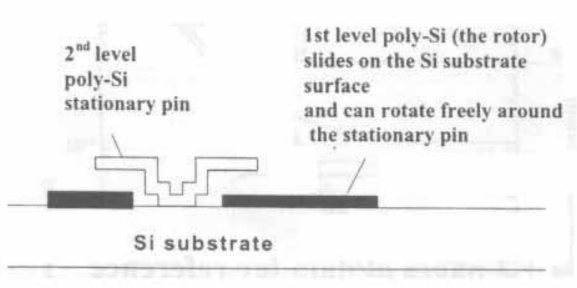
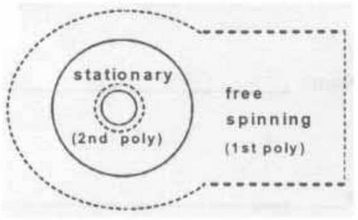
Problem 1 Sample Process Sequence (30 points total)

(a) (20 points) Using surface micromachining, a **pin joint** can be fabricated with the cross-section and top view show below. The pin joint has a stationary pin (the anchor) on the wafer surface and a free spinning rotor which slides on top of the wafer surface. Note that the top of the stationary pin has a dimension larger than that of the rotor inner hole to keep the rotor in place.





You find the following brief description of the process flow in the notebook of a former EE 143 student. Sketch the cross-sections and top views at the highlighted processing steps (marked by bold font).

Process Description	**Cross-Sections**	**Top Views**
Starting Material – Pure Si wafer	-------------------------------- Si substrate --------------------------------	
Deposit 1st level Phosphosilicate Glass (PSG) by CVD		
Deposit of 1st level Poly-Si by CVD		
Pattern 1st level poly-Si (Mask #1)		
Deposit 2nd level PSG		
Pattern opening for stationary pin(Mask #2)		
Deposit 2nd level poly-Si by CVD		
Pattern 2nd level poly-Si		
Selectively etch away 1st level And 2nd level PSG using HF acid		
Final Structure		

Problem 1 continued

(b) The following qualitative questions are related to the process flow in part (a). No partial credit will be given without and explanation or discussion.

(I) (3 points) To reduce the inertia of the rotor, some former EE 143 students proposed to replace the 1st level poly-Si with photoresist. Will this replacement be compatible with the process sequence?

(II) (3 points) Instead of depositing the 2nd level PSG by CVD, can we use thermal oxidation to form the 2nd level oxide? Discuss why or why not?

(III) (4 points) The process flow in part (a) uses two separate poly-Si deposition. Can we fabricate the device with only one layer of poly-Si? Explain why or why not?

Problem 2 Thermal oxidation (23 points total)

(a) (6 points) For a particular thermal oxidation process, it is known that the oxidation rate (dx_{ox}/dt) is 0.24 µm/hour when the oxide thickness is 0.5µm and it slows down to 0.133 µm/hour when the oxide thickness is 1 µm. Find the linear oxidation constant (B/A) and the parabolic oxidation constant B. Give answers in proper units.

(b) In a Local Oxidation Process (LOCOS), the whole Si wafer is first oxidized to a 1000 A 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 A thickness.

(i) (3 points) Draw a cross-sectional view showing the pad oxide, field oxide, and transition regions.

(ii) (6 points) Calculate the oxidation time required for the steam oxidation step. For 1000 °C, steam oxidation: $B = 5.2 \times 10^5\ (A)^2$/minute, B/A = 111 A/min.

(iii) (3 points) If the starting Si substrate is uniformly doped with arsenic, will the arsenic concentration in Si just below the SiO_2 be higher, same, or lower at the pad oxide or the field oxide region? Explain?

(c) (5 points) List several processing advantages of growing a thermal oxide at high oxidant gas pressure.

Problem 3 Ion Implantation (23 points total)

(a) (9 points)
An ion implanter with an accelerating voltage of 50kV is used to implant the following ions into Si to an ion does of 10^{15} ions/cm^2 . Use the full gaussian approximation to estimate the **maximum** concentration of the Boron profile [in B atoms/cm^3]. Show all calculation.

(1) B^+ (atomic Boron ion, singly charged)

(2) B^{2+} (atomic Boron ion, doubly charged)

(3) B_2^+ (diatomic Boron molecular ion, singly charged)

(b) (4 points) If the Si substrate is n-type (background concentration of 10^{16} /cm^3), which ion in part (a) will give the deepest junction depth?

(c) (4 points) Estimate the sheet resistance of the implant profile in part (b) using Rs ~ 1/(q•μ•atomic does)

(d) (6 points) Discuss why a much higher implant does of Boron is required to create a surface amorphous Si layer as compared with Arsenic.

