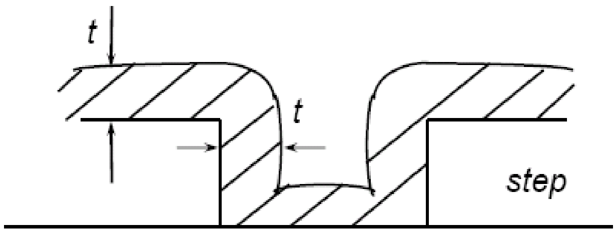
ESS4810 Lecture
Fall 2010

Introduction

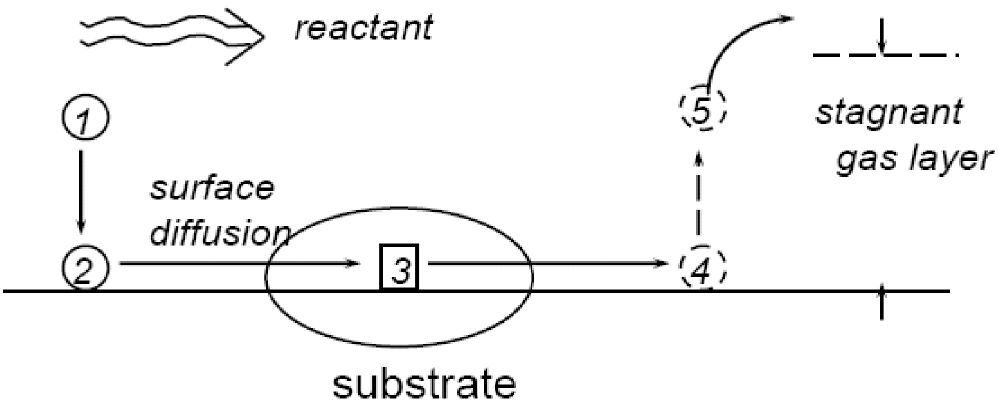
- Chemical vapor deposition (CVD) forms thin films on the surface of a substrate by thermal decomposition and/or reaction of gas compounds
- The desired material is deposited directly from the gas phase onto the surface of the substrate

Advantage

- More conformal deposition
  - Higher temperature - higher surface diffusion
  - Higher pressure – shorter mean free path



Mechanism



- 1: diffusion of reactants to surface
- 2: absorption of reactants at surface
- 3: chemical reaction at surface
- 4: desorption of gaseous by-products from surface
- 5: diffusion of gaseous by-products from surface

Silicon Deposition

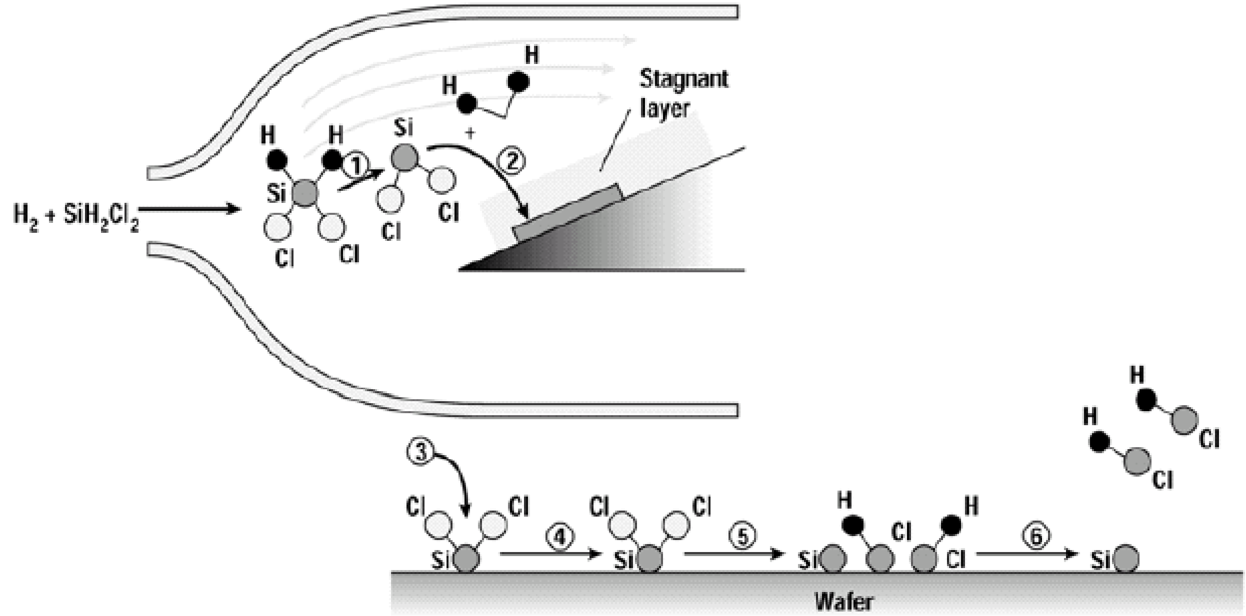
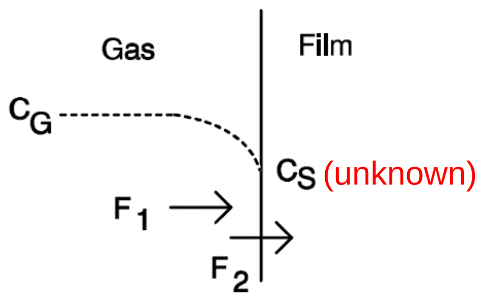


Figure 14.4 VPE steps include (1) gas-phase decomposition and (2) transport to the surface of the wafer. At the surface the growth species must (3) adsorb, (4) diffuse, and (5) decompose, and (6) the reaction by-products desorb.

Growth Rate Model



- F_1 = flux from bulk of gas to substrate surface

  $h_G(C_G - C_S)$
- F_2 = flux consumed in film-growth reaction

  $k_S \cdot C_S$
- $F_1 = F_2$

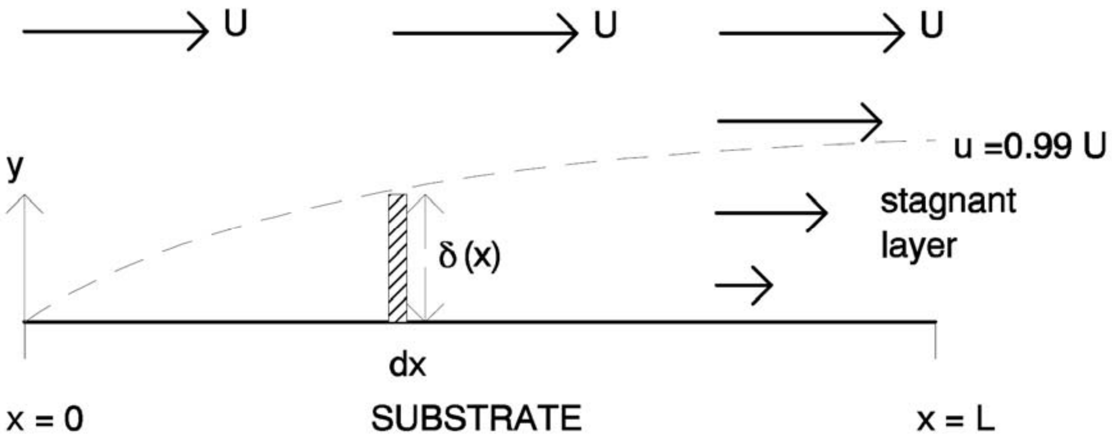
$$F = \frac{k_S h_G}{k_s + h_G} \cdot C_G$$

- Film growth rate = F/N
  - N: atomic density of the deposited film

Boundary Layer Theory

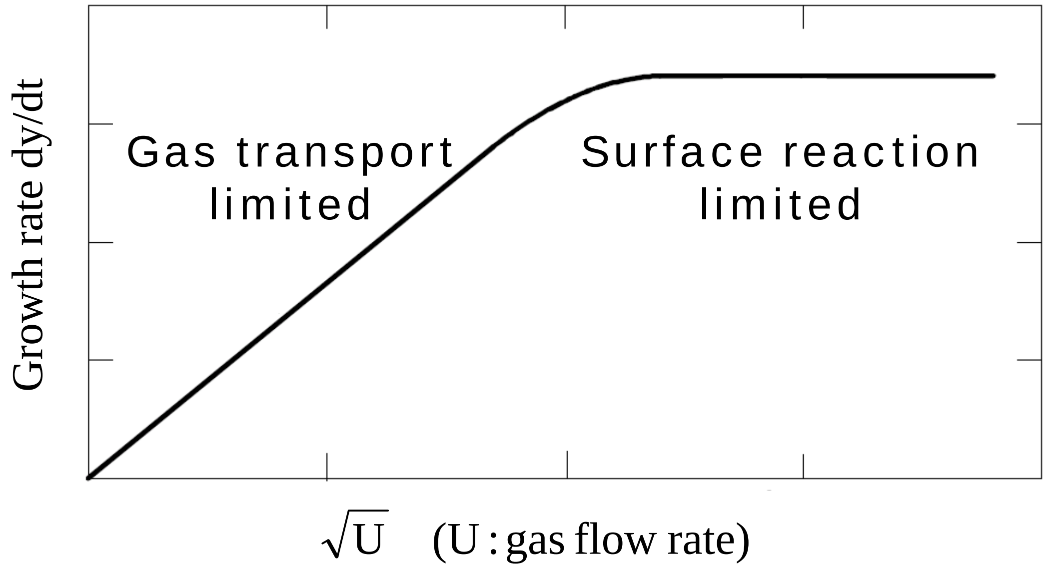
$$\bar{\delta} = \frac{1}{L}\int_0^L \delta(x)dx = \frac{2}{3}\frac{L}{\sqrt{\rho UL/\mu}}$$

boundary layer thickness

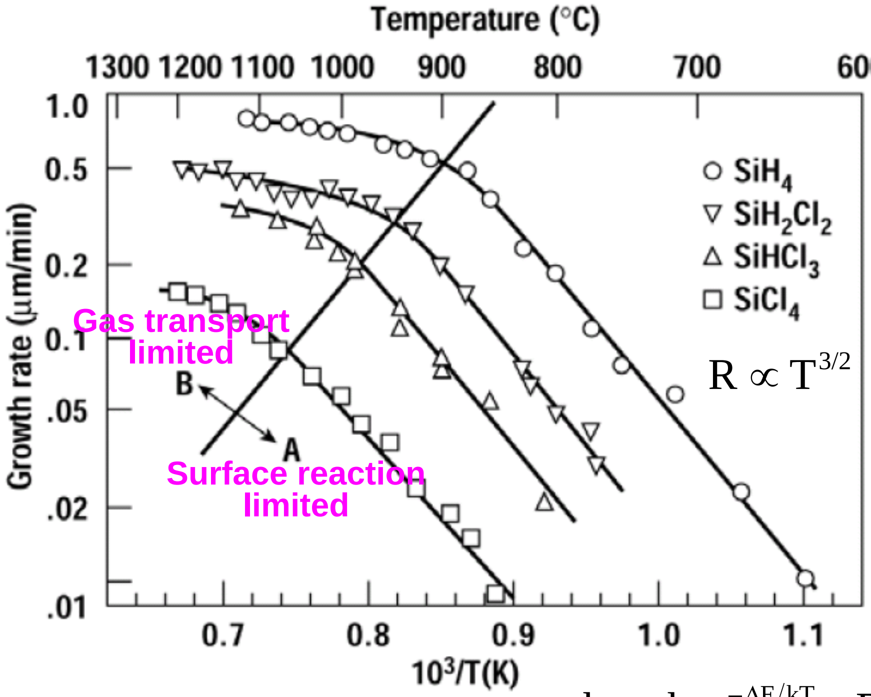


Flow Rate Dependence

$$h_G = \frac{D_G}{\bar{\delta}} \qquad \frac{dy}{dt} \propto h_G \propto \frac{1}{\bar{\delta}} \propto \sqrt{U}$$



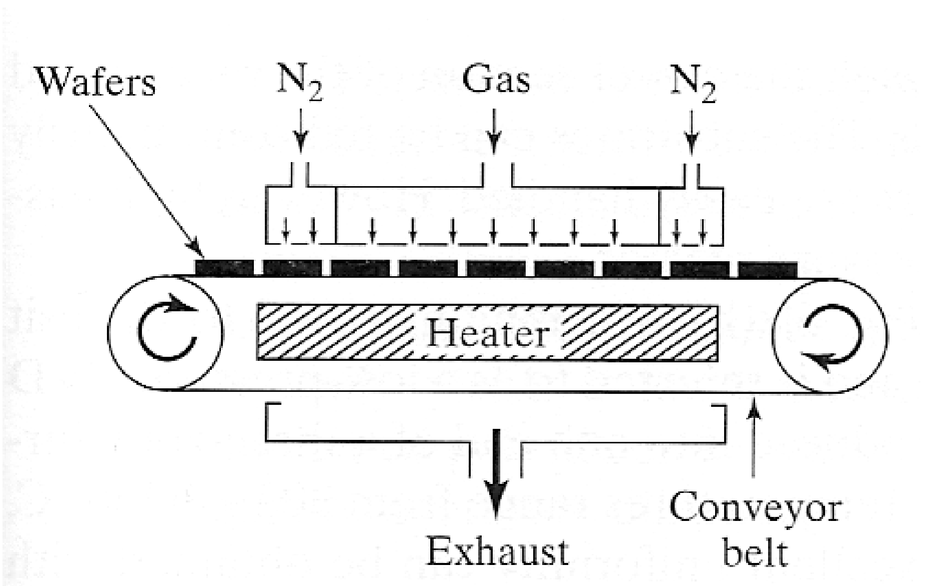
Temperature Dependence



$R \propto T^{3/2}$

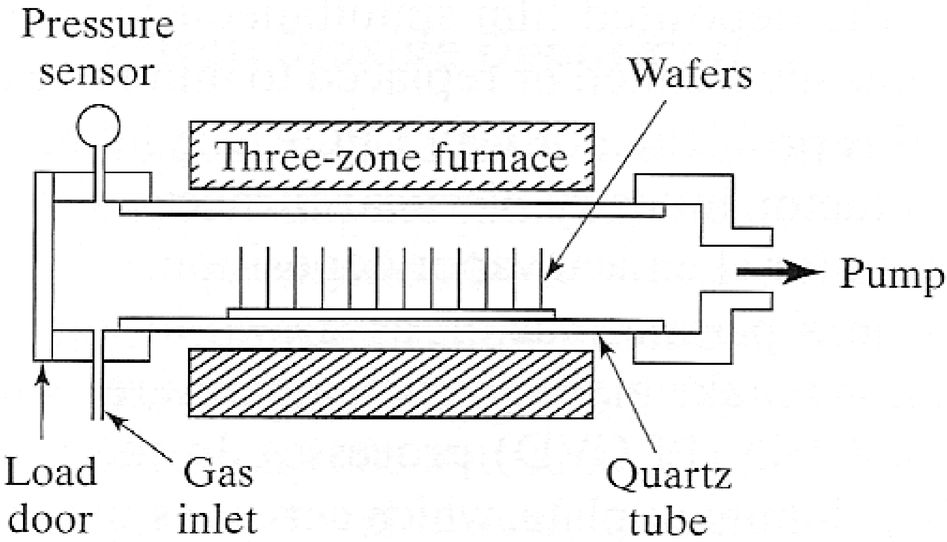
$k_s = k_0 e^{-\Delta E/kT}$ $R \propto e^{-\Delta E/kT}$

Atmospheric Pressure (APCVD)



Deposition rate is high but uniformity is poor

Low Pressure (LPCVD)



