

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

EE143 Midterm Exam #1

Family Name _____ First name _____ SID _____

Signature _____

Make sure the exam paper has 9 pages (including cover page) + 3 pages of data for reference

Instructions: DO ALL WORK ON EXAM PAGES

This is a 90-minute exam (4 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) _____

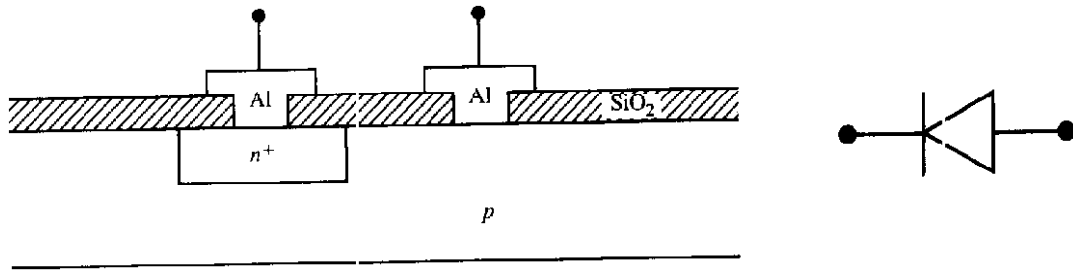
Problem 2 (25 points) _____

Problem 3 (25 points) _____

Problem 4 (25 points) _____

TOTAL (100 points) _____

Problem 1 Simple Process Sequence (25 points total)



The cross-section of a pn diode is sketched in the above figure.

(a) (10 points) Starting with a p-type Si wafer, describe the process sequence (in the left column) and sketch the cross-sections of the structure after each lithography step (in the right column)

Process Description

Cross-section

Starting material : p-type wafer

Problem 1 continued

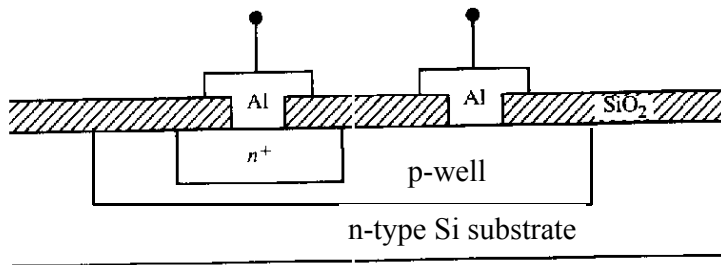
(b) (5 points) How many etching steps are used in this process sequence? List each one and describe their purpose. [DO NOT count photoresist development as etching step]

(c) (4 points) Circle the correct answer

The Al/n⁺ Si interface forms (1) a **tunneling ohmic contact** (2) a **Schottky ohmic contact**

The Al/p- Si interface forms (1) a **tunneling ohmic contact** (2) a **Schottky ohmic contact**

(d) (6 points) You probably recognize that the pn diode structure of part (a) has no electrical isolation with neighboring devices. Electrical isolation can be implemented by fabricating the diode with a p-well.



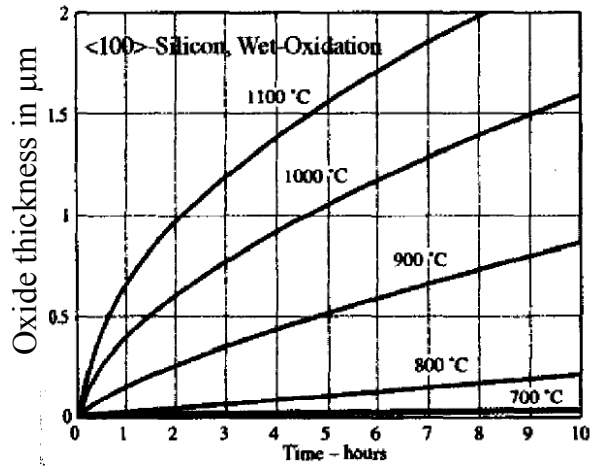
Describe the **changes** to your process sequence of part (a) such that you can implement this new structure. Note that the starting Si wafer now is n-type.

