

Problem 1

(a) Either one of the following solutions will be acceptable.

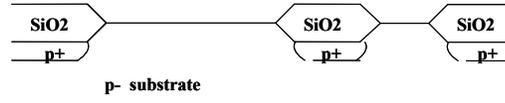
Solution 1 (best) : **One additional lithography mask** is needed to protect the MOSFET region when doing the poly-Si removal over ohmic contact area and p+ implant

Solution 2 (acceptable) : **Two additional lithography masks** are needed : 1) protect the MOSFET region when doing the p+ implant for the ohmic contact regions (without poly-Si on top) , and 2) to protect the ohmic contact region when doing the n+ implant for source/drain.

(b) All process steps same as MOSFET process. *The key steps to add the p+ ohmic contact regions are marked in italic*

Starting wafer, p- Si

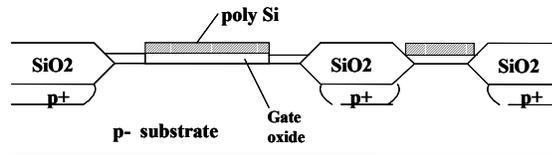
LOCOS process steps (Mask #1)



Gate oxide growth (thermal oxidation)

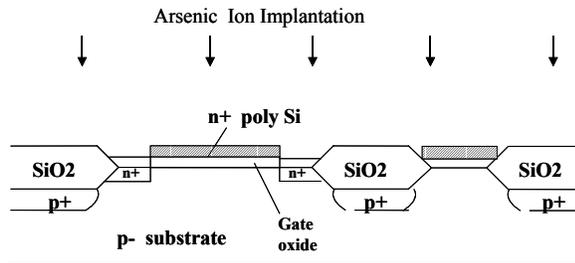
Undoped poly-Si deposition (CVD)

Pattern poly-Si (Mask#2)



Blanket As implant to form n+ poly-Si

and n+ source/drain regions

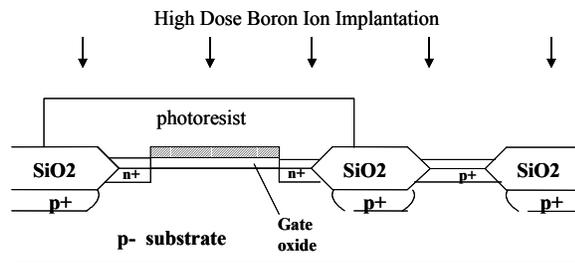


Pattern photoresist to cover all MOSFET regions

(Mask #3)-Extra mask

Etch away poly-Si over ohmic region

Boron implant to form p+ ohmic contact regions



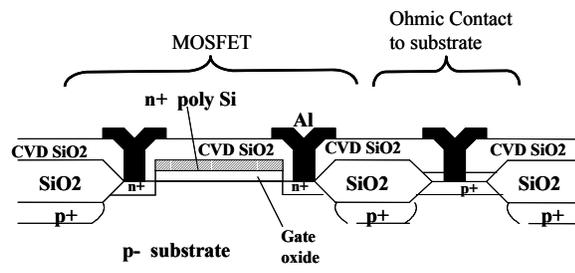
Strip resist

Deposit CVD SiO₂

Metal contact opening (Mask #4)

Al deposition

Al interconnect patterning (Mask #5)



Problem 2

(a) $x_2^2 + A x_2 = B (t + \tau)$; $x_1^2 + A x_1 = B (t)$

$(x_2^2 - x_1^2) + A (x_2 - x_1) = B \tau$

$(x_2 - x_1)(x_2 + x_1) + A (x_2 - x_1) = B \tau$

$(x_2 - x_1) = \frac{B \tau}{A + x_2 + x_1} = \frac{x_0^2 + A x_0}{A + x_2 + x_1} = x_0 \cdot \frac{A + x_0}{A + x_1 + x_2}$

(b) **No.** Since $(x_2 + x_1)$ is always larger than x_0 , $\frac{A + x_0}{A + x_1 + x_2}$ is always < 1 .

