Homework Assignment # 3 (Due 9/24, Friday, 9am)

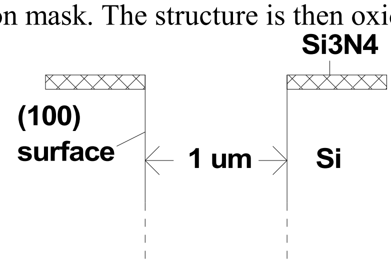
Reading Assignments

1) Chapter 3 of Jaeger on Thermal Oxidation
2) Reprint – Chapter 9 of Mayer and Lau on Thermal Oxidation.

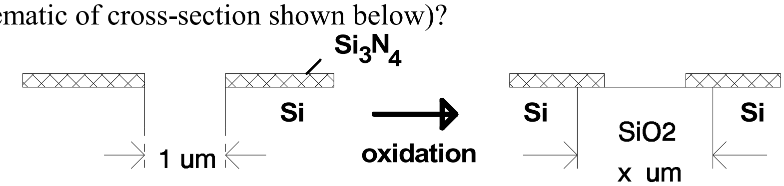
***There will be discrepancy in x_{ox} , B, and B/A values due to curve reading errors. As long as your methodology is correct and your answer is not way off, there will be no penalty on "wrong" numerical answers. Also, there will be difference between oxide growth charts (x_{ox} versus t) and algebraic method (B, and B/A) because the data were taken from different sources.**

Problem 1 Si consumed during thermal oxidation

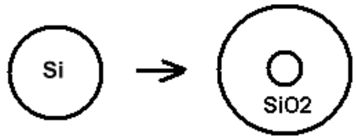
(a) A very deep vertical groove 1 μm wide is etched in Si . The Si surface is covered by Si_3N_4 which serves as an oxidation mask. The structure is then oxidized in steam at 1100°C.



What is the width of the SiO_2 (x in mm) after the groove is completely filled with oxide (idealized schematic of cross-section shown below)?

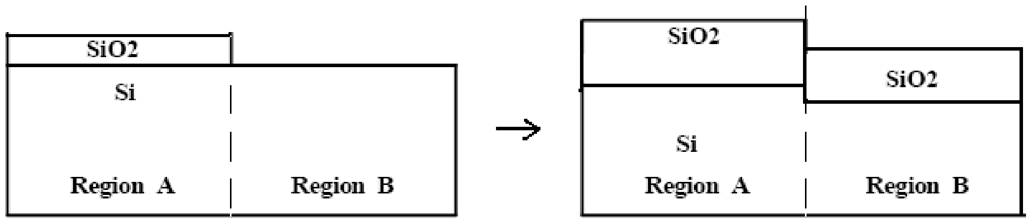


(b) Pure Si contains 5×10^{22} Si atoms per cm^3 and SiO_2 contains 2.3×10^{22} SiO_2 molecules per cm^3. A long cylindrical Si rod of radius 100nm is oxidized and a 100nm-thick SiO_2 sheath is formed. What is the radius of Si region in the middle? Assume cylindrical symmetry is maintained during thermal oxidation and ignore any effects caused by stress. (This Si consumption technique is one method to fabricate silicon nanowires down to 10nm in diameter. In reality, large stress produced in the silicon rod oxidation changes the oxidation rate and volume)

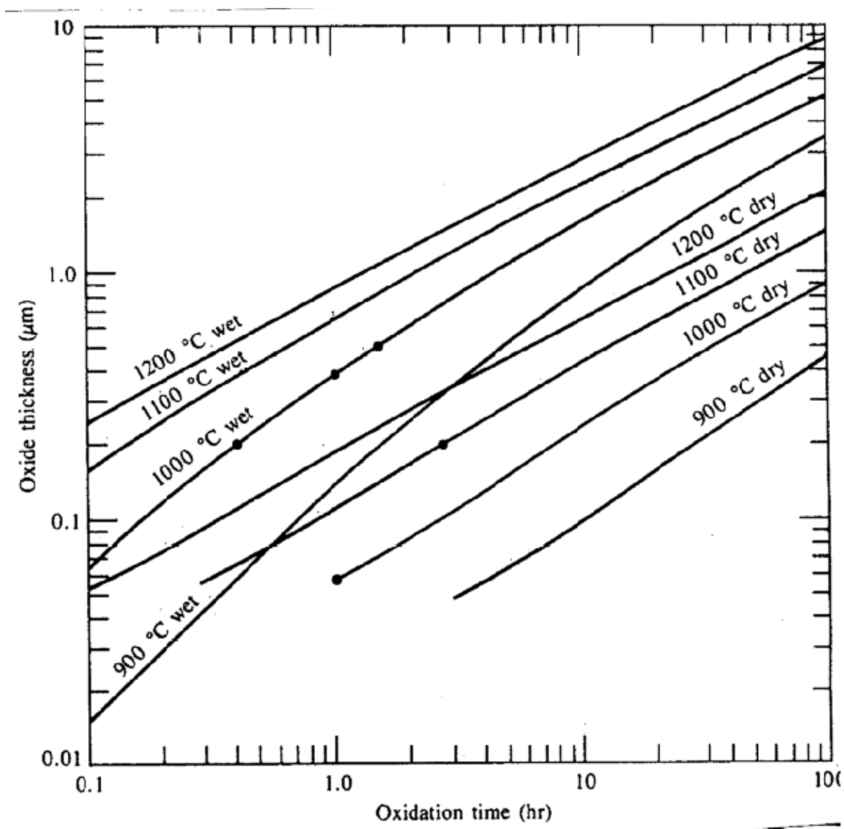


Problem 2 How to use oxidation charts

A bare Si (100) wafer is oxidized for 1 hour at 1100°C in dry O_2. It is then photomasked and has the oxide removed over half the wafer. The whole wafer is re-oxidized in steam at 1000°C for 30 minutes. Use the oxidation charts in Jaeger (attached in this HW assignment) to ***estimate*** the final oxide thickness in Region A and Region B