Problem 2 Thermal oxidation (25 points total)

The following Dry Oxidation and Wet Oxidation data are available for thermal oxidation of <100> Si wafers

**Rate constants for Dry Oxidation
<100> Si**

Oxidation Temp (°C)	B (μm ² /hr)	B/A (μm/hr)
1200	0.045	0.667
1100	0.027	0.178
1000	0.0117	0.042

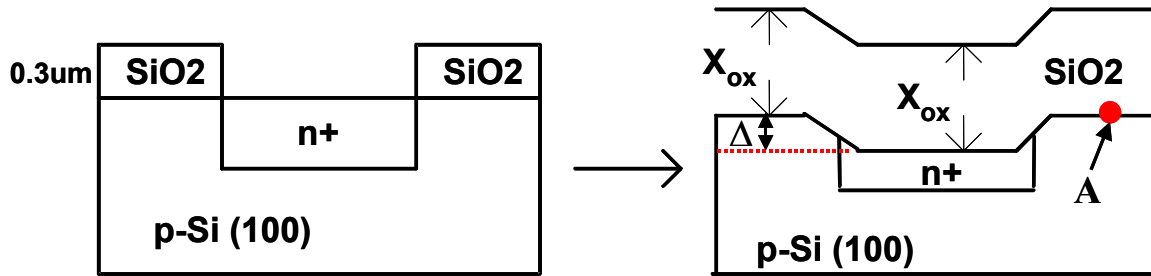


- (a) (6 points) A Si wafer has an initial oxide thickness of 0.5 μm. With **Wet-Oxidation** at 1000°C, what is the required oxidation time to obtain a total thickness of 1 μm?
- (b) (6 points) The oxidized wafer of part (a) is further subjected to **Dry-Oxidation** at 1000°C. What is the oxidation rate (in μm/hr) when the oxide has a total thickness = 2 μm?

Problem 2 continued

(c) Heavily doped Si has more charged point defects near the oxide/Si interface. The linear rate constant (B/A) increases for heavily doped Si but the parabolic rate constant (B) remains the same. The following oxide window has an initial oxide thickness = 0.3 μm . After oxidation for a certain time t , the **final** oxide thickness X_{ox} is found to be equal over both n^+ and p regions.

Given : $(B/A)_{n^+} = 4 (B/A)_p = 0.4 \mu\text{m}/\text{hour}$; $(B)_{n^+} = (B)_p = 0.15 \mu\text{m}^2 / \text{hour}$



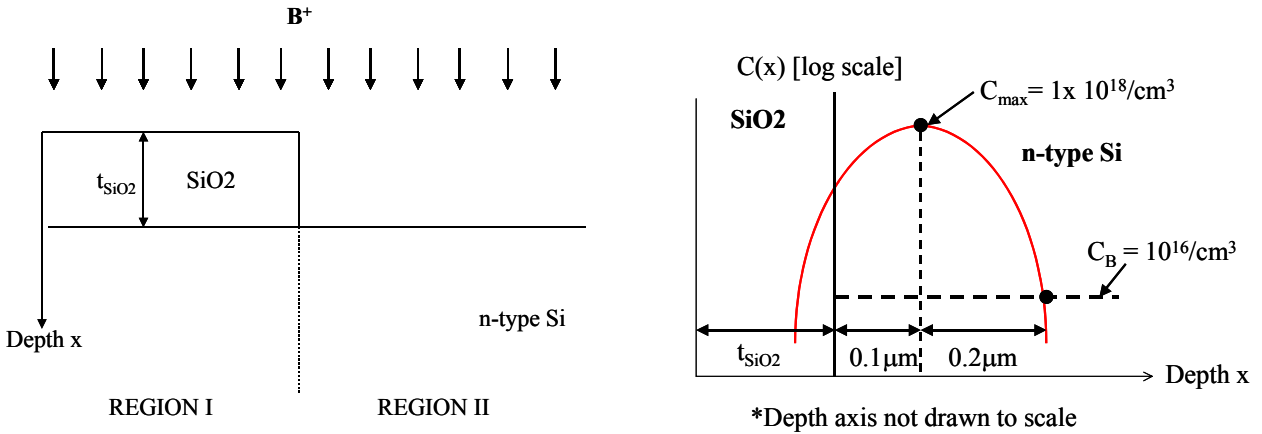
(i) (4 points) Calculate the Si substrate step height Δ .

(ii) (4 points) Do you expect the boron concentration at point A (see figure) has a higher or lower concentration than the original substrate? Briefly explain.

(iii) (7 points) Calculate this final oxide thickness X_{ox} .

Problem 3 Ion Implantation (25 points total)

(A) Boron ions (B^+) are implanted into an n-type Si wafer with background doping concentration of $10^{16}/\text{cm}^3$. Region I of the wafer is covered with SiO_2 with thickness t_{SiO_2} and Region II has no oxide. The boron concentration $C(x)$ versus depth x for Region I is sketched in the figure below. For simplicity, let us assume the SiO_2 and Si have identical energy stopping powers.