LPCVD

$$D \propto 1/P$$

from 760 torr to 1 torr, D ↑ ~ 1000x

$$\bar{\delta} \propto \sqrt{\frac{\mu}{\rho U}}$$

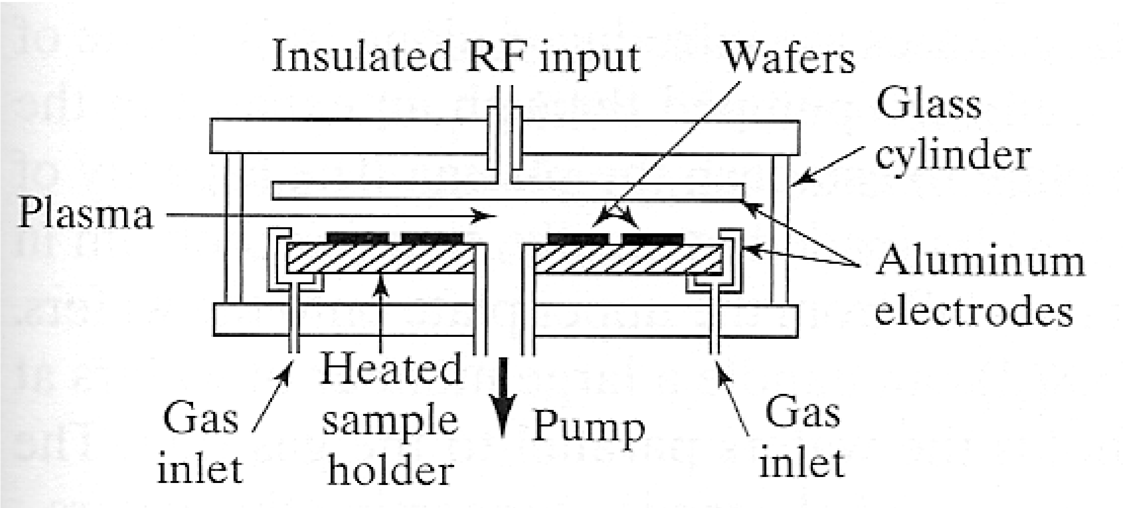
100x gas flow rate, $\bar{\delta}$ ↑ ~ 3x

$$h_G = \frac{D_G}{\bar{\delta}}$$

h_G ↑ ~ 300x

More likely to be surface reaction limited

Plasma Enhanced (PECVD)



PECVD

- Ionized chemical species allows a lower T to be used
- Film properties (e.g. mechanical stress) can be tailored by controllable ion bombardment with substrate bias voltage

	Deposition Temperature	
	LPCVD	PECVD
$SiH_4 + NH_3 \Rightarrow Si_3N_4$	850° C	200-400°C
$SiH_4 + N_2O \Rightarrow SiO_2$	800°C	200-400°C
$TEOS + O_2 \Rightarrow SiO_2$	720°C	350°C
$SiH_4 + O_2 \Rightarrow SiO_2$	400°C	

Polysilicon Deposition

$$SiH_4 \rightarrow Si + 2H_2$$

- LPCVD
- 600ºC~650ºC
- 25~150 Pa
- 100% silane or 20%~30% silane diluted with nitrogen
- 100~200 Å/min

Silicon Dioxide Deposition

$$SiH_4 + O_2 \rightarrow SiO_2 + 2H_2$$

- phospho-silicate glass (PSG) [P_2O_5+SiO_2]

$$4PH_3 + 5O_2 \rightarrow 2P_2O_5 + 6H_2$$

300ºC~500ºC

- tetraethylorthosilicate (TEOS)

$$Si(OC_2H_5)_4 \rightarrow SiO_2 + \text{byproducts}$$

LPCVD, 650ºC~750ºC

Silicon Nitride Deposition

$$3SiH_4 + 4NH_3 \rightarrow Si_3N_4 + 12H_2$$

APCVD, 700ºC~900ºC

$$3SiCl_2H_2 + 4NH_3 \rightarrow Si_3N_4 + 6HCl + 6H_2$$

LPCVD, 700ºC~800ºC

- Thermal growth of Si_3N_4 is possible but not very practical
- 1000ºC~1100ºC
- The growth rate is very low

CVD Metal Deposition

$$WF_6 + 3H_2 \rightarrow W + 6HF$$

- Mo, Ta, and Ti can be deposited in an LPCVD system through reaction with hydrogen

$$2MCl_5 + 5H_2 \rightarrow 2M + 10HCl$$

Reactive Ion Etching

ESS4810 Lecture
Fall 2010

Introduction

- Dry etching: physically/chemically
- High-pressure plasma etching
- Ion milling
- Reactive ion etching
- Deep reactive ion etching

High-Pressure Plasma Etching

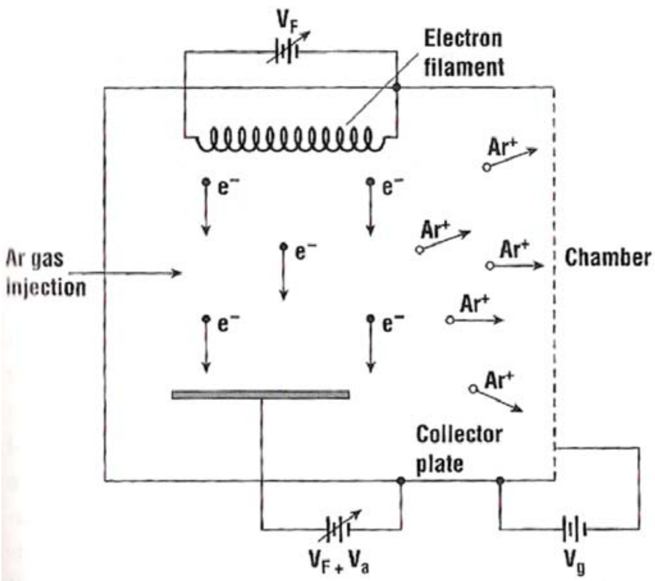
- High-pressure and low-power
- The plasma is used to start and stop the etching by producing a reactive species from an inert precursor
- Depends primarily on the chemistry

Ion Milling

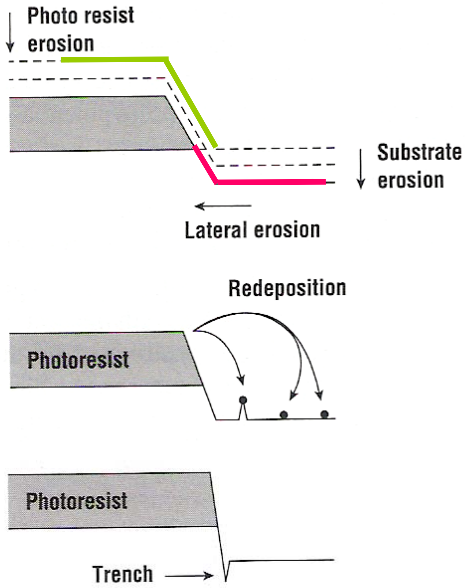
- Low-pressure and high-power
- Pure ion milling or ion-beam etching involves no chemical reactions
- Strictly mechanical process, chemistry independent
- Two significant advantages
  - Directionality
  - Applicability

Ion Milling

Kaufman source



Problems



Dry etching spectrum

Depending on the pressure range in the reactor, the reaction mechanism in dry etching goes from physical sputtering (<100 mTorr), over physical–chemical (100 mTorr range), to chemical etching (>100 mTorr).

< 100 MILLITORR

PHYSICAL SPUTTERING
(and Ion Beam Milling)

- Physical momentum transfer
- Directional etch (anisotropic) possible
- Poor selectivity
- Radiation damage possible

HIGHER EXCITATION ENERGY

RIE (Halocarbon Gas)

100 MILLITORR RANGE

- Physical (ion) and chemical
- Directional
- More selective than sputtering

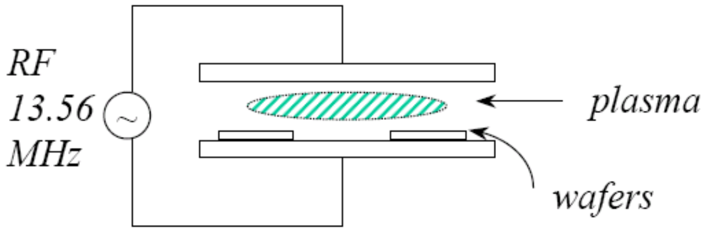
PLASMA ETCHING

HIGHER PRESSURE

- Chemical, thus faster by 10-1000X
- Isotropic
- More selective
- Less prone to radiation damage

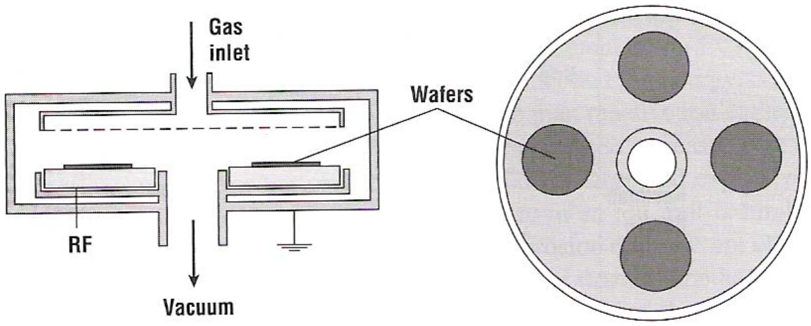
Reactive Ion Etching

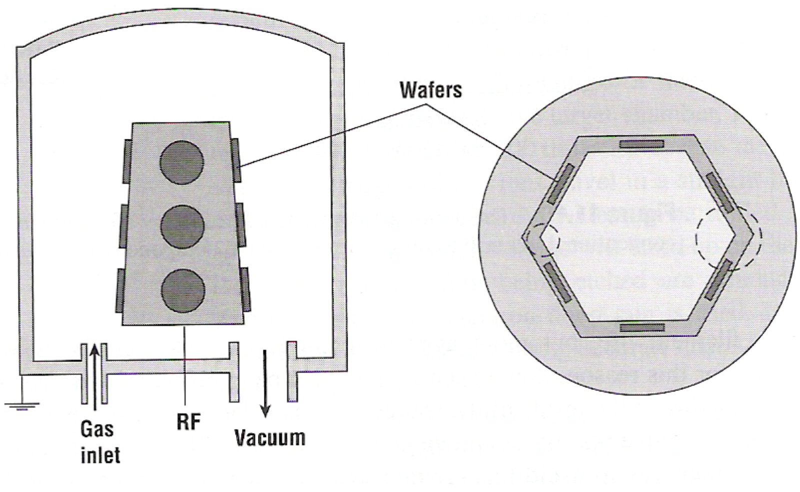
- Parallel-plate reactor



- Plasma generates
  - Ions: sputtering
  - Activated neutrals: enhance chemical reaction

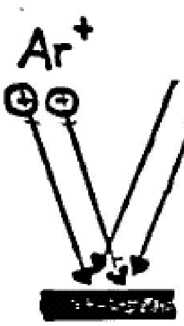
System Configuration

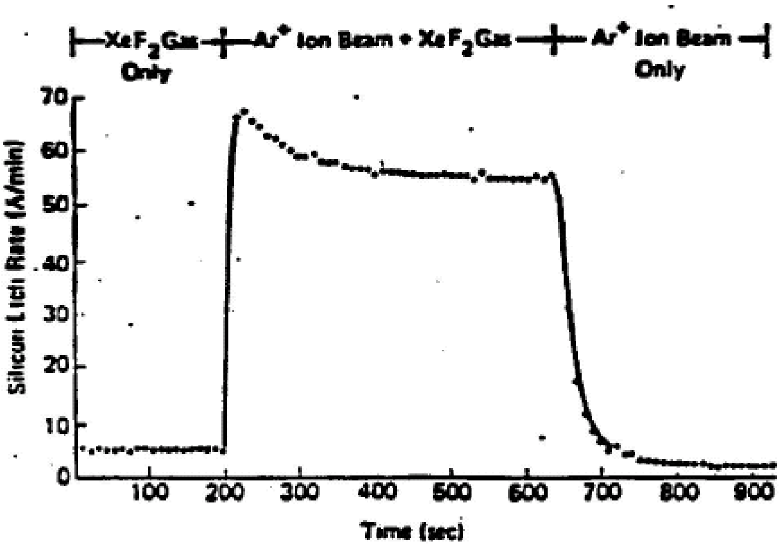




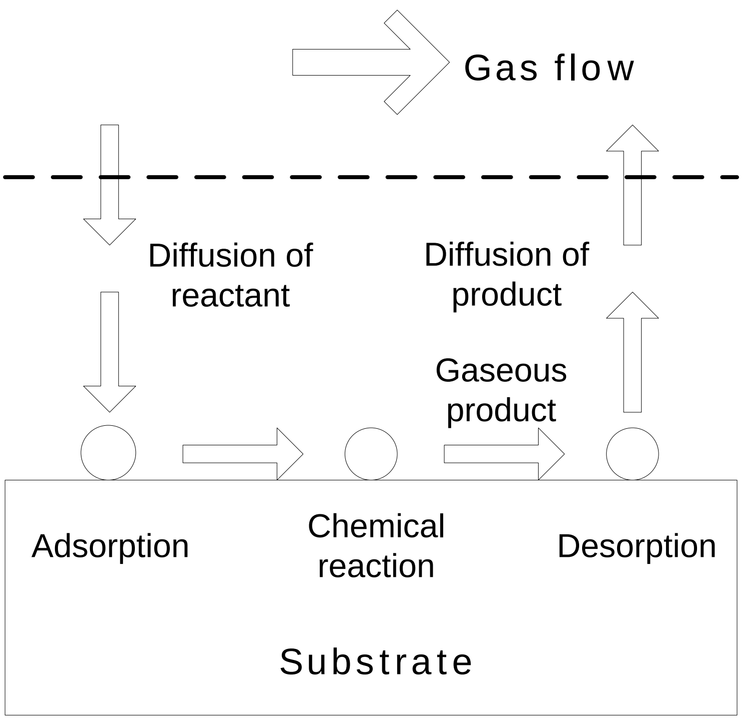
Ion-Assisted Etching

- Synergism of ion bombardment + chemical reaction give the high RIE rates





Etching Sequence



Volatility of Etching Product

- Higher vapor pressure usually means higher volatility
- Example

$Si + 4F^* \rightarrow SiF_4 \uparrow$ high vapor pressure

$Cu + Cl \rightarrow CuCl$ low vapor pressure

Difficult to RIE Al-Cu alloy with high Cu content

BOILING POINT (°C) AT 1 atm

Chlorides		Fluorides	
$AlCl_3$	177.8	AlF_3	1291
$SiCl_4$	57.6	SiF_4	86
Cu_2Cl_2	1490	Cu_2F_2	1100
$TiCl_4$	136.4	TiF_4	284
WCl_6	346.7	WF_6	17.5

Chemistry	Primary Films Etched
Cl-based (Cl_2, BCl_3)	Al alloys, Ti, TiN, resist
F-based (SF_6, CF_4, CHF_3)	W, TiW, SiO_2, resist
O-based (O_2, O_3, CO_2, H_2O)	Resist