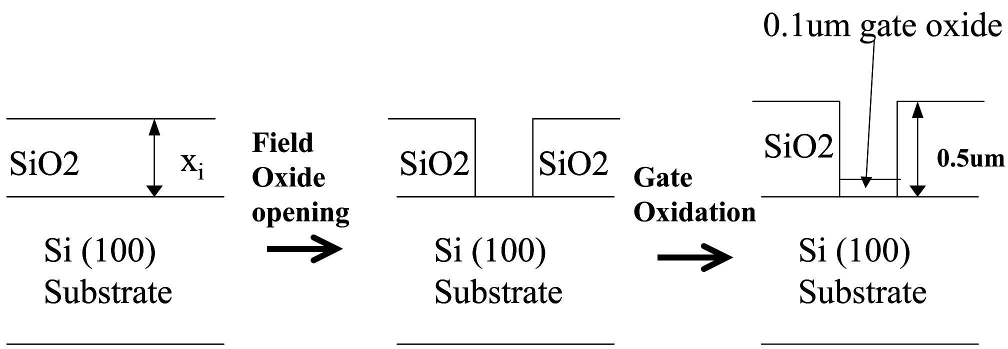
Reference Figure for Problem 2



Wet and dry silicon dioxide growth for ⟨100⟩ silicon

Problem 3 Oxidatiom calculation given B and B/A values

(a) An oxidized Si wafer has an initial field oxide thickness of x_i. Patterned windows of the field oxide are completely cleared by etching. Dry O_2 at 900°C is then used to grow a thin gate oxide in these cleared regions.



Schematic cross-sections (Si consumption effect not shown)

(i) Find the oxidation time to grow 0.1μm of gate oxide ? [Given : B = 5600 (Å $)^2$/min, $\frac{B}{A}$ = 2 Å /min] [Note : 1 **Å** = 10 $^{-4}$ μm]

(ii) After the 0.1 μm gate oxidation step, total thickness in the field oxide region is found to be 0.5 μm. What is the original field oxide thickness x_i?

(b) After the oxidation steps described in part (a) , buffered HF is used to strip off all oxides. What is the step height in the Si substrate.

Problem 4 Deal-Grove Model Calculations

A Si wafer has an unknown initial oxide thickness $\mathbf{x_i}$. The wafer then goes through a particular oxidation process with a linear oxidation constant B/A =1.2 μm /hour and a parabolic oxidation constant B = 0.3 μm^2/hour. After thermal oxidation for 1 hour, the total oxide thickness is measured to be **x** μm. With an ***additional*** 3 hours of oxidation, the total oxide thickness becomes **2x** μm. Find the numerical values of **x** and $\mathbf{x_i}$**.**

[Hint: The solution for the quadratic equation $ax^2 + bx + c = 0$ is $x = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$]

Problem 5 LOCOS and Dopant Redistribution

In a Local Oxidation Process (LOCOS), the whole Si wafer is first oxidized to a 1000 Å pad-oxide thickness. The active regions are then masked with Si_3N_4 and the wafer is further oxidized (1000°C in steam) until the field oxide reaches the desired 5000 Å thickness.

(i) Draw a cross-sectional view showing the pad oxide, field oxide, and transition regions.

(ii) Calculate the oxidation time required for the steam oxidation step. For 1000 °C, steam oxidation: B = 5.2 ×10^5 (Å $)^2$/minute , $\frac{B}{A}$ = 111 Å /min

(iii) If the starting Si substrate is uniformly doped with arsenic, compare the arsenic concentration in Si just below the SiO_2 at the pad oxide region and that of the field oxide region. Which one is relatively higher ? Describe your reasoning.

Problem 6 Why non-ideal Deal-Grove behavior? (Past exam question)
A lightly doped Si wafer was processed by some unknown IC processing steps. You then perform a thermal oxidation experiment [fixed temperature and fixed oxidizing ambient] with this wafer and observed the following results:

Oxidation Time	**SiO_2 Thickness**
0 hour	0
1 hour	2000 Å
4 hours	2500 Å

We now try to deduce the unknown IC processing steps experienced by the Si wafer. Are the following conjectures consistent with the observed oxidation results (TRUE or FALSE)? You have to give brief explanations to justify your answers.

Conjecture 1: The processed Si wafer was oxidized first to an oxide thickness of 100 **Å** and then have the oxide dissolved in HF.
Conjecture 2: The processed Si wafer has a highly doped surface layer (doping>$10^{19}/cm^3$) which is less than 1000 Å thick.
Conjecture 3: The processed Si wafer has a thin layer of poly-Si layer on top surface.