(a) (6 points) What is the kinetic energy of the B^+ ions (in keV) ?

(b) (2 points) What is the boron implantation dose (in $\#/\text{cm}^2$) ?

(c) (2 points) What is the thickness of the SiO_2 (t_{SiO_2}) ?

(d) Calculate the **sheet resistance R_S of Region II** (i.e., the no oxide region) using the following two different methods :

(i) (3 points) The approximate expression $R_S \sim 1/(q \cdot \mu_{\text{effective}} \cdot \text{dose})$

(ii) (4 points) The Irvin's curves

Problem 3 continued

(B) (4 points) Explain in your own words what is solid phase epitaxial growth (SPEG) of Si after the Si crystal is subjected to a high dose implantation step. Use sketches to illustrate your ideas if necessary.

(C) (4 points) Explain in your own words why a higher dose of boron ions is needed to transform crystalline Si into amorphous Si as compared with arsenic ions.

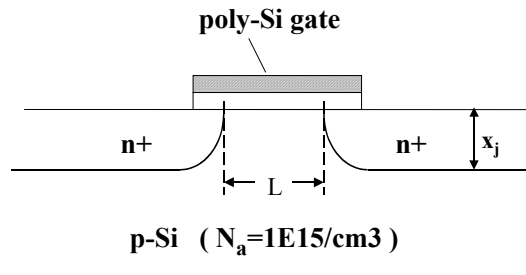
Problem 4 Diffusion (25 points total)

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

(i) (5 points) What is the Dt product of the predeposition process?

ii) (5 points) What is the junction depth x_j of the predeposition profile if the n-type substrate has a background concentration of $10^{15}/\text{cm}^3$.

(b) Three doping recipes are proposed to form the source and drain of a MOS transistor.



(Process A) Shallow diffusion predeposition dose of Q phosphorus atoms /unit area, followed by a drive-in at 1100°C for 60 minutes.

(Process B) Shallow diffusion predeposition dose of Q phosphorus atoms /unit area, followed by a drive-in at 1150°C for 30 minutes.

(Process C) Shallow implantation dose of Q phosphorus atoms / unit area, followed by a drive-in at 950°C for 10 minutes

Use the following diffusivity values and neglect high-concentration diffusion effects:

TEMPERATURE	D (Phosphorus)
950°C	$5 \times 10^{-5} \mu\text{m}^2 / \text{min}$
1100°C	$2 \times 10^{-3} \mu\text{m}^2 / \text{min}$
1150°C	$5 \times 10^{-3} \mu\text{m}^2 / \text{min}$

Problem 4 continued

(i) (5 points) Which process will give the **shortest** MOSFET channel length **L** ? Explain your reasoning.

(ii) (4 points) If the substrate doping N_a is increased , which of the three processes will exhibit the **biggest change** in channel length **L** ? Use a qualitative sketch to illustrate your reasoning.

(iii) (6 points) Doping concentration of source and drain regions are typically larger than $10^{20}/\text{cm}^3$. Indicate with an “**X**” in the following table for those effects which will increase the dopant diffusivity.

	E-field Enhancement	Charge Point Defects	Transient Enhanced Diffusion
Process A			
Process B			
Process C			