Examples

- Silicon, use CF_4 gas

$$CF_4 \rightarrow F^* + CF_3$$

$$CF_4 + e \Leftrightarrow CF_3^+ + F^* + 2e$$

$$Si + 4F^* \rightarrow SiF_4 \uparrow$$

- Aluminum $$CCl_4 + e \Leftrightarrow CCl_3^+ + Cl^* + 2e$$

$$Al + 3Cl^* \rightarrow AlCl_3 \uparrow$$

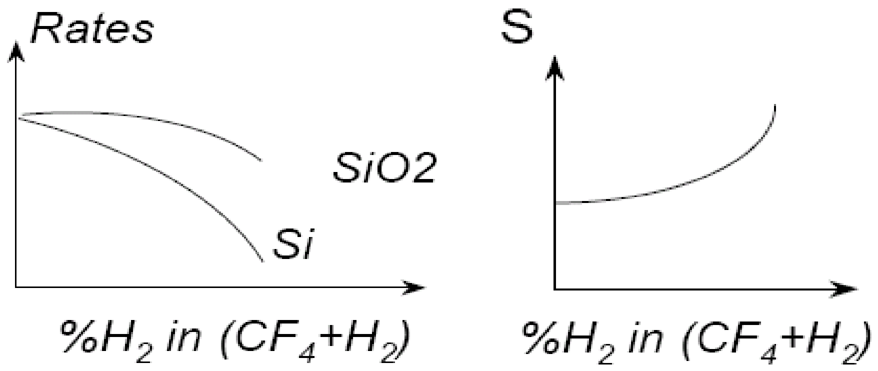
- Photoresist

$$C_xH_yO_z + O_2 \rightarrow CO_x,\ HO_x$$

Selectivity

- SiO_2 etching in CF_4+H_2 plasma

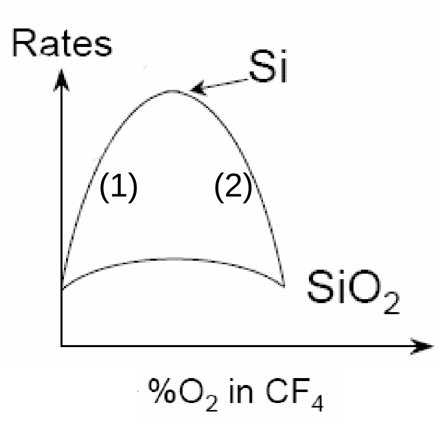
  S = rate of SiO_2 / rate of Si

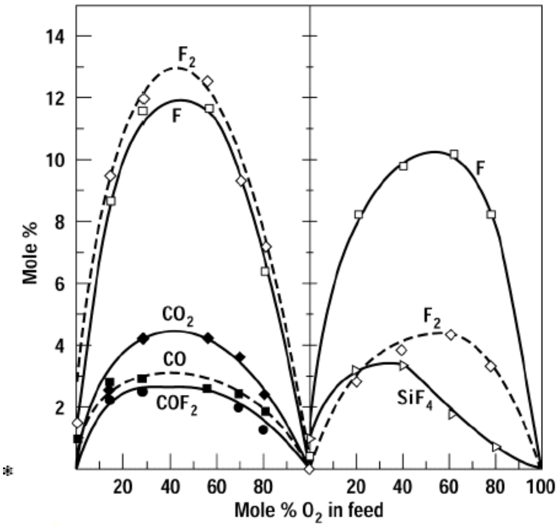


- Reason

$$F^* + H \rightarrow HF \quad \therefore F^* \text{ content} \downarrow \quad SiF_4 \downarrow$$

Si Etching in CF_4+O_2 Mixture



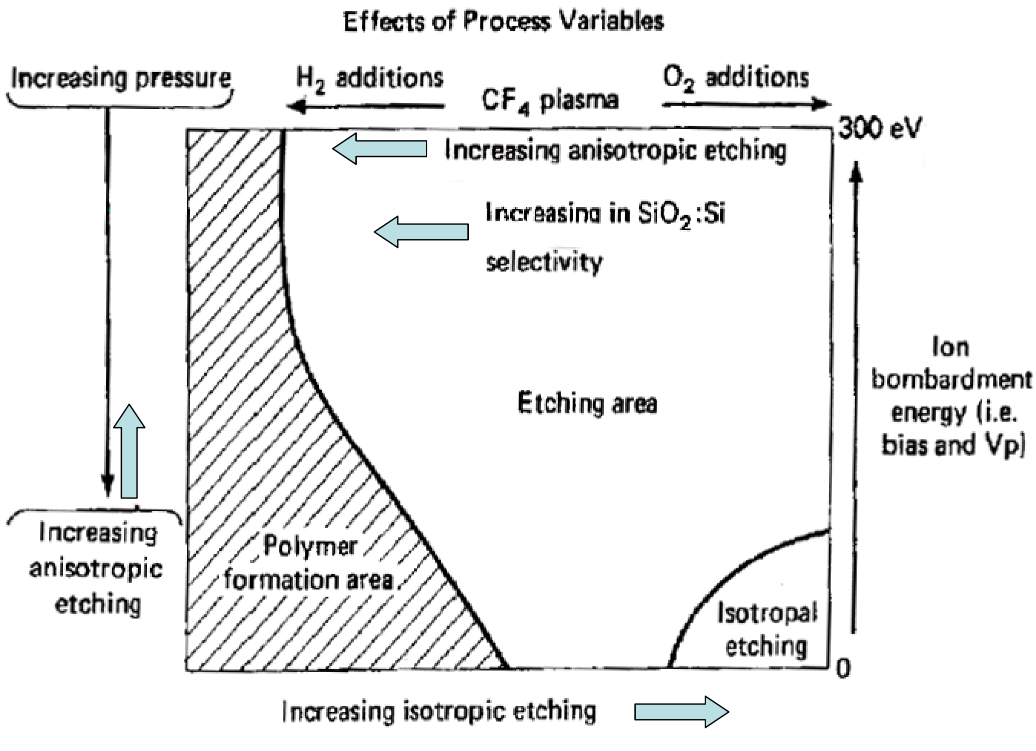


(1) $O + CF_x \rightarrow COF_x + F^*$

F* increases Si etching rate

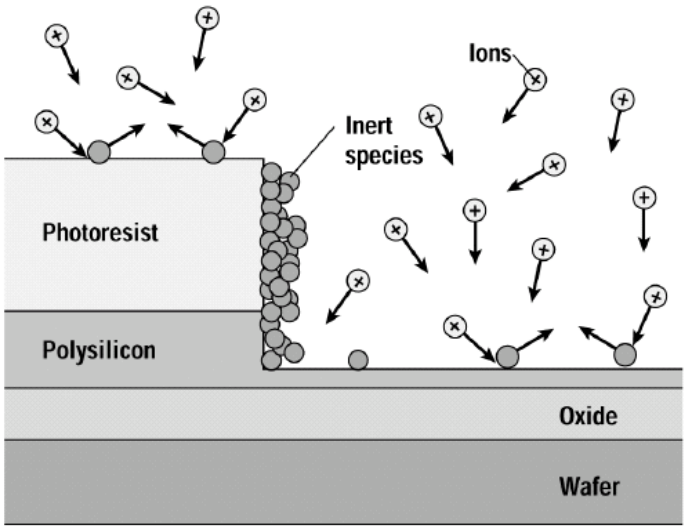
(2) $Si + O_2 \rightarrow SiO_2$

Characteristics



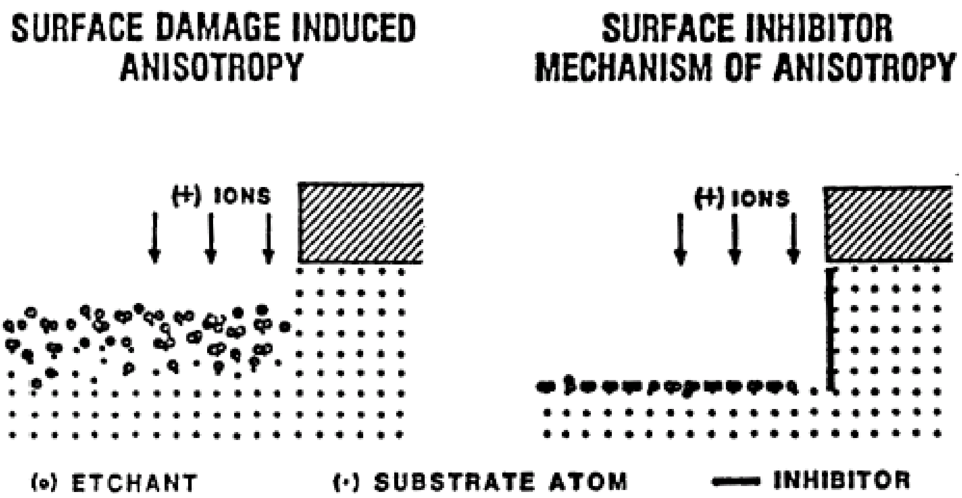
Etching Mechanism

- Removal of surface film and deposition of plasma reaction products can occur simultaneously

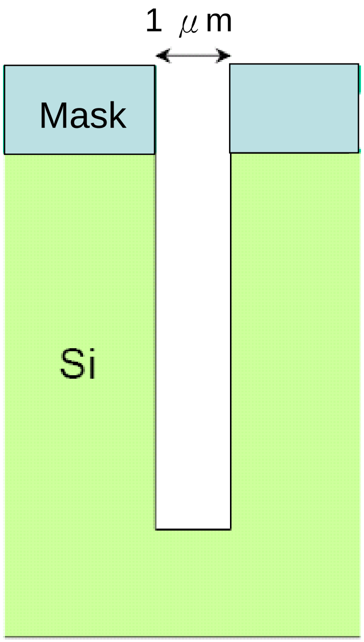


Anisotropy

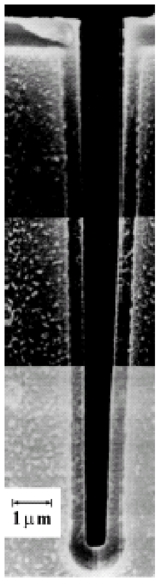
- Ionic bombardment to damage expose surface
- Sidewall coating by inhibitor prevents etching

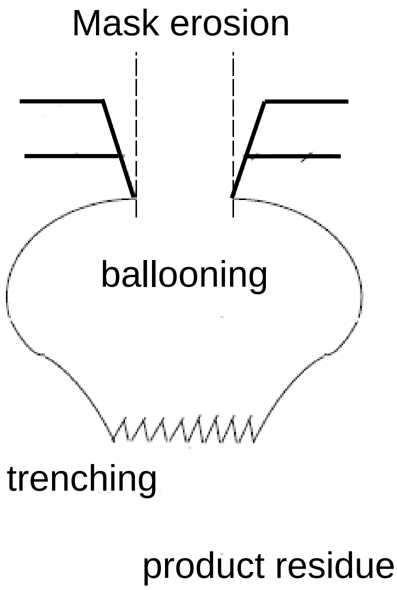


Deep Reactive Ion Etching



“ideal”





“problems”

Deep Reactive Ion Etching

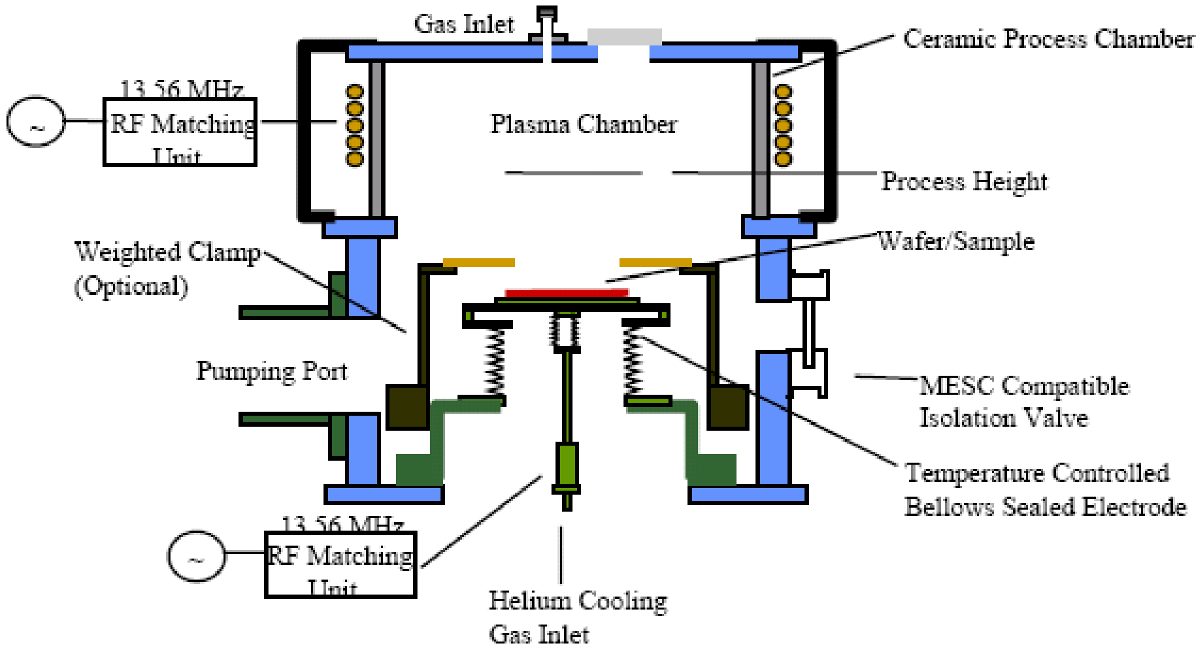
- Ballooning

  Use chemistry with a good sidewall inhibitor
- Trenching

  Use high pressure to increase ion-neutral scattering (ion trajectory less directional)
- Bottom Roughness

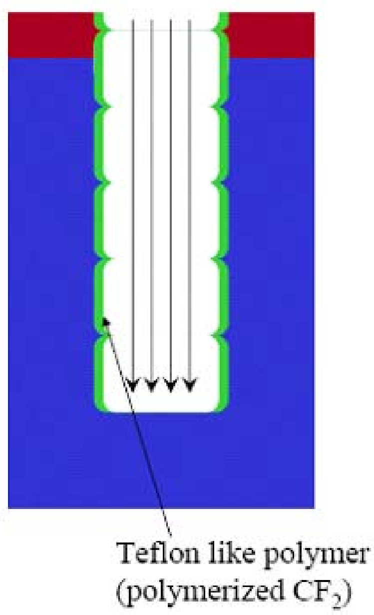
  Increase vapor pressure of etching product

Surface Technology System



Etching Mechanism

- Alternating between etching and protective polymer deposition
- Etching
  - SF_6/Ar + substrate bias
- Polymerization
  - CHF_3/Ar or
  - C_4F_8/SF_6