(c) For large t , both x_2 and x_1 will approach ∞ . Therefore $(x_2 - x_1) \rightarrow 0$.

(d) $\Delta = x_0 + 0.54 (x_2 - x_0) - 0.54 x_1 = 0.46 x_0 + 0.54 (x_2 - x_1)$

(e)

	Effect on Δ	Brief Explanation
Initial oxide thickness $x_0 \uparrow$	+	Original step height is larger
Oxidation time $t \uparrow$	-	x_1 gets closer to x_2
Oxidation temperature \uparrow	-	Faster oxidation rate, x_1 gets closer to x_2
Oxidant gas pressure \uparrow	-	Faster oxidation rate, x_1 gets closer to x_2

(f) At lower dopant concentration, we have mainly neutral vacancies. At higher doping concentrations, we have more electrons (or holes) to create extra charged vacancies V^+ , V^- , $V^=$ etc with concentrations proportional to (p/n_i) , (n/n_i) , $(n/n_i)^2$ etc from Law of Mass Action. **When charge carrier concentration is larger than n_i ($\sim 10^{19}/\text{cm}^3$ at 1000C), the increase of charged vacancies can be substantial.** The B/A parameter is related to the interfacial reaction term k_s . More vacancies (broken Si bonds) available at the SiO_2/Si interface will increase k_s .

Problem 3

(a) For 200 keV $P \rightarrow \text{Si}$,

$R_p = 0.254 \mu\text{m}$, $\Delta R_p = 0.0775 \mu\text{m}$

Peak concentration $C_p = (0.4 \times 10^{13}) / (0.0775 \times 10^{-4}) = 5.2 \times 10^{17} / \text{cm}^3$

From the mobility curve for electrons (using peak conc as impurity conc), $\mu_n = 350 \text{ cm}^2 / \text{V-sec}$

$R_s = \frac{1}{q\mu_n\phi} = \frac{1}{1.6 \times 10^{-19} \times 350 \times 10^{13}} \approx 1780 \Omega/\text{square}$.

(b) $C_p \exp[-(x_j - 0.254)^2 / 2 (\Delta R_p)^2] = N_B$ with x_j in μm

$\therefore (x_j - 0.254)^2 = 2 \times (0.0775)^2 \ln [5.2 \times 10^{17} / 10^{16}]$ or $x_j = 0.254 \pm 0.22 \mu\text{m}$;

$x_{j1} = 0.032 \mu\text{m}$ and $x_{j2} = 0.474 \mu\text{m}$

(c) For implant profile with annealing, $C(x,t) = \frac{N_p}{[1 + \frac{4Dt}{2(\Delta R_p)^2}]^{1/2}} \exp[-\frac{(x - R_p)^2}{2(\Delta R_p)^2 + 4Dt}]$

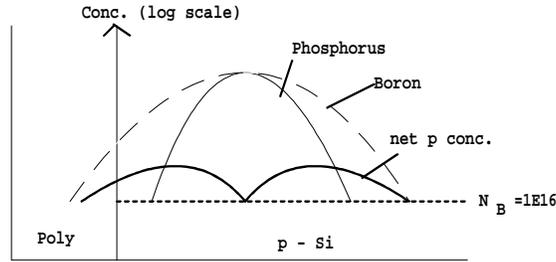
Since the **Dt product (10^{-12} cm^2) is $\ll (\Delta R_p)^2$ ($6.4 \times 10^{-11} \text{ cm}^2$)**, the implant profile is basically unchanged after this thermal annealing step.

(d) The Phosphorus peak is $(0.5 + 0.254) = 0.754 \mu\text{m}$ below the poly-Si surface.

We therefore need **$\sim 320 \text{ keV}$** Boron to make the Boron peak position coincides with the Phosphorus peak.

(e) ΔR_p for Boron is $0.105 \mu\text{m}$. Required Boron dose $\phi = 5.2 \times 10^{17} \times 0.105 \times 10^{-4} / 0.4 = 1.4 \times 10^{13} / \text{cm}^2$.