Information which may be useful

$1 \mu\text{m} = 10^{-4} \text{cm} = 1000\text{nm} = 10^4 \text{\AA}$

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

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

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

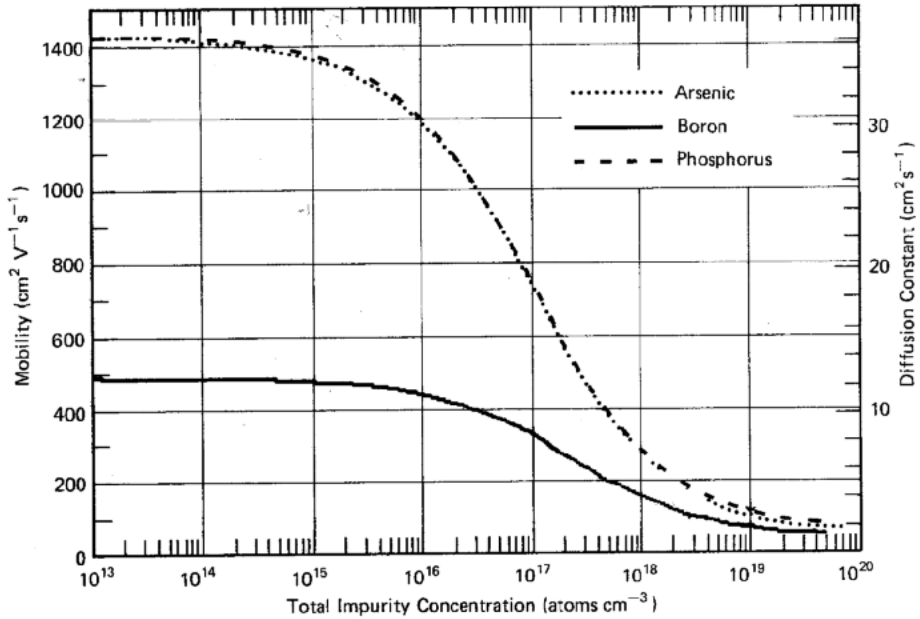
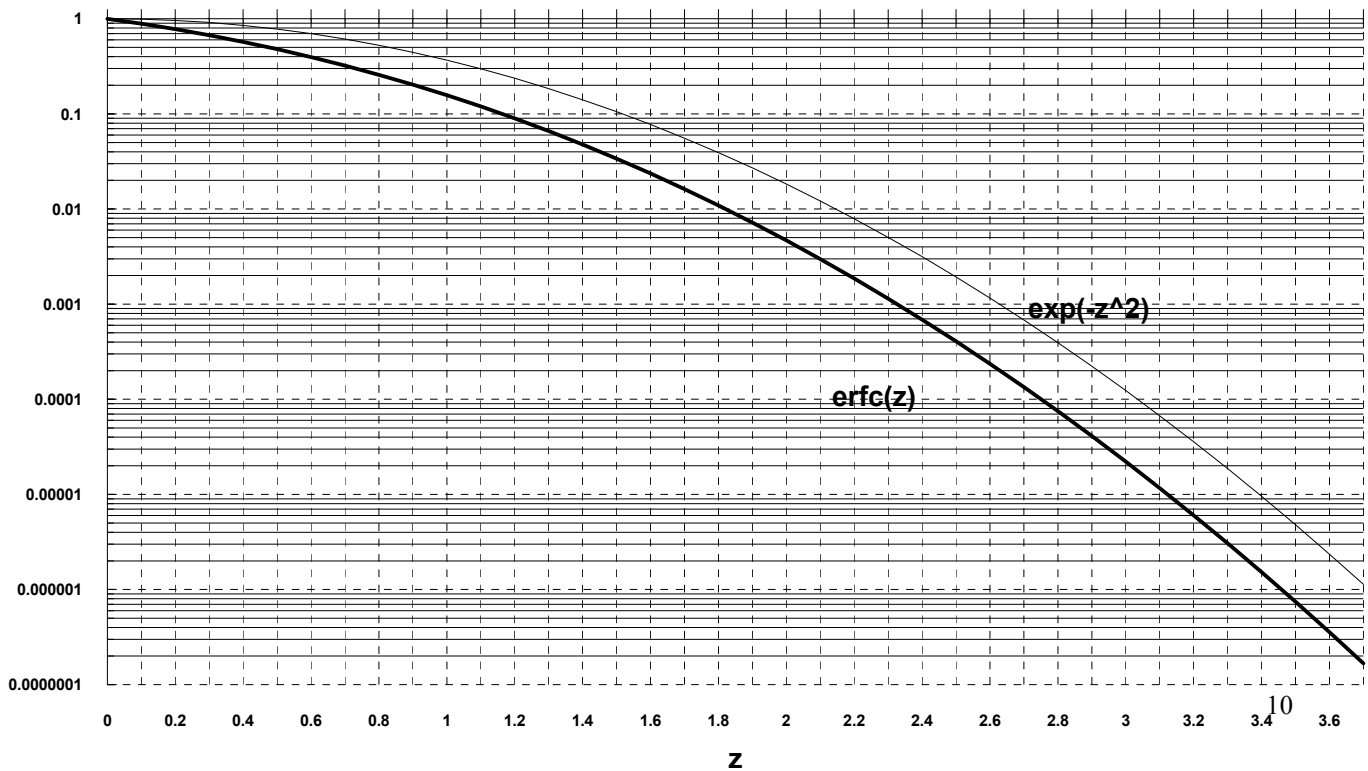
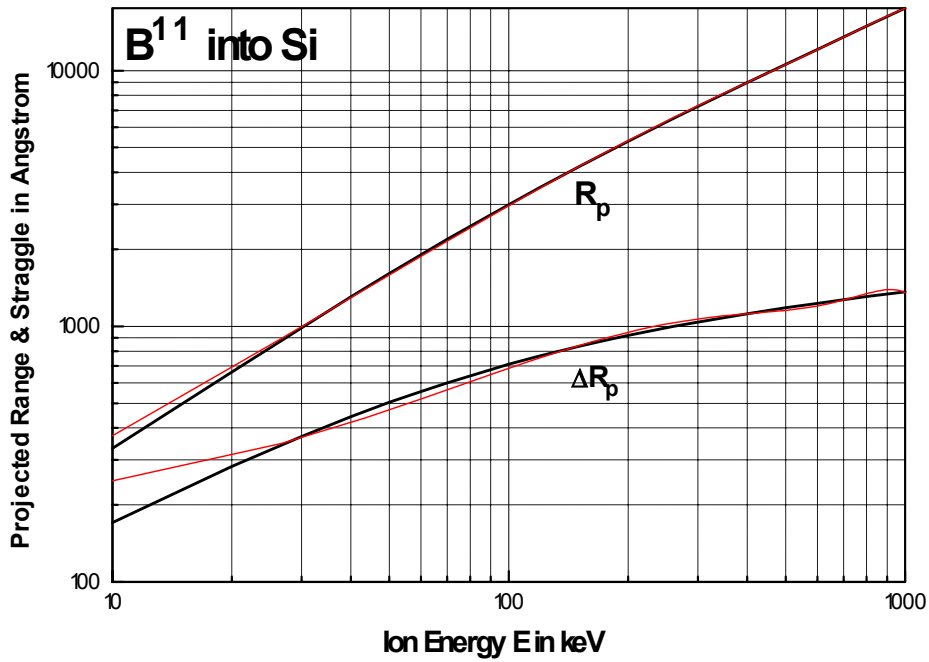