HARSE Process

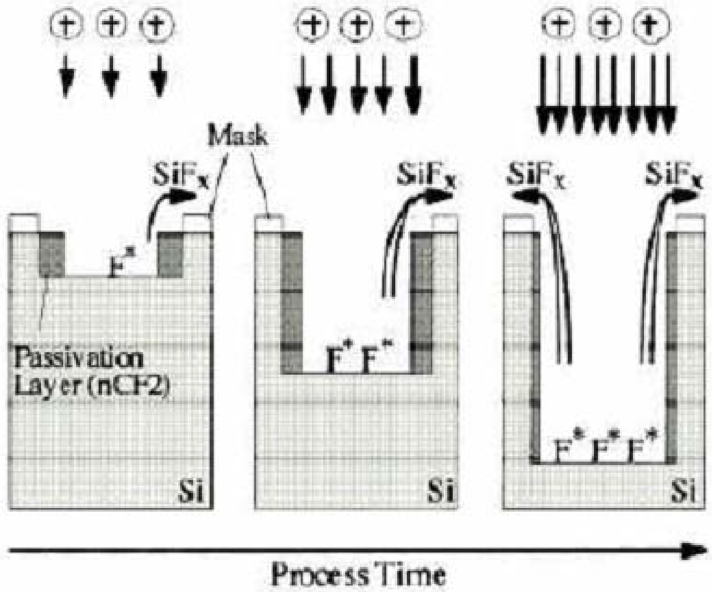
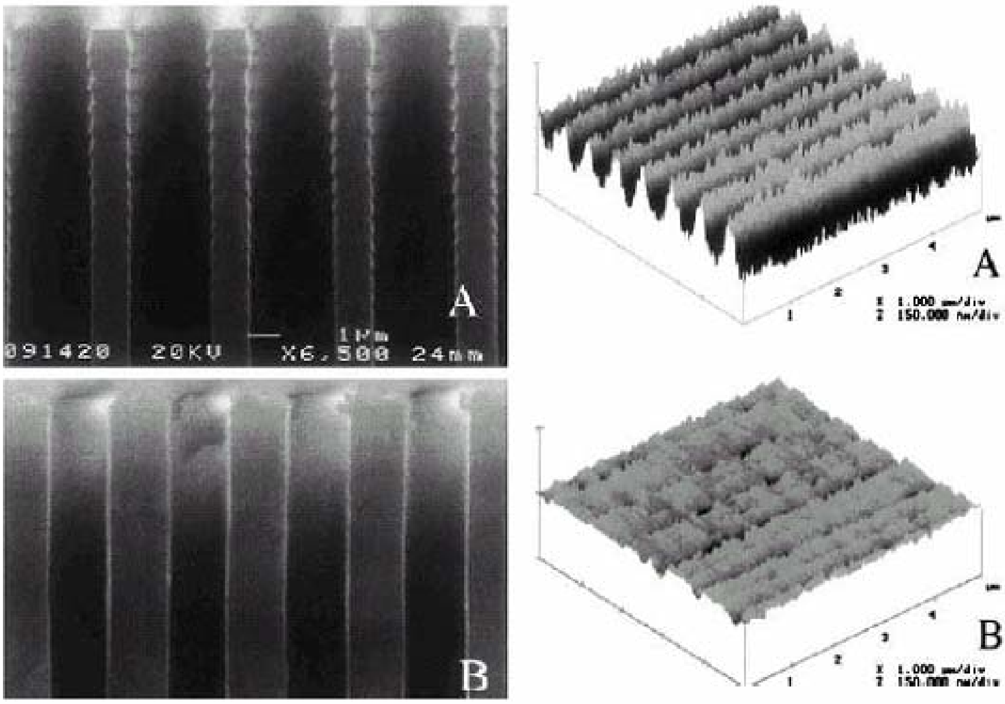
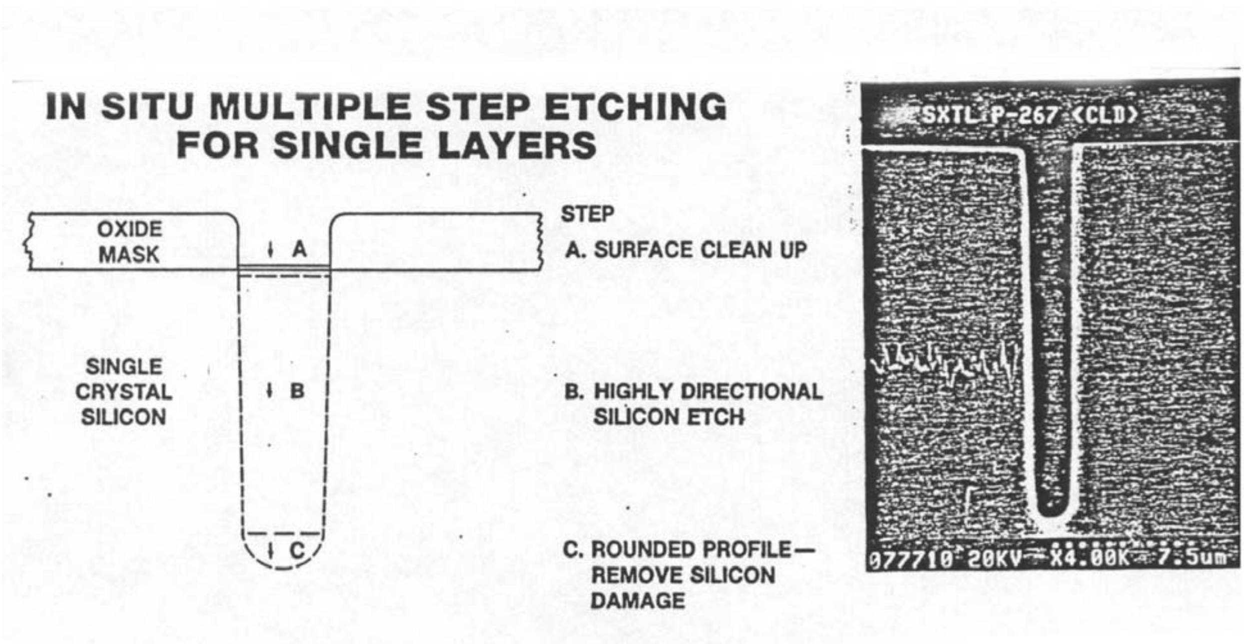


Fig. 1. Mechanism of the multiple-step HARSE process consisting of gradually increasing the silicon etch efficiency as a function of the silicon depth previously etched

HARSE Process

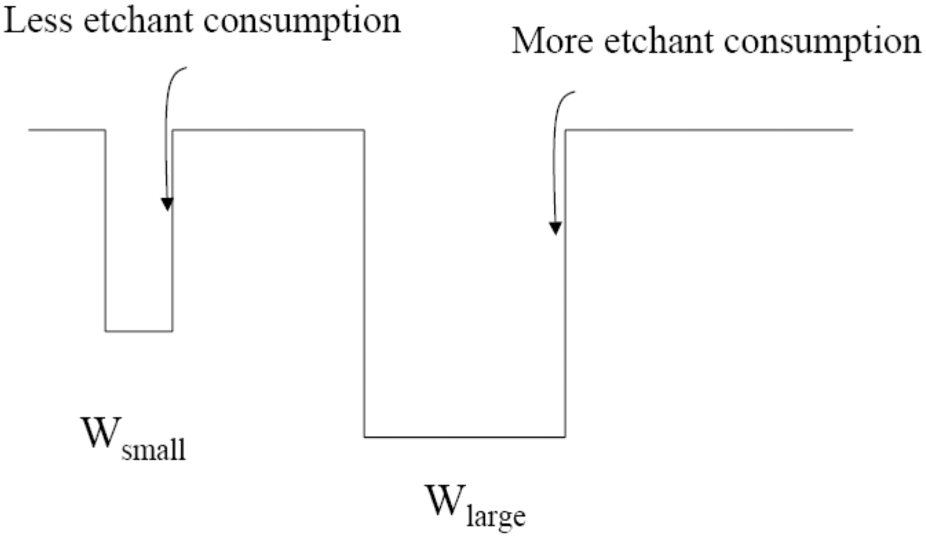


Solution: Multiple step RIE sequence

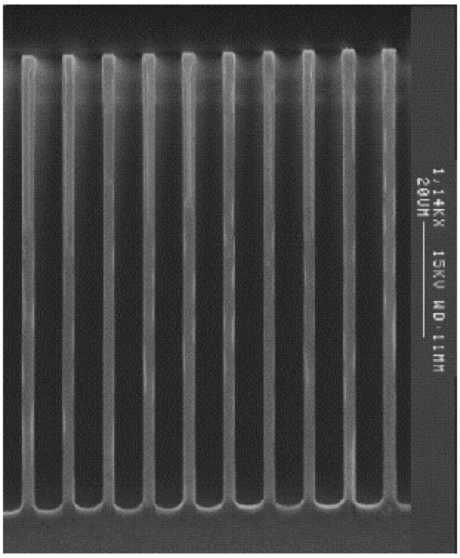


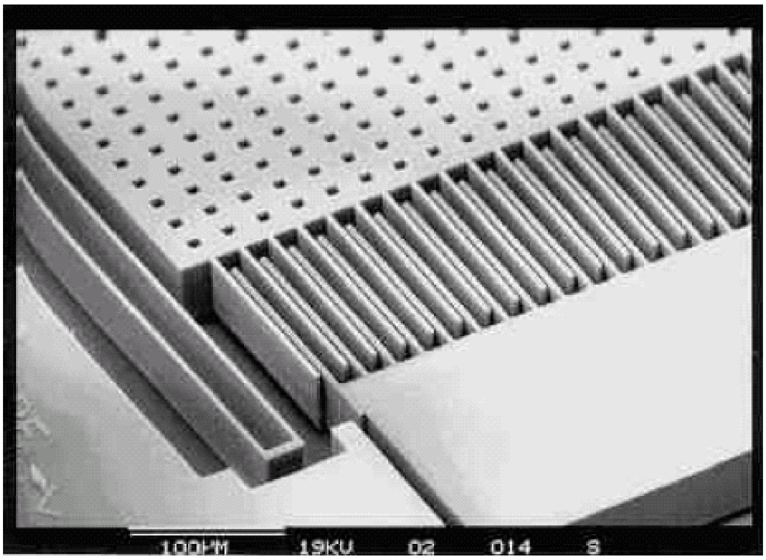
Local Loading Effect

- Smaller trenches etch at a slower rate than larger trenches



Deep Reactive Ion Etching





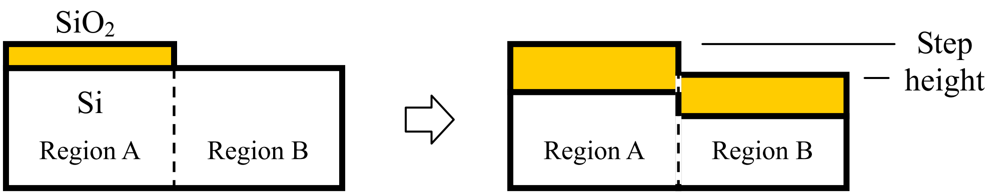
ESS4810 Micro System Fabrication and Experiment
Midterm Exam (Fall 2009)

Problem 1 - Clean Room, Wafer Cleaning, and Thermal Oxidation (14%)

(a) Why should a microfabrication clean room be environmentally controlled with respect to (1) airborne particulates and (2) lighting? (3%) Which one of the following two clean rooms has worse control over airborne particulates, class 10 or class 1000? (1%)

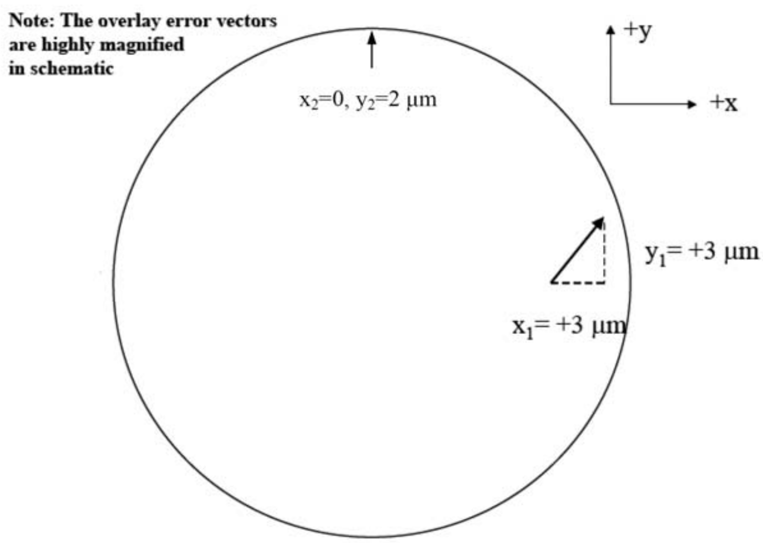
(b) List 2 different ways that are capable of removing residue photoresist. (2%)

(c) A bare silicon wafer is oxidized for 3 hours at 1200°C in dry O_2. After a series of lithography and etching steps, SiO_2 on half of the wafer is removed. The whole wafer is then re-oxidized at 1000°C in steam. The final oxide thickness in region A is measured to be 0.6 μm. Use the attached oxidation chart to estimate the final oxide thickness in Region B and the step height between A and B. (8%).



Problem 2 - Lithography (20%)

(a) We only measure the overlay errors of the Top and Right alignment marks of a 100 mm diameter wafer.



	Top	Right	Center	Left	Bottom
x	0	+3 μm	x_t (Not measured)	Not measured	Not measured
y	2 μm	+3 μm	y_t (Not measured)	Not measured	Not measured

(i) Calculate the x and y components of the translational error (x_t, y_t). (3%)

(ii) Calculate the rotational error (also indicate CW or CCW in the answer). (2%)

(iii)Calculate the overlay error of the Left alignment marks. (3%)

(b) An established optical lithography process using G-line illumination (λ=436 nm) can produce a minimum printable feature (=k • λ/NA) of 0.5 μm with a depth of focus (=$\lambda/2(NA)^2$) of 1 μm. A new IC product requires a minimum printable feature of 0.2 μm with a depth of focus = 0.15 μm. Two optical steppers are available with the following specifications:

	λ	NA
Stepper A	365 nm (I-line)	N_1
Stepper B	248 nm (excimer laser)	N_2

Assuming the technology factor k for minimum printable feature remains the same, what are the ranges of NAs (N_1 and N_2) that will meet both the minimum printable feature and DOF requirements? (7%)

(c) Describe briefly what the so-called lift-off process is. (3%)

(d) Compare positive and negative PRs in terms of resolution and sensitivity. (2%)

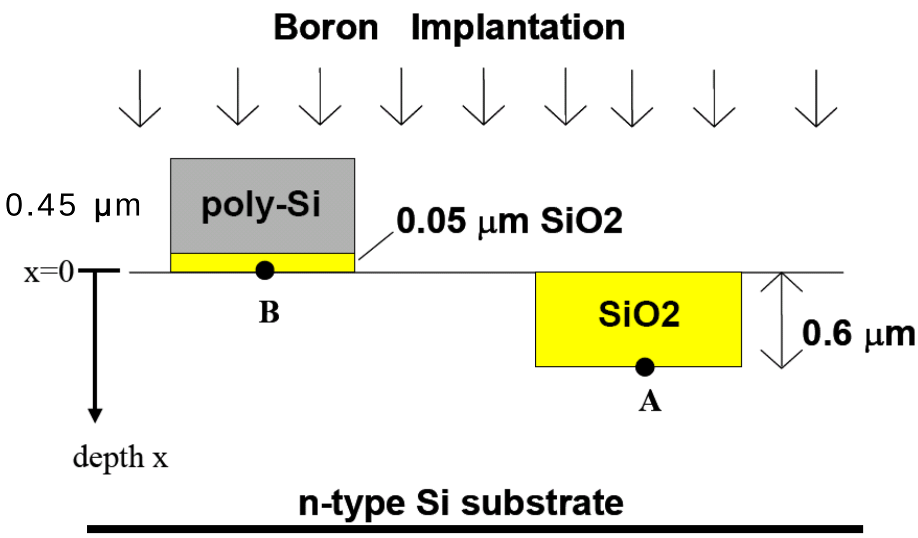
Problem 3 - Ion Implantation (15%)

Boron implantation is performed to the following structure with a boron dose of $1x10^{14}/cm^2$. The B^+ ion energy is chosen such that the boron concentration (right after implantation) at location A is a maximum. Assume that the ion stopping powers and ion scattering characteristics are identical for both silicon and silicon dioxide.

(a) What is the required B^+ ion energy? (3%)

(b) The post-implant heat-treatment is 1000°C for 50 minutes with a boron diffusion constant equal to 1.5×10^{-6} μm^2/sec. Calculate the boron concentration (after the heat treatment) at location B and A. (7%)

(c) The n-type substrate has a uniform doping concentration of $1x10^{15}/cm^3$. Calculate the junction depth underneath location B before and after the heat treatment. (5%)

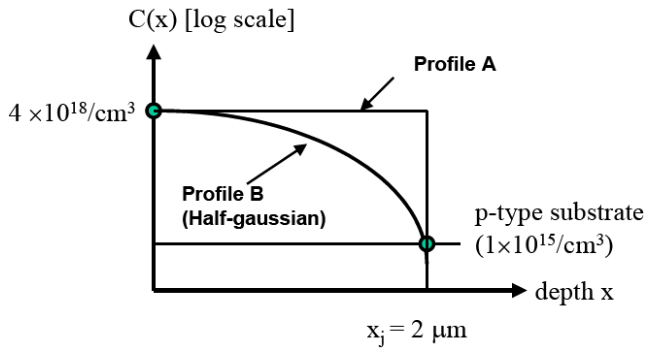


Problem 4 – Diffusion (8%)

(a) Explain briefly what thermal budget is. (2%)

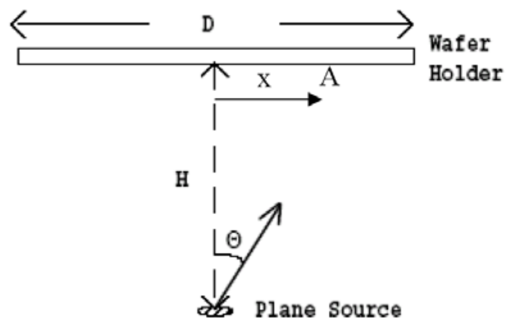
(b) The following profile B is subjected to an additional drive-in step such that $(Dt)_{drive\text{-}in} = 3(Dt)_{predep}$. Calculate the surface concentration after drive in. (4%)

(c) List 2 major advantages of ion implantation versus dopant diffusion. (2%)

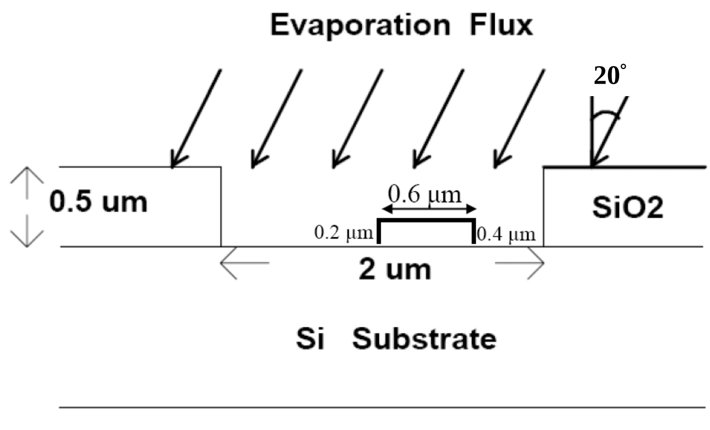


Problem 5 – Vapor Deposition (23%)

(a) A wafer of diameter D is placed at a height H above a small planar evaporation source. Derive an expression for the ratio of the deposited film thickness at location A to that at the center, in terms of x, D, and H. (4%)



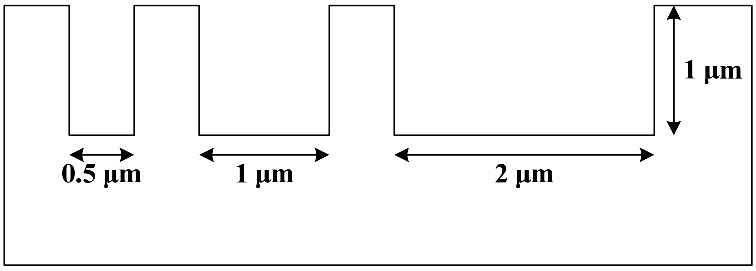
(b) If the evaporation source is very far from the wafer, we can treat the evaporation fluxes to be uniform and parallel. The following contact opening has vertical SiO_2 sidewalls and the evaporating flux is making an angle of 20° with respect to the normal of the wafer's surface. If the deposition rate is 1000 Å/min, sketch the cross-sectional profile of the deposited film after 5 min. (7%)



(c) What is the working principle of (1) sputtering (2%) and (2) a cryopump? (2%)

(d) List 2 major advantages of using CVD versus PVD for thin film deposition. (3%)

(e) Assume a starting substrate profile shown below. A ideal conformal deposition is then performed with a deposition rate of 0.1 μm/min. Sketch the cross-sections of the deposited film after 1, 2, and 4 minutes of deposition. (5%)



Problem 6 – Etching (21%)

The (100) wafer shown below has nitride masks on its top and bottom surfaces.