(f) Since ΔR_p for Boron is $0.105 \mu\text{m}$ which is larger than the Phosphorus implant ΔR_p ($= 0.0775 \mu\text{m}$) and the Boron implant peak concentration equal to that of Phosphorus, the Boron will overcompensate the Phosphorus at all depths.



(B)

Parameter	Channel Length L
Implant Dose ↑	↓
Substrate conc. N_B ↑	↑
Polysilicon (poly) thickness ↑	0
Arsenic ion energy ↑	↓
Implant ions changed from Arsenic to Phosphorus (same ion energy)	↓

(C)

A small fraction of the incoming ions can still be scattered by random collision into various crystallographic axes or planars. These “lucky” ions can penetrate deeper into the substrate as compared with a substrate with randomly arranged atoms. One possibility to eliminate these small channeling tail is to turn the Si surface first into amorphous Si (e.g. implant fo Si into Si substrate) before the dopants are implanted. Crystallinity of the implanted alyers can be restored by the solid phase epitaxial growth process (SPEG) .

Problem 4

(A)

- (a) n-type wafer has a background concentration of $4.0 \times 10^{15}/\text{cm}^3$.
So: $5 \times 10^{18} \times \exp[-x_j^2/4Dt] = 4.0 \times 10^{15}$.
Solving for Dt with $x_j = 4 \times 10^{-4}$ cm yields **Dt = 5.61×10^{-9} cm²**.
- (b) Using Fig. 4.16(c) of Irvin's curve with a surface concentration of $5 \times 10^{18}/\text{cm}^3$ and a background concentration of $4.0 \times 10^{15}/\text{cm}^3$ yields $R_s x_j = 330$ ohm- μm or **$R_s = 83$ ohms/sq** for $x_j = 4 \mu\text{m}$.
- (c) Dose $Q = N_0 (\pi Dt)^{1/2} = 5 \times (\pi \times 5.6 \times 10^{-9}) = \mathbf{6.6 \times 10^{14}/\text{cm}^2}$.

(B)(a) Assume a solid-solubility limited constant source, predeposition dose $Q = 2N_0 (Dt/\pi)^{1/2}$

For **T = 1000 °C**. $N_0 = 1 \times 10^{21}/\text{cm}^3$ and $D = 10.5 \exp(-3.69/8.617 \times 10^{-5} \times 1273) = 2.58 \times 10^{-14}$. Solving for Dt yields $Dt = 3.46 \times 10^{-13}$ **and t = 13.4 sec** which is too short to control.

For **T = 900 °C**. $N_0 = 5.5 \times 10^{20}/\text{cm}^3$ and $D = 1.47 \times 10^{-15}$. Solving, **t = 13 minutes** which is short but more controllable using a furnace.

(b) Using 900 °C predep step, $N_0 \cdot \text{erfc}(x_j / 2(Dt)^{1/2}) = N_B$

$$(x_j / 2(Dt)^{1/2}) = \text{erfc}^{-1} \left(\frac{\text{of } 4.0 \times 10^{15}}{5.5 \times 10^{20}} \right) = \text{erfc}^{-1}(7.3 \times 10^{-6}) \sim 3.16 \text{ from erfc curve}$$

$$x_j = 3.16 \times 2 \times (1.47 \times 10^{-15} \times 780)^{1/2} = 6.8 \times 10^{-6} \text{ cm} = \mathbf{0.07 \mu\text{m}}$$

(C) (a) Part (A) has a concentration profile less than $5 \times 10^{18}/\text{cm}^3$ for all depths and is slightly less than n_i ($\sim 10^{19}/\text{cm}^3$ at 1000 °C). High concentration effort is not very significant. Junction depth is slightly deeper or not affected much.

(b) Part (B) has a surface concentration (5.5×10^{20}) $\gg n_i$. High concentration effort is significant. Junction depth is deeper because of the enhanced diffusivity.