

Problem1

- (i) The pad oxide is very thin (~100 Å). It can easily be prepared by thermal oxidation. The silicon nitride is prepared by chemical vapor deposition (CVD)
- (ii) Peak concentration of implant profile = $0.4 \phi / \Delta R_p$. For the shallow channel stop implant, $\Delta R_p \sim 0.1 \mu\text{m}$, peak concentration $\sim 4E17/\text{cm}^2$
- (iii) **The gate oxide oxidation step** is performed before poly-Si deposition.
- (iv) We prefer As for shallow junctions because As has a slower diffusion constant than Phosphorus [Other secondary reasons: As has a higher solid solubility than P. Therefore, lower sheet resistance and contact resistance. Also, for the same implant energy, the projected range of As is smaller]
- (v) We cannot use thermal oxidation step to replace CVD oxide. The oxide layer is to electrically isolate the Al metallization from the poly-Si gate and substrate and require sufficient thickness. If too much poly-Si is consumed by using thermal oxidation, the gate dimensions will be significantly reduced.
- (vi) We cannot replace the poly-Si by Al as gate material in this process flow. There is a high temperature annealing step (>900 °C) after source/drain implantation. This step will melt the Al.

Problem2

(i) $x_{ox}^2 + Ax_{ox} = B(t + \tau)$

For 900°C, O₂: B = 5600 (Å)²/minute, $\frac{B}{A} = 2 \text{ Å} / \text{min} \therefore A = 2800 \text{ Å}$

\therefore For $x_{ox} = 1000\text{Å}$, $\tau = 0 \Rightarrow t = 680 \text{ min}$.

- (ii) Let x_i be the oxide grown during the steam oxidation step such that the final oxide thickness $x_{ox} = 5000\text{Å}$ after dry oxidation

$\therefore (5000)^2 + 2800 \cdot (5000) = 5600 (680) + x_i^2 + 2800 x_i \Rightarrow x_i = 4700\text{Å}$.

- (iii) Using a high pressure for oxidation increases the oxidant concentration on the oxide surface (Henry's Law). The oxidation rate will increase according to the Grove Model. Since it takes less time to grow the 0.1 μm gate oxide, the additional oxide grown on the field oxide is less. We need a **larger** x_i initially to make the final field oxide thickness = 0.5 μm .

- (iv) (111) Si surface has more reaction sites than (100) Si. This will increase the surface reaction term (k_s). The oxidation rate will increase according to the Grove Model. Since it takes less time to grow the 0.1 μm gate oxide, the additional oxide grown on the field oxide is less. We need a **larger** x_i initially to make the final field oxide thickness = 0.5 μm .

Problem 3

(a) $(0.5 - x) \cdot 2.17 = 0.5 \Rightarrow x = 0.27 \mu\text{m}$

(b) (i) $R_p = 0.5 \mu\text{m}$ $\Delta R_p = 0.09 \mu\text{m}$

The boron will need a kinetic energy of 186 keV

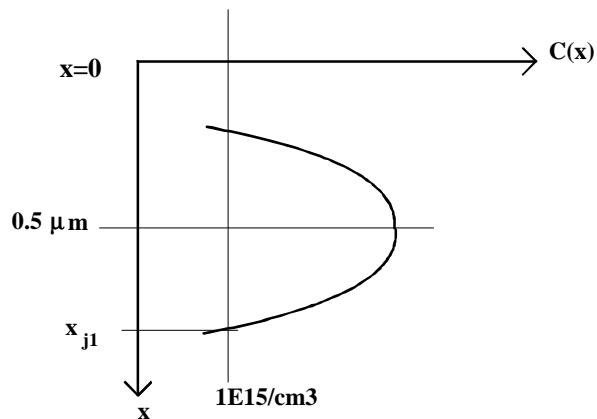
(A) For B⁺ ions, we need 186kV accelerating voltage

(B) For BF₂⁺ ions, we need $186 \times \frac{11+19+19}{11} =$

828 kV accelerating voltage

(ii) $N_p = \frac{10^{13}}{\sqrt{2\pi\Delta R_p}} = 4.4 \times 10^{17} / \text{cm}^3$