(1) With KOH, the etch selectivity between the {100} and {111} planes is 400:1 (use ∞:1 in your calculation), and the {100} etch rate is 1.4 μm/min.

(2) With TMAH, the etch selectivity between the {100} and {111} planes is 40:1, and the {100} etch rate is 1.2 μm/min.

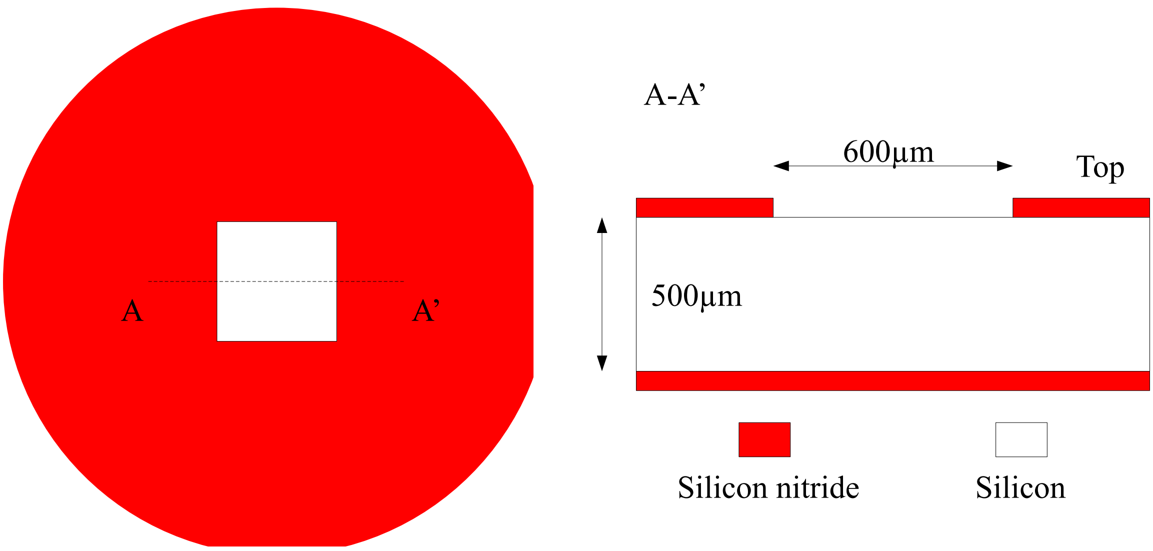
(3) With HNA, the isotropic etch rate is 1 μm/min.

For anisotropic etching, assume that the nitride layers and all other silicon crystal planes are not etched. Sketch the wafer cross sections after 200 minutes of etching (3%) and determine the following dimensions after etching in the all three cases:

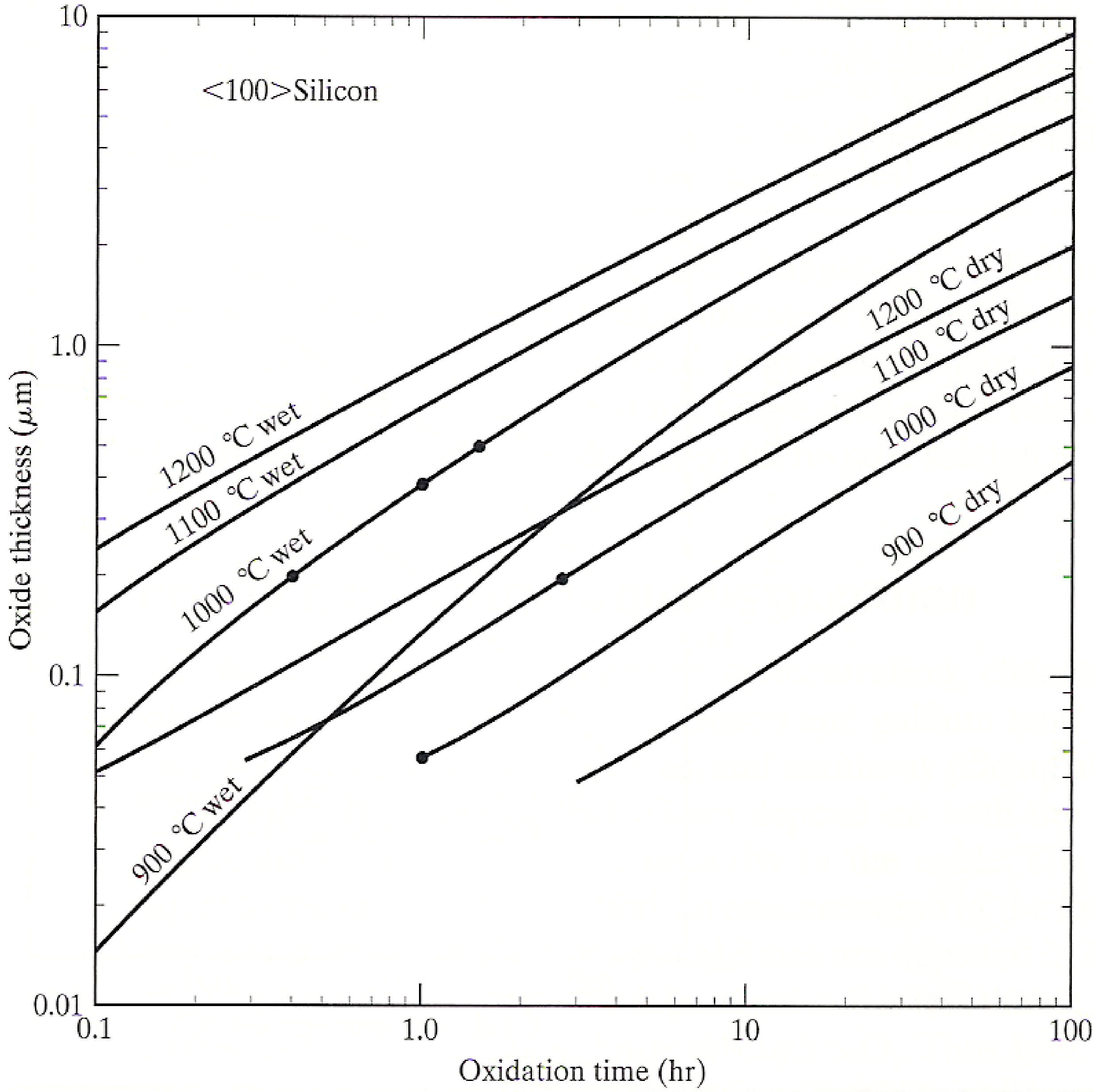
(a) Silicon etch depth (3%)

(b) Silicon etch width at top (6%)

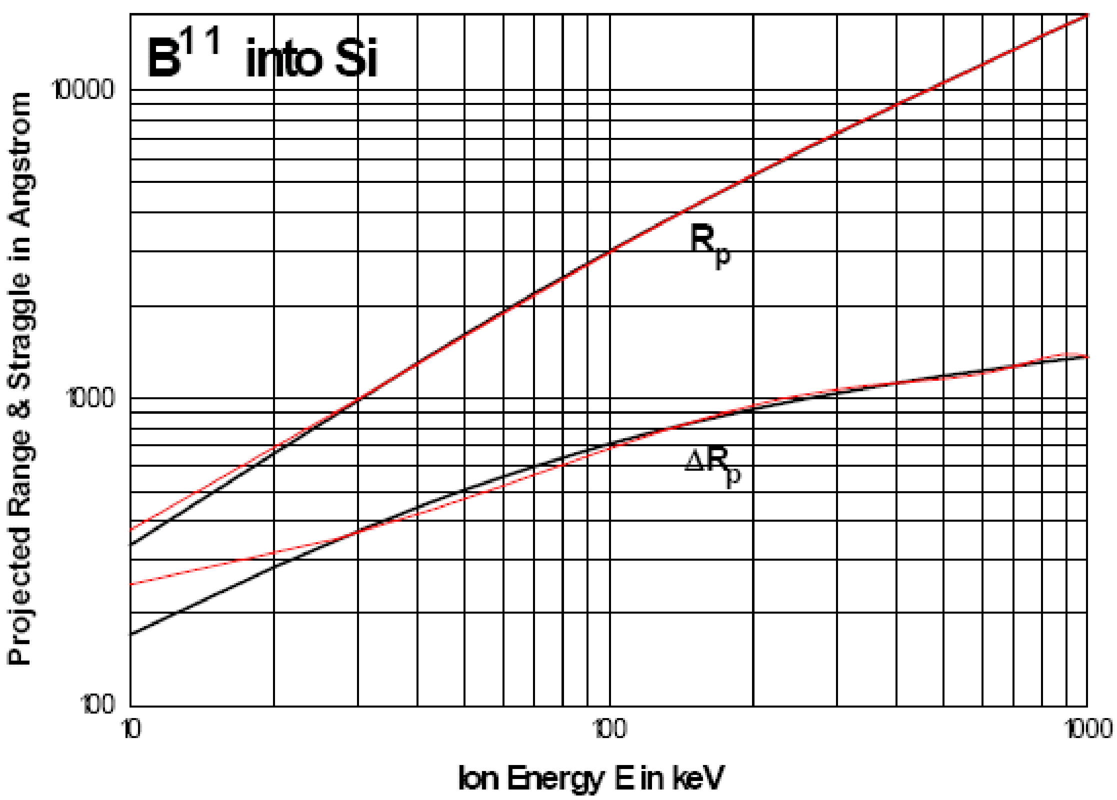
(c) Silicon etch width at bottom (3%)



(d) Compare high-pressure plasma and reactive ion etching in terms of their reaction mechanisms. (3%) How to realize ideal high aspect ratio etching? (3%)



<100>Silicon
1200 °C wet
1100 °C wet
1000 °C wet
900 °C wet
1200 °C dry
1100 °C dry
1000 °C dry
900 °C dry
Oxide thickness (μm)
10
1.0
0.1
0.01
0.1
1.0
10
100
Oxidation time (hr)



B11 into Si
Rp
ΔRp
Projected Range & Straggle in Angstrom
10000
1000
100
10
100
1000
Ion Energy E in keV

ESS4810 Micro System Fabrication and Experiment

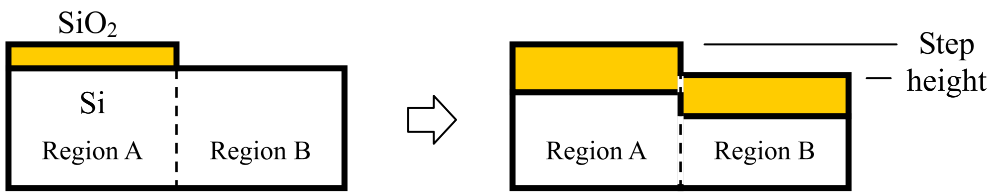
Midterm Exam (Fall 2008)

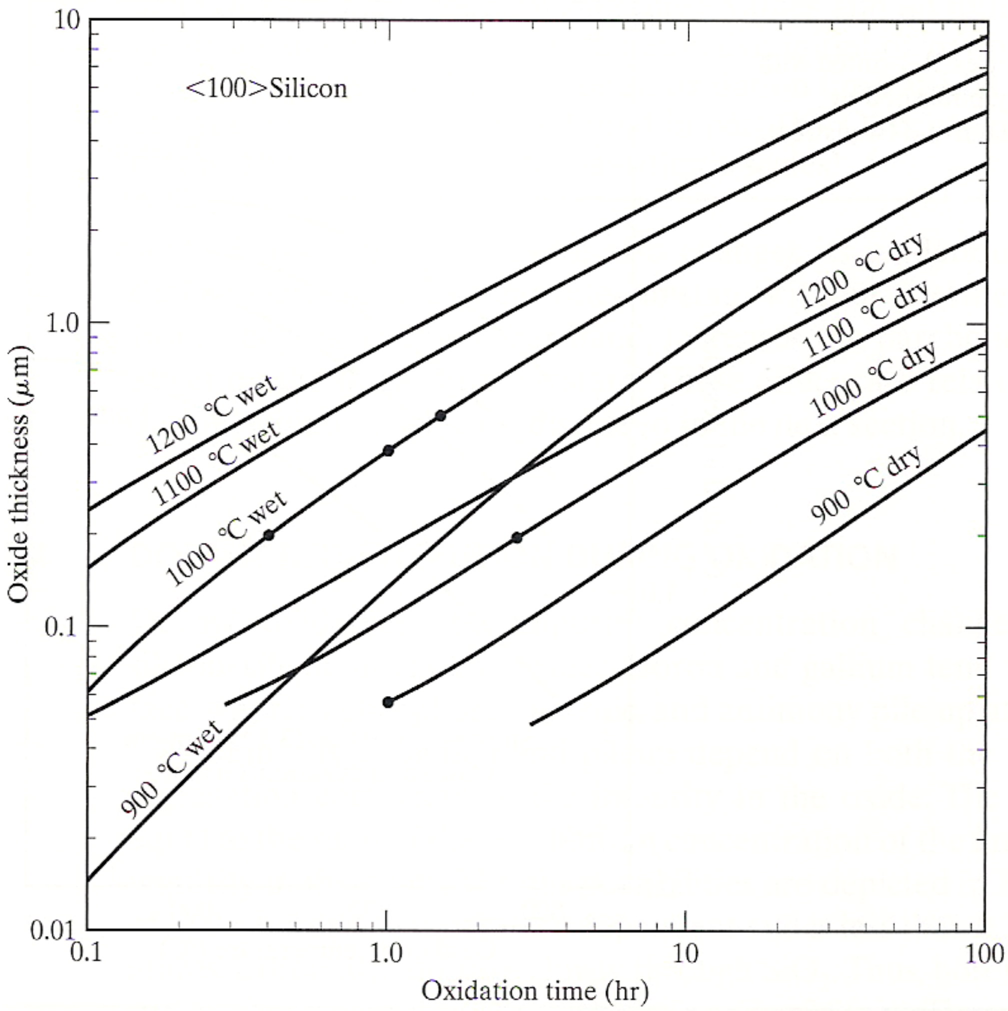
Problem 1 - Clean Room, Wafer Cleaning, and Thermal Oxidation (20%)

(a) A microfabrication clean room should be environmentally controlled with respect to airborne particulates and what else? List at least 3 of them. (4.5%) Which one of the following two clean rooms has better control over airborne particulates, class 1 or class 100? (2%)

(b) List at least 2 different ways that is capable of removing residue photoresist. (4%)

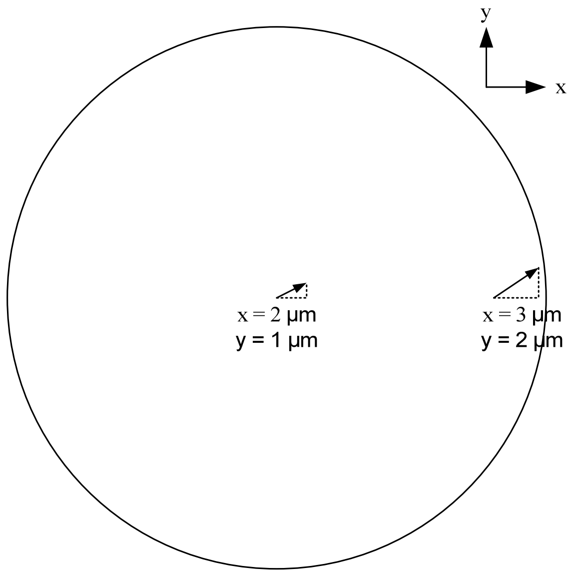
(c) A bare Si {100} wafer is oxidized for 40 minutes at 900°C in steam. After a series of lithography and etching steps, SiO_2 on half of the wafer is removed. The whole wafer is then re-oxidized in dry O_2 at 1100°C. The final oxide thickness in region A is measured to be 0.2 μm. Use the attached oxidation chart to estimate the final oxide thickness in Region B and the step height between Region A and B. (9.5%)





Problem 2 – Lithography (24%)

(a) We only measure the overlay errors of the Center and Right alignment marks of a 100 mm diameter wafer.