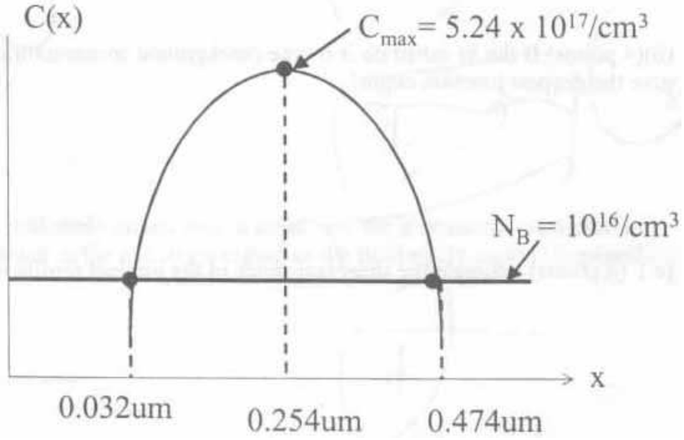
Problem 4 Diffusion and Sheet Resistance (24 points total)

(a) Sheet Resistance Calculations

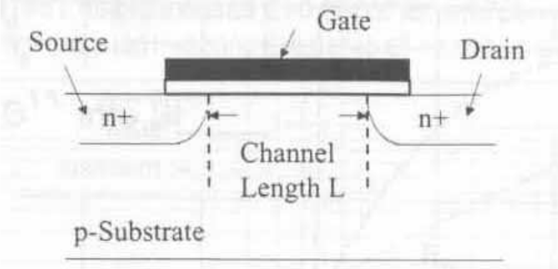
(i) (2 points) What is the sheet resistance of a 1-µm-thick copper thin film with a resistivity of 2 x 10^{-6} ohm-cm?

(ii) (3 points) Diffusion Predeposition of Arsenic is used to form a shallow junction in p-type Si (N_B = 1 x 10^{15} /cm^3). The solid solubility of As in Si is known to be 1 x 10^{21} /cm^3. if the allowed junction depth is less than 0.1 µm, what is the lowest sheet resistance which can be achieved?

(iii) (3 points) Phosphorus is implanted into p-type (N_B = 10^{16} /cm^3) Si to form a full gaussian depth profile. The peak concentration and the junction depths are show in the sketch below. Use the **Irvins Curve** to calculate the sheet resistance of the phosphorus implant layer.



(b) You are faced with the following three choices for forming the source and drain of a NMOS transistor.



(i) Shallow implantation does of Q phosphorus atoms/unit area, followed by an annealing step at 950 ^{o}C for 10 minutes to recover crystalline damage and to activate dopants.

(ii) Shallow diffusion predeposition does of Q phosphorus atoms/unit area, followed by a drive-in at 1150^{o}C for 30 minutes.

(iii) Shallow implantation does of Q phosphorus atoms/unit area, followed by an annealing step at 950^{o}C for 10 minutes to recover crystalline damage and to activate dopants and an additional drive-in at 1100^{o}C for 60 minutes.

Given:

TEMPERATURE	D(Phosphorus)
950°C	5×10^{-5} μm^2 / min
1100°C	2×10^{-3} μm^2 / min
1150°C	5×10^{-3} μm^2 / min

(A)(5 points) Which process will give the shortest MOSFET channel length L?

(B)(5 points) If the substrate doping is increased from 1 x 10^{15} to 1 x 10^{16} boron atoms/cm^3 , which of the three process in part (A) will exhibit the **greatest change in channel length**? Justify your answer with an explanation.

(c) (6 points) A Si wafer has a **high concentration** Arsenic drive-in depth profile. It is then subjected to a thermal oxidation step. Sketch the Arsenic depth profile in Si after oxidation and describe all major physical mechanisms which contribute to enhanced diffusion.