$\therefore 4.4 \times 10^{17} e^- (x_j - R_p)^2 / 2\Delta R_p = 10^{15}$



$$\therefore (x_j - R_p)^2 = 2(0.09)^2 \cdot \ln\left(\frac{4.4 \times 10^{17}}{10^{15}}\right) = 0.099 \mu\text{m}^2$$

$$\therefore x_j = R_p \pm 0.314 \mu\text{m}$$

$$\text{For } x_{j1}; x_{j1} = R_p + 0.314 = 0.814 \mu\text{m}$$

(iii) $N_o = 4.4 \times 10^{17}/\text{cm}^3$, $N_B = 10^{15}/\text{cm}^3$, half-gaussian profile of p into n-type substrate.

The Irvin's curves gives $R_S x_j \approx 2000 \text{ ohm}\cdot\mu\text{m}$.

Since x_{ji} is only $0.314 \mu\text{m}$ underneath the SiO2 interface, $x_j = \mathbf{0.314 \mu\text{m}}$, therefore $R_S \approx 6400 \text{ ohm/square}$

(d) For some particular angles of incidence along crystallographic axis or planes, a fraction of the incident ions can transverse the crystalline substrate with little nuclear scattering. This will give a deeper implantation profile than that of an amorphous substrate. Although a tilt-and-rotate geometry can minimize the primary channeling effect, we can still have a small fraction of the scattered ions bouncing into various axis or planes, giving a "channeling tail" of the doping profile.

Problem 4

(i) We just consider the diffusion of phosphorus under the poly region

$$10^{21} \operatorname{erfc}\left[\frac{x_j}{2\sqrt{Dt}}\right] = 10^{15} \Rightarrow \frac{x_j}{2\sqrt{Dt}} = \operatorname{erfc}^{-1}(10^{-6}) = 3.45$$

$$2\sqrt{Dt} = 2\sqrt{3 \times 10^{-13} \times 3600} = 6.6 \times 10^{-5} \text{ cm}$$

$$\therefore x_j = 6.6 \times 10^{-5} \text{ cm} \times 3.45 = 2.26 \mu\text{m}$$

$$(ii) \frac{Q}{\sqrt{\pi Dt}} e^{-x_j^2/4Dt} = 10^{15}/\text{cm}^3$$

$$Dt \text{ for As} = 3 \times 10^{-14} \times 3600 = 1.08 \times 10^{-10} \text{ cm}^2 \text{ at } 1100^\circ\text{C}$$

$$\therefore \frac{Q}{\sqrt{\pi Dt}} = \frac{10^{15}}{\sqrt{\pi \cdot 1.08 \times 10^{-10}}} = 5.4 \times 10^{19}/\text{cm}^3$$

$$\therefore x_j^2 = 4Dt \ln\left(\frac{5.4 \times 10^{19}}{10^{15}}\right) = 4.7 \times 10^{-9} \text{ cm}^2$$

$$\therefore x_j = 0.69 \mu\text{m}$$

$$(iii) 2\sqrt{Dt} \text{ of As} = 2.1 \times 10^{-5} \text{ cm}$$

$$\text{At a depth of } 2.26 \mu\text{m} \text{ below surface } y = \frac{x}{2\sqrt{Dt}} = 10.8$$

Since both the $\operatorname{erfc}(y)$ and $\exp(-y^2)$ functions decrease rapidly with y , the contribution due to As at depths below $2.26 \mu\text{m}$ is $\ll N_B = 10^{15}$. Therefore, the As profile contribution is negligible.

(iv) Electric field enhancement and Charge Point Defects enhancement

(v) Ion implantation will create a large concentration of vacancies and interstitials. They should recombine to form perfect Si again after subsequent annealing. However, **during the initial stage of annealing (~ seconds)**, the dopant diffusion will experience a very high diffusion constant already due to point defect enhancement. The depth junction will increase rapidly. After the vacancies and interstitials recombine with sufficient annealing time, this extra enhancement effect will disappear. Unfortunately, the junction depth may be too deep already if we want to form ultra-shallow junctions.