	Top	Right	Center	Left	Bottom
x	N/A	3 μm	2 μm	x_1	N/A
y	N/A	2 μm	1 μm	y_1	N/A

(i) Calculate the thermal run in (or out) error. (3%)

(ii) Calculate the rotational error (also indicate clockwise or counterclockwise in your answer). (3%)

(iii)Calculate the overlay errors of the Left alignment marks. (3%)

(b) An established optical lithography process using G-line illumination (λ=436 nm) can produce a minimum printable feature (=**k** • λ/NA) of 0.5 μm with a Depth of Focus ($=\lambda/2(NA)^2$) of 1 μm. A new IC product requires a minimum printable feature of 0.2 μm with a Depth of Focus = 0.15 μm. Three optical steppers are available with the following specifications:

	λ	NA
Stepper A	365 nm (I-line)	0.7
Stepper B	248 nm (excimer laser)	0.85
Stepper C	193 nm (ArF)	0.85

Assuming the technology factor **k** for minimum feature remains the same, which stepper will meet both the minimum feature and DOF requirements? Show calculations to justify your choice. (10%)

(c) Describe briefly what the so-called lift-off process is. (3%)

(d) List at least 2 differences between positive and negative photo-resists. (2%)

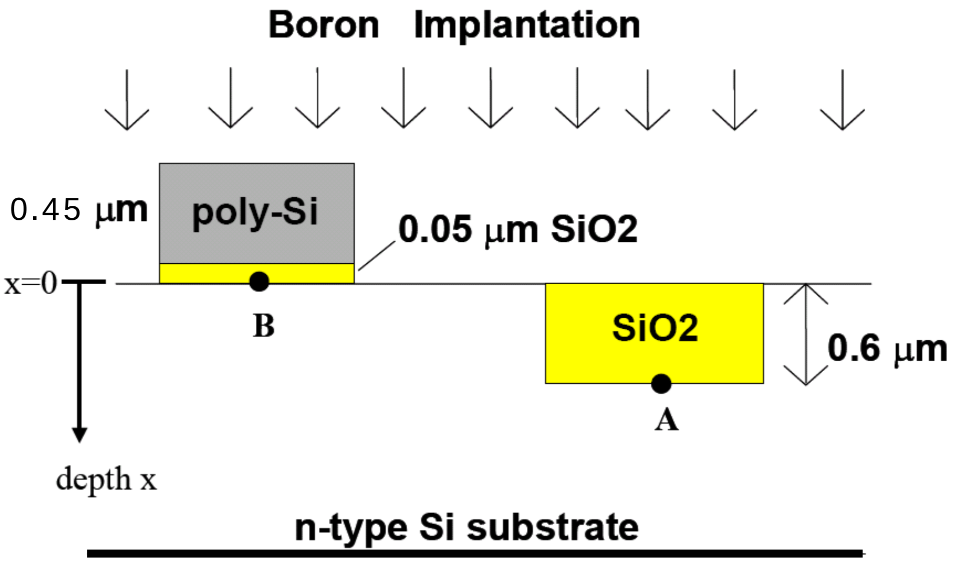
Problem 3 - Ion Implantation (17%)

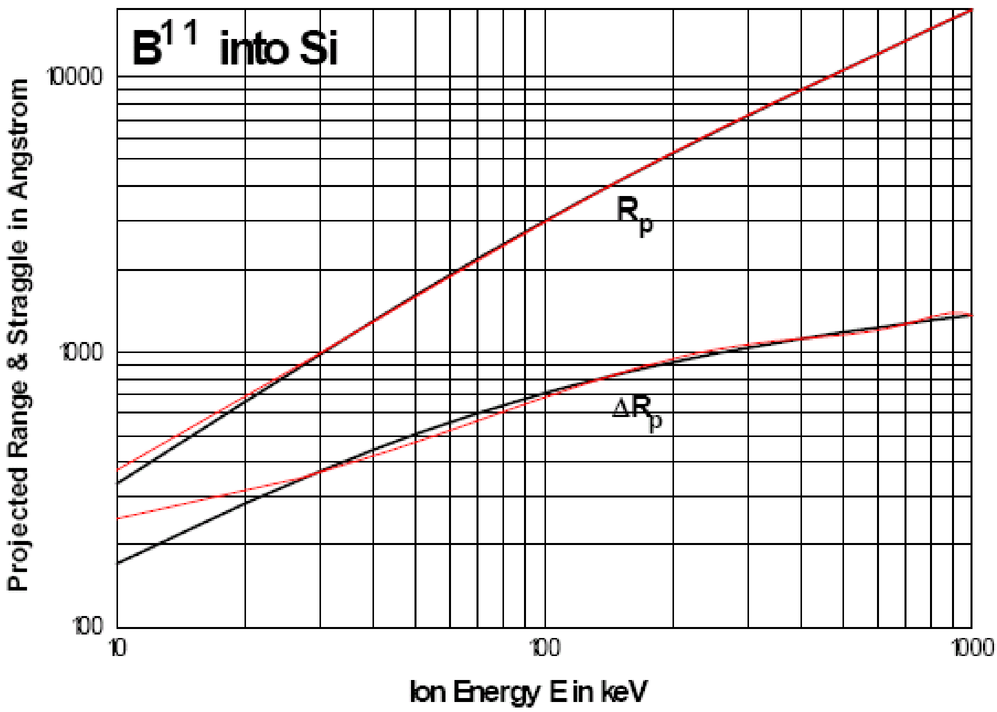
Boron implantation is performed to the following structure with a boron dose of $8 \times 10^{13}/cm^2$. The B^+ ion energy is chosen such that the boron concentration (right after implantation) at location B is a maximum. Assume that the ion stopping powers and ion scattering characteristics are identical for both silicon and silicon dioxide.

(a) What is the required B^+ ion energy? (3%)

(b) The post-implant heat-treatment is 1000°C for 40 minutes with a boron diffusion constant equal to 1.8×10^{-6} μm^2/sec. Calculate the boron concentration (after the heat treatment) at location B and A. (10%)

(c) The n-type silicon substrate has a uniform doping concentration of $1 \times 10^{15}/cm^3$. Calculate the junction depth x_j underneath location A. (4%)





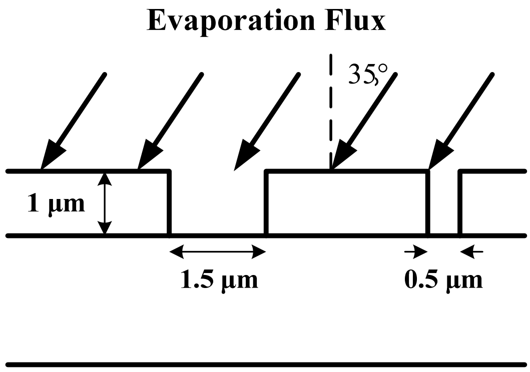
Problem 4 – Diffusion (8%)

(a) Explain briefly what thermal budget is. (3%)

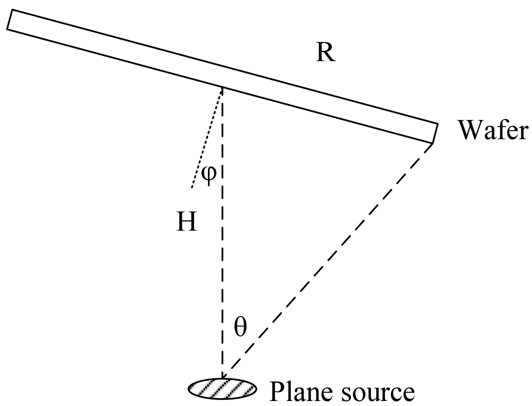
(b) A boron pre-deposition step is performed into an n-type Si substrate at 1000°C. The solid solubility of boron in silicon is known to be $3.5\times 10^{20}/cm^3$ at 1000°C and the incorporated boron dose Q is $1\times10^{15}/cm^2$. What is the junction depth x_j of the pre-deposition profile if the n-type substrate has a background concentration of $10^{15}/cm^3$? (5%)

Problem 5 – Physical Vapor Depostion (19%)

(a) If the evaporation source is very far from the wafer, we can treat the evaporation fluxes to be uniform and parallel. The following contact opening has vertical SiO_2 sidewalls and the evaporating flux is making an angle of 35° with respect to the normal of the wafer's surface. If the deposition rate is 1200 Å/min, sketch the cross-sectional profile of the deposited film after 5 min. (5%)



(b) A Si wafer of 10 cm diameter with a tilting angle (φ) of 5° is placed at a height of 30 cm above a planar evaporation source. Calculate the ratio of the deposited thickness at the center to that at the edge of the wafer. (7%)



(c) What is the working principle of sputtering? (3%) What are the advantages of sputtering over evaporation? (2%)

(d) Which one of the following two pumps can achieve higher vacuum, diaphragm pump or turbomolecular pump? (2%)

Problem 6 – Etching (18%)

The silicon (100) wafer shown below has patterned silicon nitride masks on its top and bottom surfaces.

(1) With KOH, the etch selectivity between the {100} and {111} planes is 400:1 (use ∞:1 in your calculation), and the {100} etch rate is 1.4 μm/min.

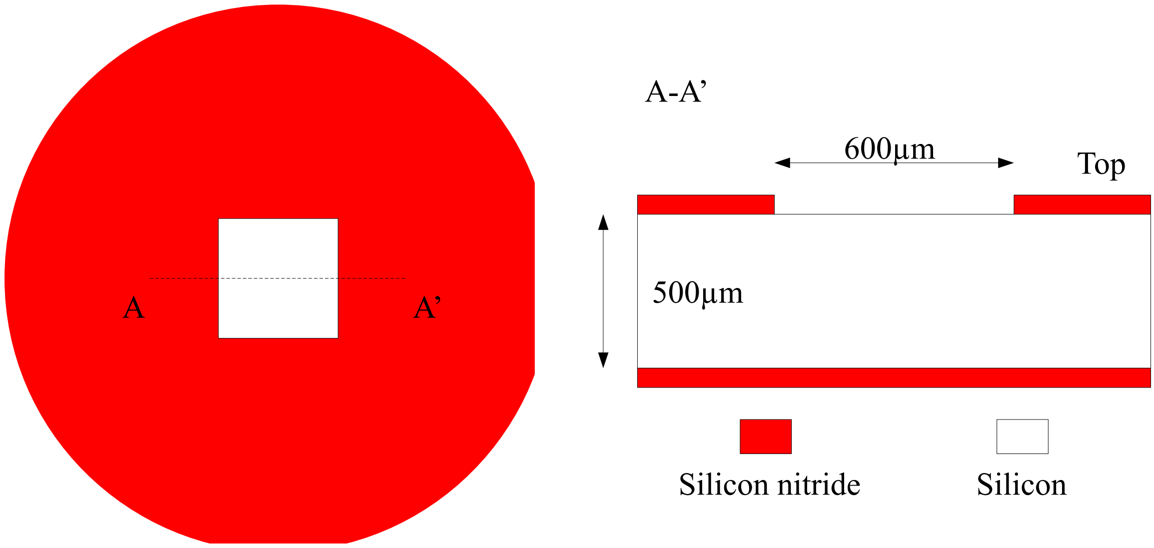
(2) With TMAH, the etch selectivity between the {100} and {111} planes is 40:1, and the {100} etch rate is 1.2 μm/min.

Assuming that the silicon nitride layers and all other silicon crystal planes are not etched, sketch the wafer cross sections after 300 minutes of etching (3%) and determine the following dimensions after etching in both KOH and TMAH cases:

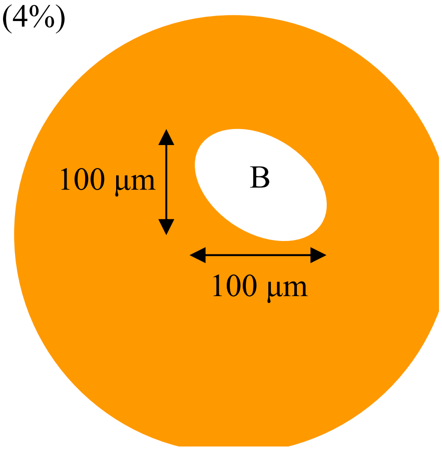
(a) Silicon etching depth (2%)

(b) Silicon etch width at top (5%)

(c) Silicon etch width at bottom (4%)



(d) In case there is an elliptic opening B on the top nitride mask, what will be the final shape of the cavity after 300 minutes of KOH etching? (Sketch both the top and cross-sectional views.) (4%)



ESS4810 Micro System Fabrication and Experiment
Midterm Exam (Fall 2007)

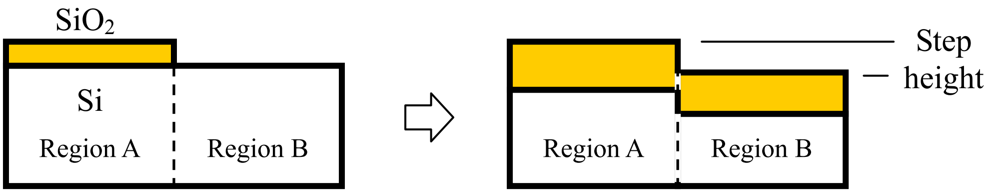
Problem 1 - Clean Room, Wafer Cleaning, and Thermal Oxidation (20%)