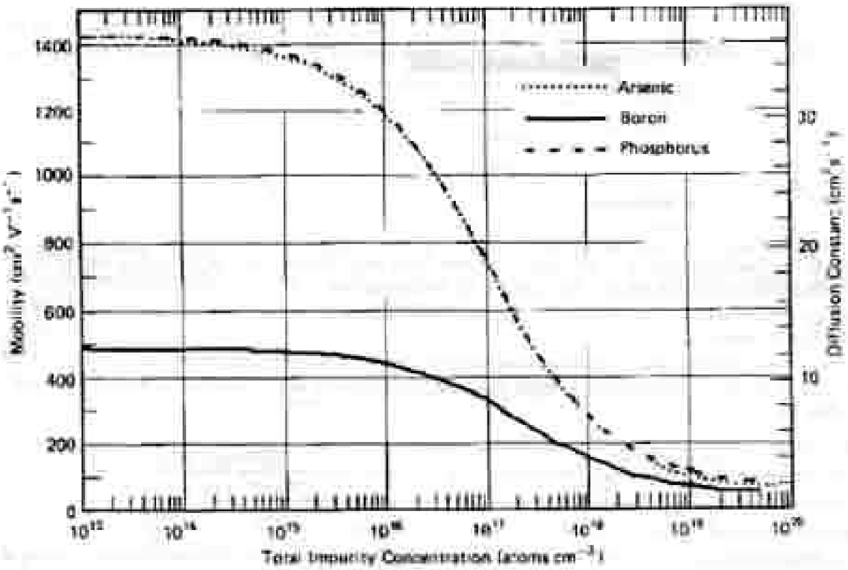
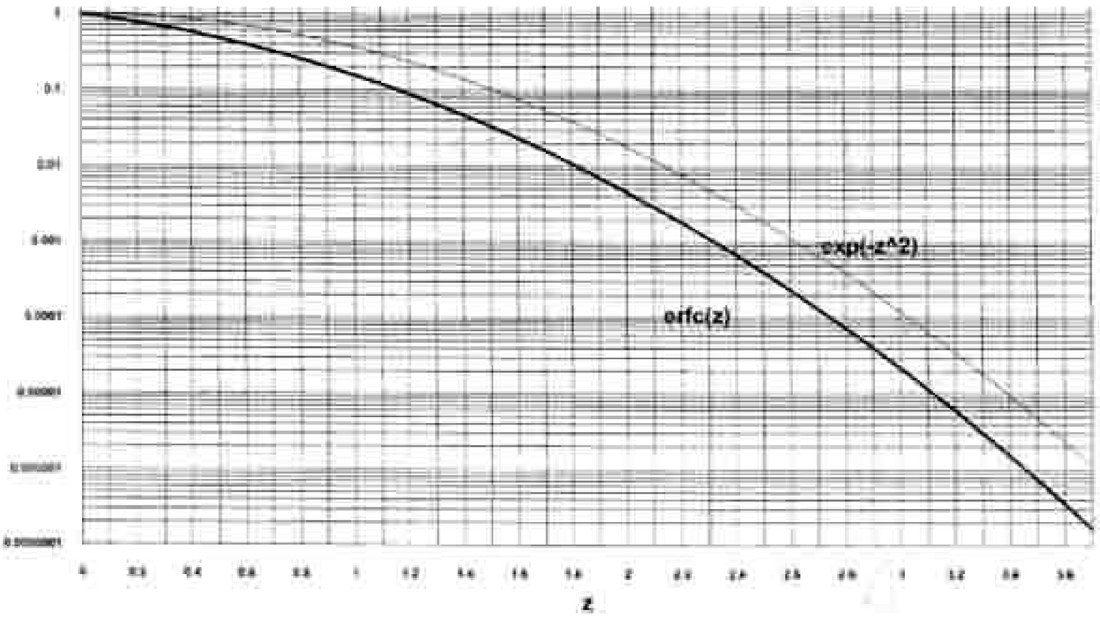
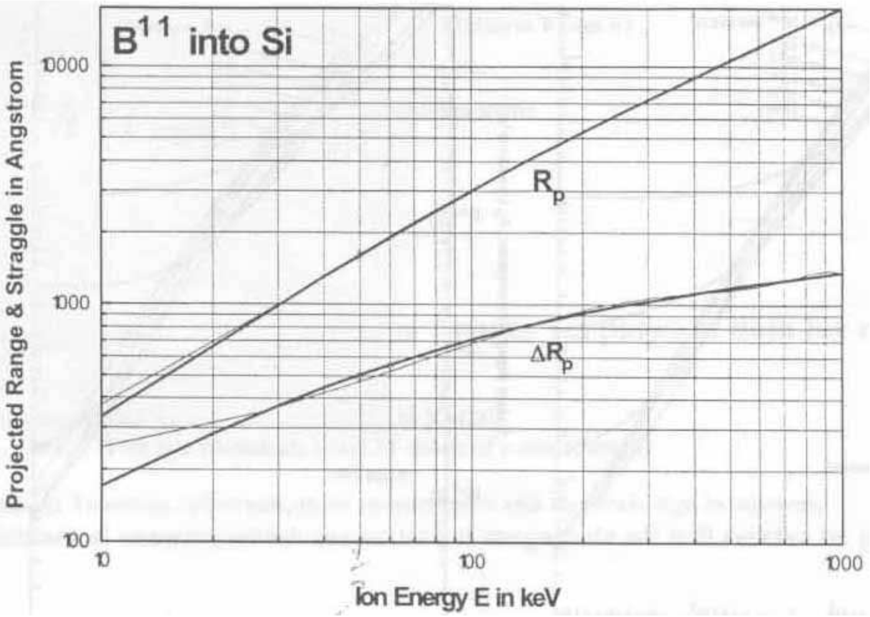


Figure 1.15 Electron and hole mobilities in silicon at 300 K as functions of the total dopant concentration. The values plotted are the results of curve fitting measurements from several sources. The mobility curves can be generated using Equation 1.2.10 with the following parameter values:[4]



$Rp = 51.051+32.60883\ E - 0.033837\ E^2 + 3.758e\text{-}5\ E^3 - 1.433e\text{-}8\ E^4$

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



GENERAL IMFORMATION

$Q = 1.6 \times 10^{-19}$ coulombs

$\varepsilon_s = 1.036 \times 10^{-12}$ F/cm for Si

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

$= 1.45 \times 10^{10}\ \text{cm}^{-3}$ at 300K

Eg of Si = 1.12 eV at 300K

Electron Affinity of Si = 4.05 eV

$D/\mu = kT/q = 0.0259$ volts at 300K

Irvin Curves