Figure 1.15 Electron and hole mobilities in silicon at 300 K as functions of the total dopant concentration. The values plotted are the results of curve fitting measurements from several sources. The mobility curves can be generated using Equation 1.2.10 with the following parameter values:³



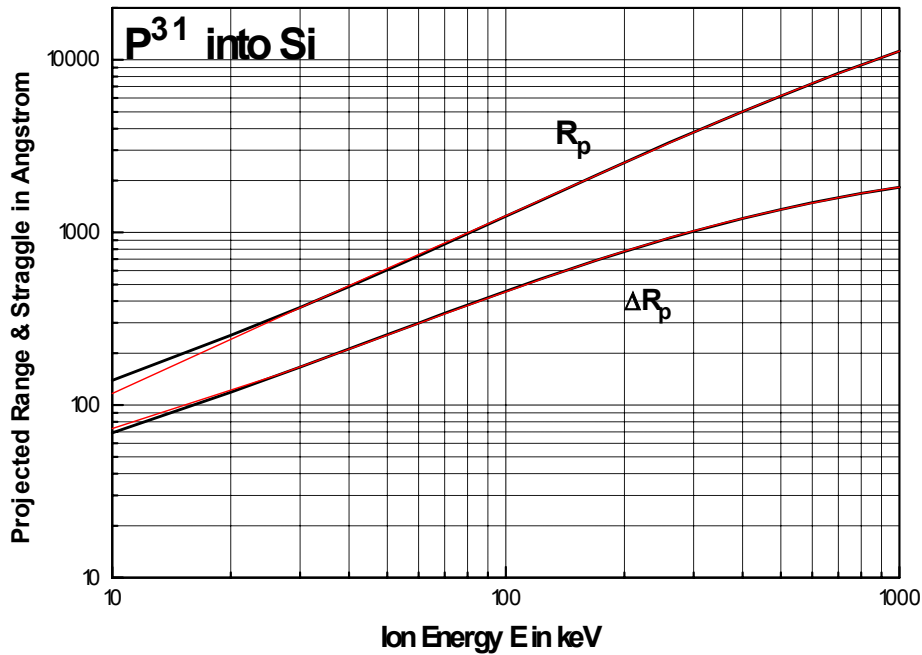
$$R_p = 51.051 + 32.60883 E - 0.03837 E^2 + 3.758e-5 E^3 - 1.433e-8 E^4$$

$$\Delta R_p = 185.34201 + 6.5308 E - 0.01745 E^2 + 2.098e-5 E^3 - 8.884e-9 E^4$$



$$R_p = 7.14745 + 12.33417 E + 0.00323 E^2 - 8.086e-6 E^3 + 3.766e-9 E^4$$

$$\Delta R_p = 24.39576 + 4.93641 E - 0.00697 E^2 + 5.858e-6 E^3 - 2.024e-9 E^4$$



Irvin Curves