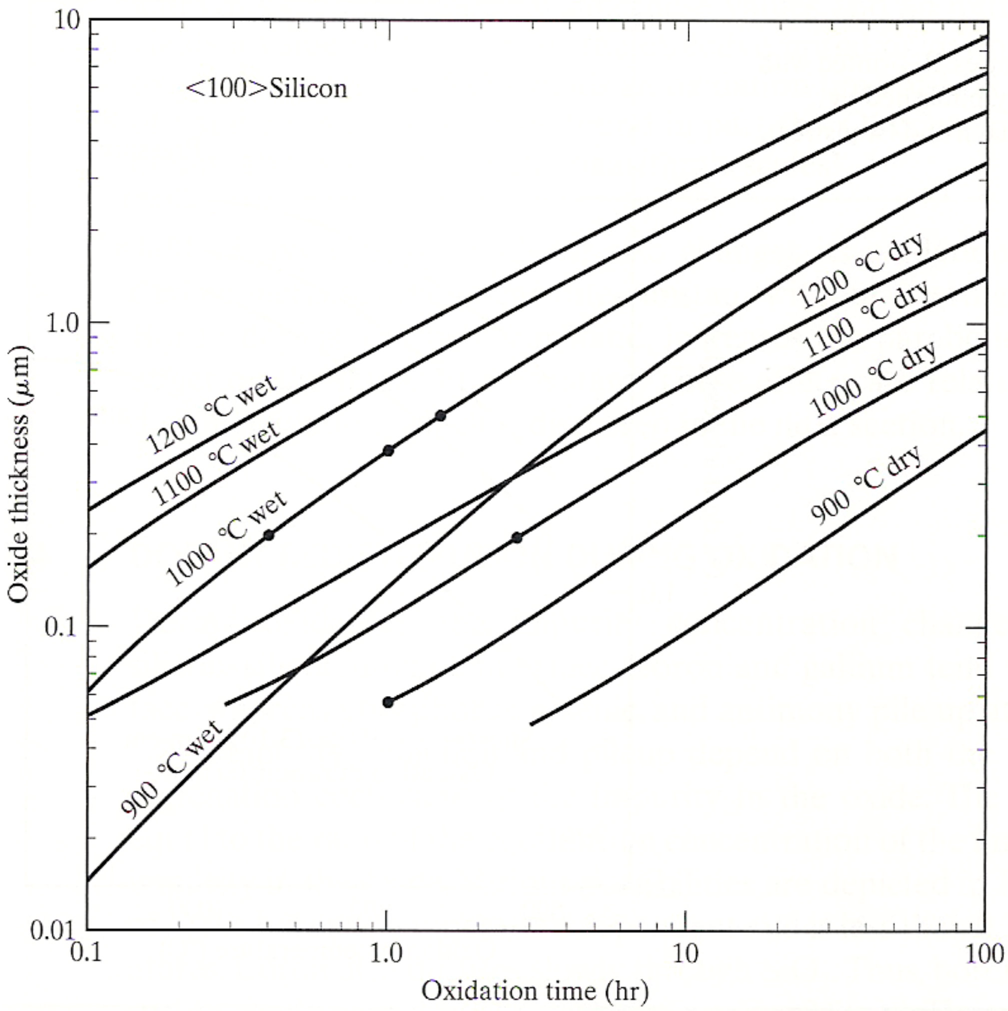
(a) List at least 3 basic requirements for a microfabrication clean room. (3%) Which one of the following two clean rooms has better control over airborne particulates, class 1 or class 100? (1.5%)

(b) List at least 3 major functions of SiO_2 in microfabrication. (2.5%)

(c) List at least 2 advantages of wet wafer cleaning over dry wafer cleaning. (2%)

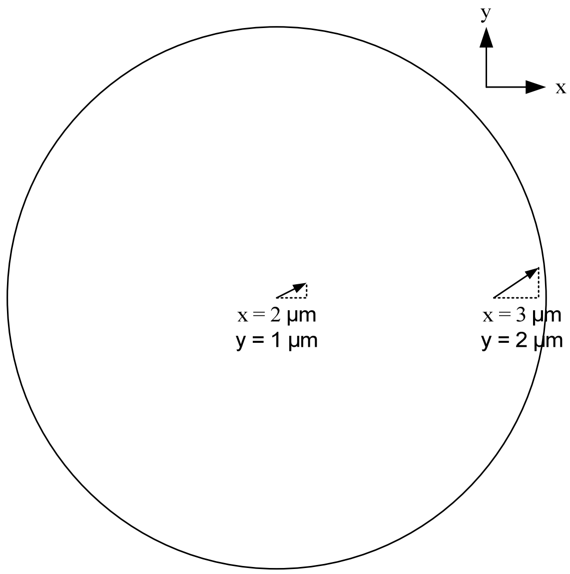
(d) A bare Si {100} wafer is oxidized for 40 minutes at 900°C in steam. After a series of lithography and etching steps, SiO_2 on half of the wafer is removed. The whole wafer is then re-oxidized in dry O_2 at 1100°C. The final oxide thickness in region A is measured to be 0.2 μm. Use the attached oxidation chart to estimate the final oxide thickness in Region B and the step height between Region A and B. (11%)





Problem 2 – Lithography (24%)

(a) We only measure the overlay errors of the Center and Right alignment marks of a 100 mm diameter wafer.



	Top	Right	Center	Left	Bottom
x	N/A	3 μm	2 μm	x_1	x_2
y	N/A	2 μm	1 μm	y_1	y_2

(i) Calculate the thermal run in (or out) error. (3%)

(ii) Calculate the rotational error (also indicate clockwise or counterclockwise in your answer). (3%)

(iii) Calculate the overlay errors of the Left and Bottom alignment marks. (6%)

(b) For projection lithography, the printable resolution R equals to $k\lambda/(NA)$ and the depth of focus DOF equals to $\lambda/2(NA)^2$. The k-factor is known as the technology factor since it depends on both diffraction and resist effects. Suppose we improve on the resist technology such that k is reduced by 25%. For fixed λ and R, calculate the percentage of change in DOF. (3%)

(c) What is the typical procedure of a photo-lithography process? (3%)

(d) List at least 2 differences between positive and negative photo-resists. (2%)

(e) Describe briefly what the so-called lift-off process is. (4%)

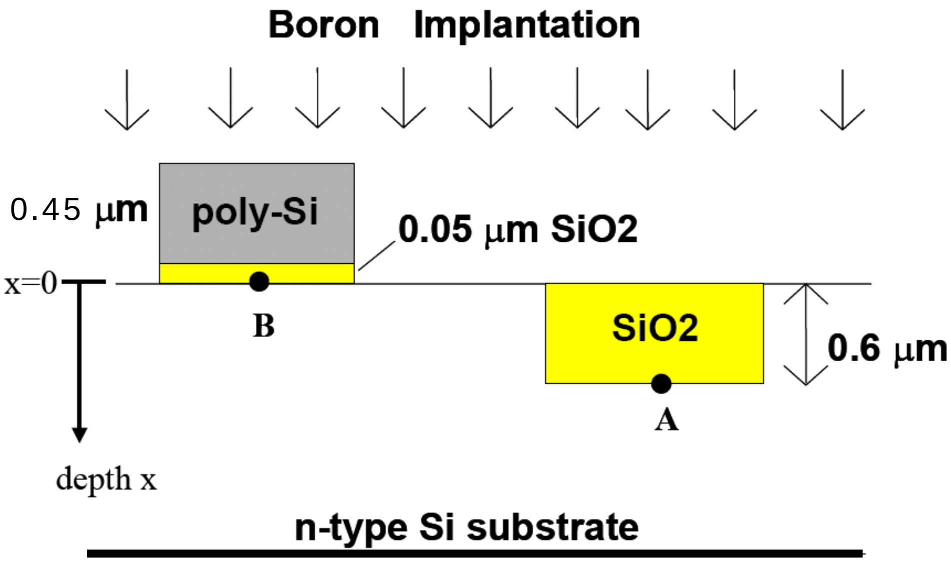
Problem 3 - Ion Implantation (17%)

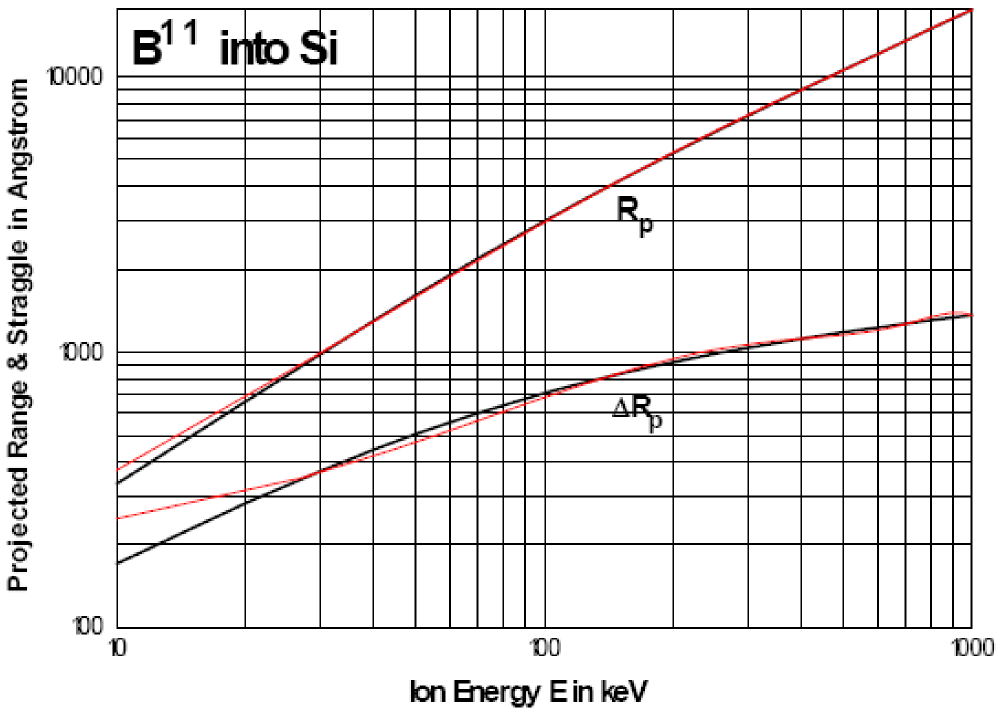
Boron implantation is performed to the following structure with a boron dose of $5\text{x}10^{13}/\text{cm}^2$. The B^+ ion energy is chosen such that the boron concentration at location B is a maximum. For simplicity, let us assume the ion stopping powers and ion scattering characteristics are identical for both silicon and silicon dioxide.

(a) What is the required B^+ ion energy? (3%)

(b) The post-implant heat-treatment is 1000°C for 30 minutes with a boron diffusion constant equal to 1.6×10^{-6} $\mu\text{m}^2/\text{sec}$. Calculate the boron concentration at location B and A. (10%)

(c) The n-type silicon substrate has a uniform doping concentration of $2\text{x}10^{15}/\text{cm}^3$. Calculate the junction depth x_j underneath location A. (4%)





Problem 4 – Diffusion (9%)

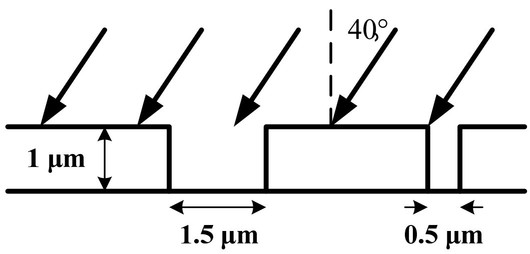
(a) Describe briefly the two-step diffusion process. (2%) List 2 disadvantages of diffusion over ion implantation (2%)

(b) A boron pre-deposition step is performed into an n-type Si substrate at 1000°C. The solid solubility of boron in silicon is known to be $3.5\times 10^{20}/cm^3$ at 1000°C and the incorporated boron dose Q is $2\times10^{15}/cm^2$. What is the junction depth x_j of the pre-deposition profile if the n-type substrate has a background concentration of $10^{15}/cm^3$? (5%)

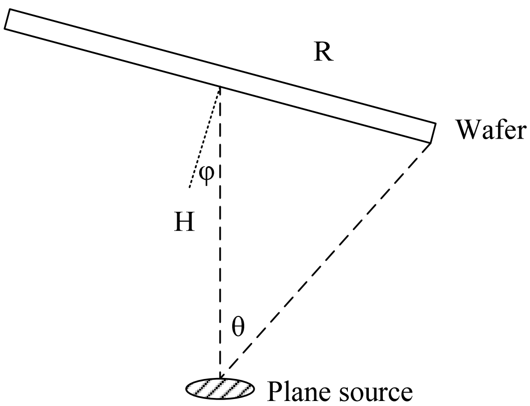
Problem 5 – Evaporation (20%)

(a) If the evaporation source is very far from the wafer, we can treat the evaporation fluxes to be uniform and parallel. The following contact opening has vertical SiO_2 sidewalls and the evaporating flux is making an angle of 40° with respect to the normal of the wafer's surface. If the deposition rate is 1000 Å/min, sketch the cross-sectional profile of the deposited film after 5 min. (5%)

Evaporation Flux



(b) A Si wafer of 10 cm diameter with a tilting angle (φ) of 10° is placed at a height of 30 cm above a planar evaporation source. Calculate the ratio of the deposited thickness at the center to that at the edge of the wafer. (7%)



(c) What are the working principles of evaporation and sputtering? (4%) Why must these processes be operated under vacuum? (2%)

(d) List 2 methods for high vacuum measurement. (2%)

Problem 6 – Etching (20%)

The silicon (100) wafer shown below has patterned silicon nitride masks on its top and bottom surfaces.

(1) With KOH, the etch selectivity between the {100} and {111} planes is 400:1 (use ∞:1 in your calculation), and the {100} etch rate is 1.5 μm/min.

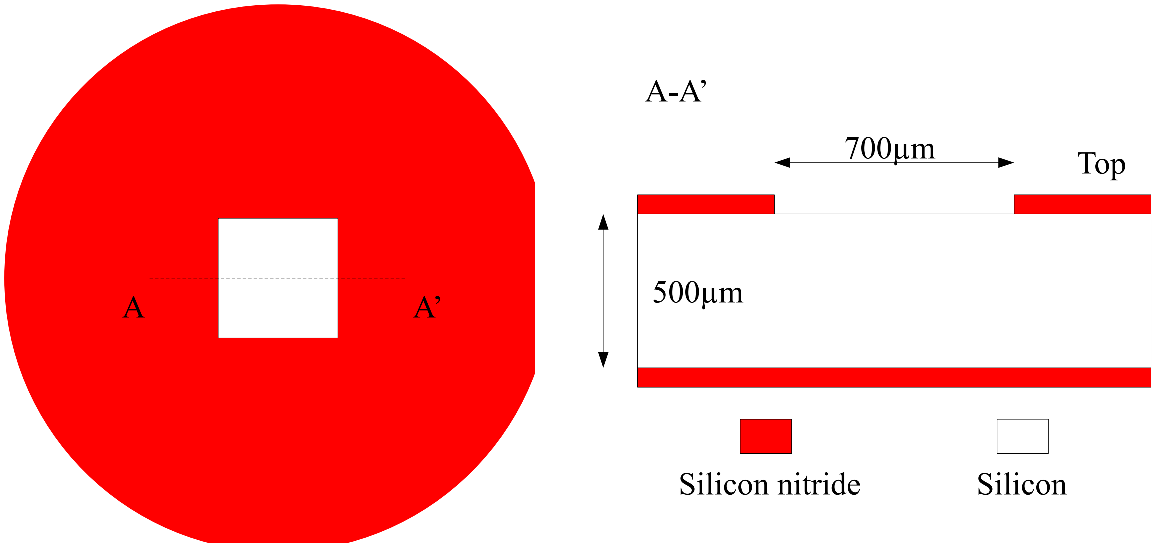
(2) With TMAH, the etch selectivity between the {100} and {111} planes is 30:1, and the {100} etch rate is 1.2 μm/min.

Assuming that the silicon nitride layers and all other silicon crystal planes are not etched, sketch the wafer cross sections after 250 minutes of etching (4%) and determine the following dimensions after etching in both KOH and TMAH cases:

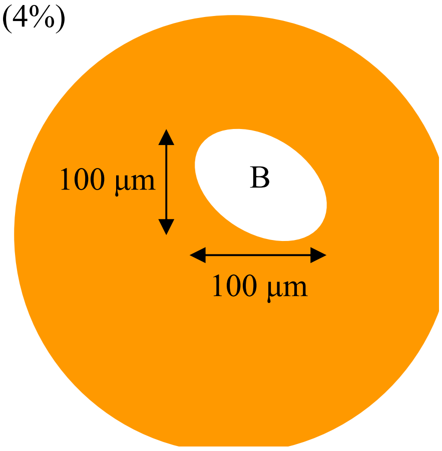
(a) Silicon etching depth (2%)

(b) Silicon etch width at top (5%)

(c) Silicon etch width at bottom (5%)



(d) In case there is an elliptic opening B on the top nitride mask, what will be the final shape of the cavity after 300 minutes of KOH etching? (Sketch both the top and cross-sectional views.) (4%)



ESS4810 Micro System Fabrication and Experiment
Midterm Exam (Fall 2006)

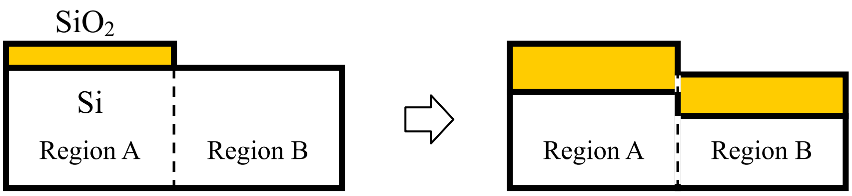
Problem 1 - Clean Room, Wafer Cleaning, and Thermal Oxidation (18%)

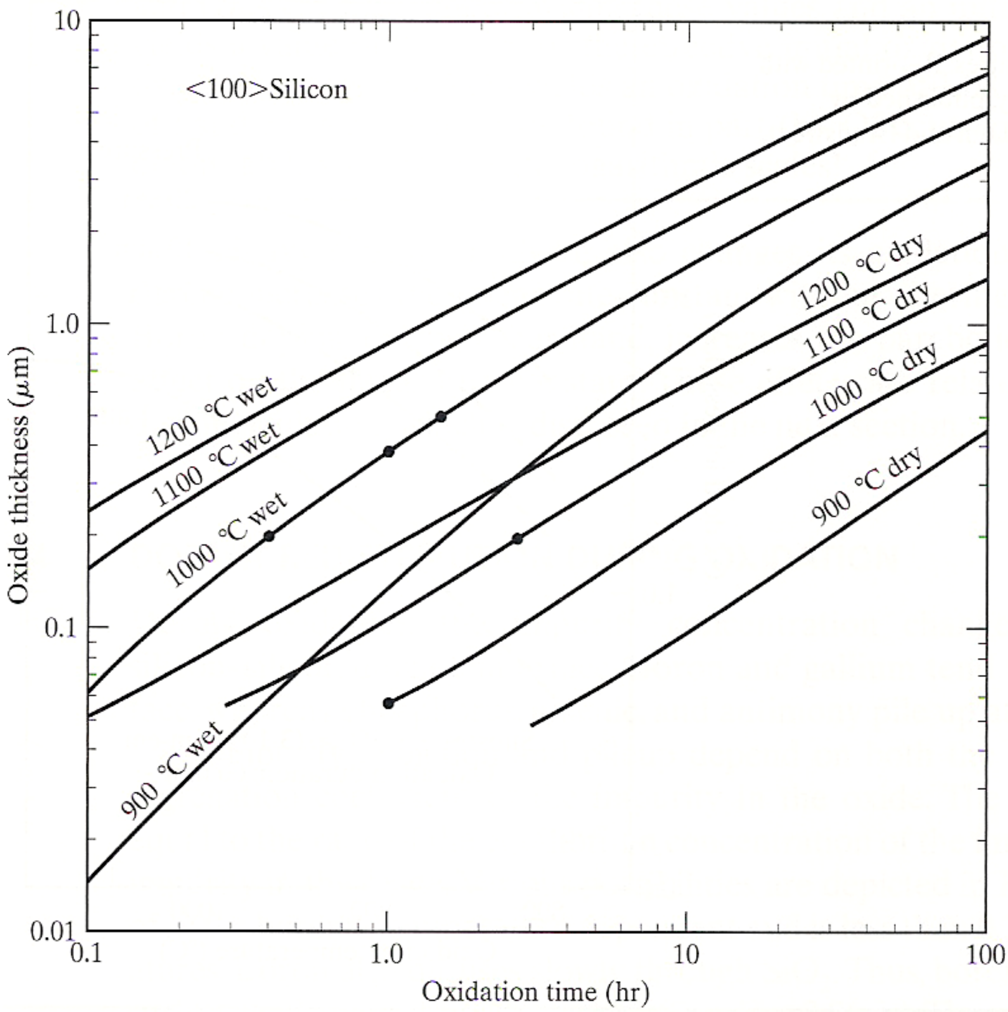
(a) What are the requirements for a microfabrication clean room? (3%) For what purposes? (2%)

(b) What are the major functions of SiO_2 in micro system fabrication? (3%)

(c) List 2 methods for wafer cleaning. (2%)

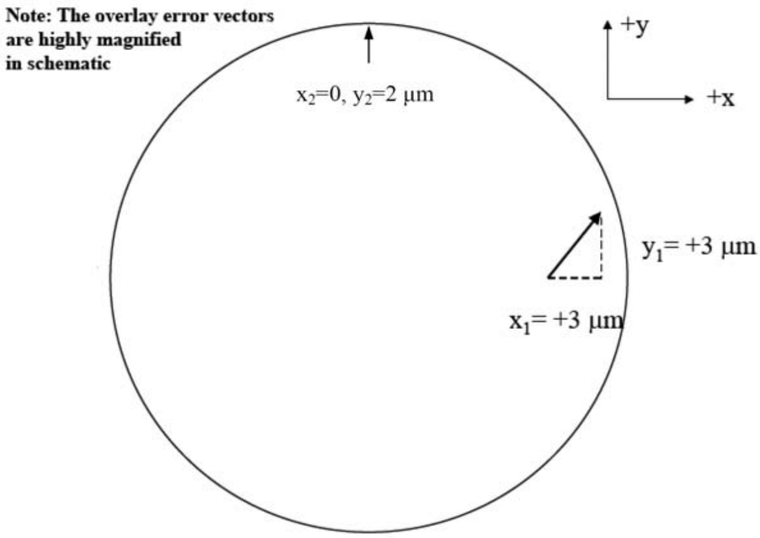
(d) A bare Si (100) wafer is oxidized for 3 hours at 1200°C in dry O_2. After a lithographic and etching step SiO_2 on half of the wafer is removed. The whole wafer is then re-oxidized in steam at 1000°C. The final oxide thickness in region A is measured to be 1 μm. Use the oxidation chart to estimate the oxide thickness in Region B. (8%)





Problem 2 – Lithography (17%)

(a) We only measure the overlay errors for the Right and Top alignment marks near the edge of a 100 mm diameter wafer.



	Top	Right	Center	Left	Bottom
x	0	+3 μm	x_t (Not measured)	Not measured	Not measured
y	2 μm	+3 μm	y_t (Not measured)	Not measured	Not measured

(i) Calculate the x and y components of the translational error (x_t, y_t). (5%)

(ii) Calculate the thermal run in / run out error. (3%)

(iii)Calculate the rotational error (also indicate clockwise or counterclockwise in your answer). (3%)

(b) What is the typical procedure of a photo-lithography process? (3%)

(c) What are the differences between positive and negative photo-resists? (3%)

Problem 3 - Ion Implantation (19%)

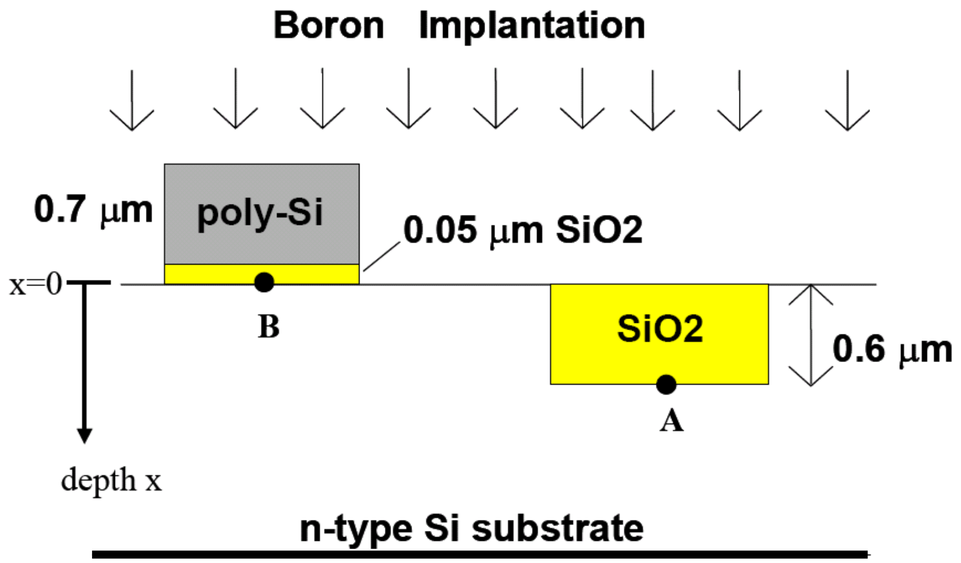
Boron implantation is performed to the following structure with a boron dose of $2.5 \times 10^{13}/cm^2$. The B^+ ion energy is chosen such that the boron concentration at location B is a maximum. For simplicity, let us assume the ion stopping powers and ion scattering characteristics are identical for both silicon and silicon dioxide.

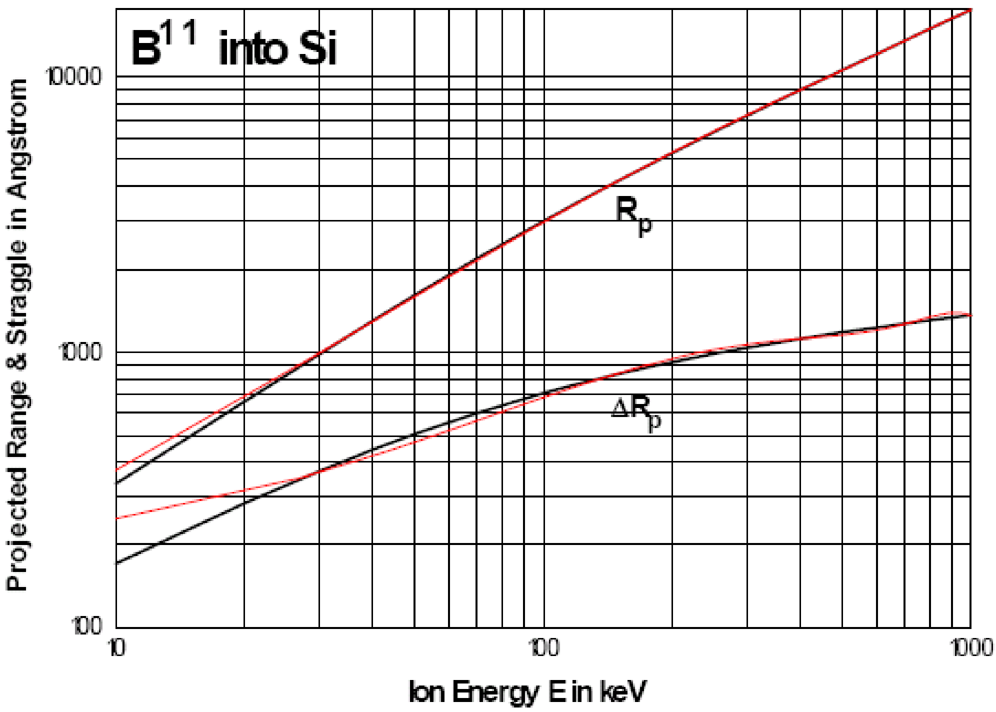
(a) What is the B^+ ion energy? (3%)

(b) Calculate the boron concentration at location B and A. (8%)

(c) The n-type silicon substrate has a uniform doping concentration of $2 \times 10^{15}/cm^3$. Calculate the junction depth x_j underneath location A. (4%)

(d) What are the advantages of ion implantation over diffusion? (4%)





Problem 4 – Diffusion (14%)

(a) Describe the two-step diffusion process in details. (4%)

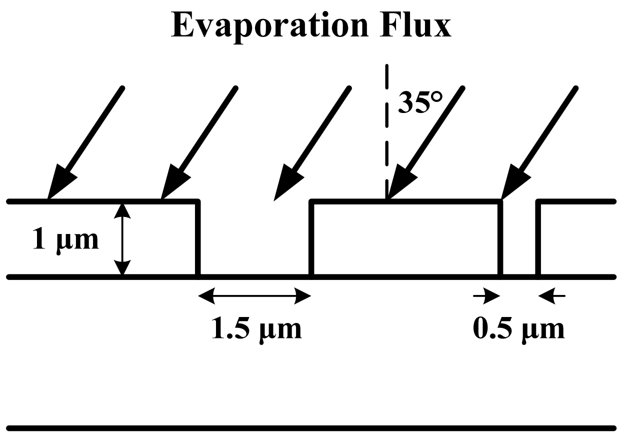
(b) Boron pre-deposition step is performed into an n-type Si substrate at 1000°C. Boron solid solubility at 1000°C is known to be 3.5× 10^{20}/cm^3 and the incorporated boron dose Q is 3 ×10^{15}/cm^2.

(i) What is the Dt product of the pre-deposition process? (5%)

(ii) What is the junction depth x_j of the pre-deposition profile if the n-type substrate has a background concentration of 10^{15}/cm^3? (5%)

Problem 5 – Evaporation (16%)

(a) If the evaporation source is very far from the wafer, we can treat the evaporation fluxes to be uniform and parallel. The following contact opening has vertical SiO_2 sidewalls and the evaporating flux is making an angle of 35° with respect to the normal of the wafer's surface. If the deposition rate is 1200 Å/min, sketch the cross-sectional profile of the deposited film after 5 min. (7%)



(b) What are the working principle of evaporation and sputtering? (5%) Why must these processes be operated under vacuum? (2%)

(c) List 2 methods for vacuum measurement. (2%)

Problem 6 – Etching (16%)

The silicon {100} wafer shown below has patterned silicon nitride masks on both top and bottom surfaces.

(1) With KOH, the etch selectivity between the {100} and {111} planes is 400:1 (use ∞:1 in your calculation), and the {100} etch rate is 1.4 μm/min.

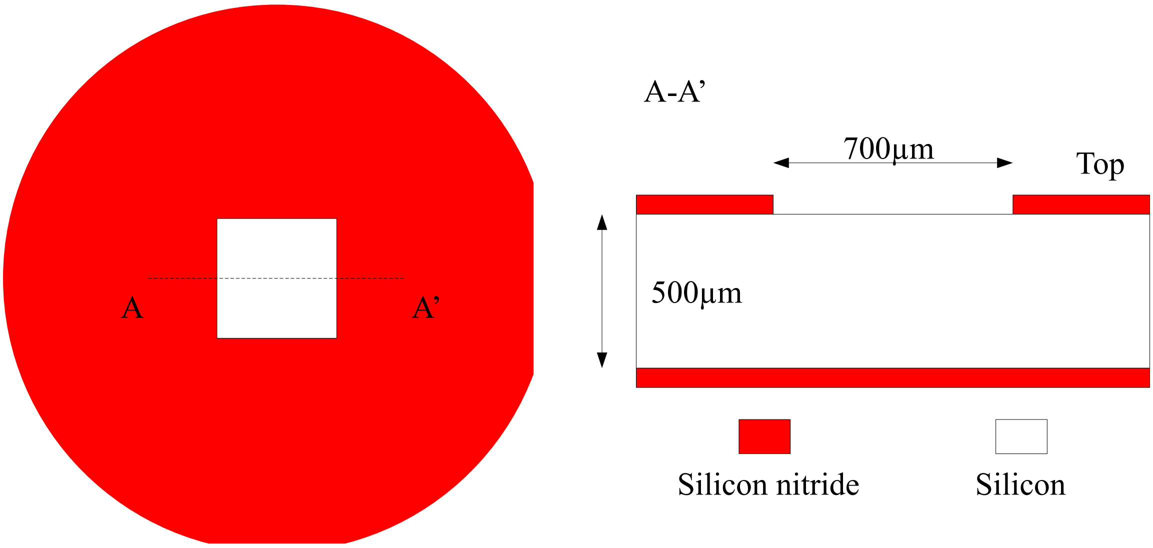
(2) With TMAH, the etch selectivity between the {100} and {111} planes is 40:1, and the {100} etch rate is 1.1 μm/min.

Assuming that the silicon nitride layer and all other silicon crystal planes are not etched, sketch the wafer cross section after 300 minutes of etching (3%) and determine the following dimensions after etching in both KOH and TMAH cases:

(a) Silicon etching depth (2%)

(b) Silicon etch width at top (4%)

(c) Silicon etch width at bottom (4%)



(d) In case there is an elliptic opening B on the nitride mask, what will be the final shape of the cavity after 300 minutes of KOH etching? (3%)