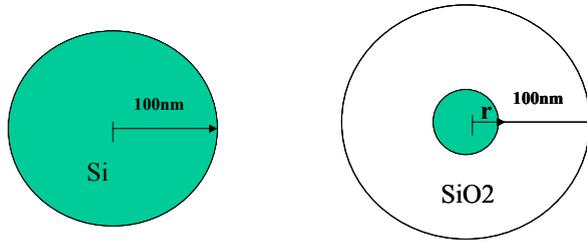


Problem 1

(a) 0.46 μm Si gives 1 μm SiO₂.

Let width of SiO₂ groove be x μm then $\frac{x - 1}{0.46} = x \Rightarrow x = 1.85 \mu\text{m}$

b) Consider the conservation of silicon atoms, ignore the effect of stress on volume and assume the radius of silicon left in middle is r.



Si consumed

Si in SiO₂

$$5 \times 10^{22} \times \pi \times (100^2 - r^2) = 2.3 \times 10^{22} \times \pi \times [(r+100)^2 - r^2]$$

$$\Rightarrow 5 \times (100^2 - r^2) = 2.3 [(r+100)^2 - r^2]$$

$$\Rightarrow 5r^2 + 460r - 2700 = 0$$

$$\Rightarrow r = 40.7 \text{ (nm)}$$

so the radius of silicon left in middle is 40.7 nm

Problem 2

B-side: 1000°C, 30 min in steam → 0.2 μm SiO₂ grown

A-side: 1100°C, 60 min in O₂ → 0.11 μm SiO₂. This step is equivalent to 10 min in steam at 1000°C.

∴ 1000°C, (30 + 10) min, in steam → 0.25 μm SiO₂ grown.

Problem 3

(a)

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

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

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

(ii) Let x_i be the oxide grown during the steam oxidation step such that the final oxide thickness

$x_{\text{ox}} = 5000 \text{ Å}$ after dry oxidation

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

(b) oxide grown in window area = 1000 Å

new oxide grown in field oxide area = 300 Å

Si step height = (1000 - 300)/2.16 = 324 Å

Problem 4

(a)

From the Grove model, we have : $x_{\text{ox}}^2 + Ax_{\text{ox}} = B(t + \tau)$

Therefore,

$$2x_{\text{ox}} \frac{dx_{\text{ox}}}{dt} + A \frac{dx_{\text{ox}}}{dt} = B$$

$$\text{or } \frac{dx_{\text{ox}}}{dt} = \frac{B}{A+2x_{\text{ox}}}$$

From $0.24 = \frac{B}{A+0.5 \times 2}$ and $0.133 = \frac{B}{A+1 \times 2}$, we get

$A=0.25 \mu\text{m}$, $B=0.3 \mu\text{m}^2/\text{hour}$ and $B/A = 1.2 \mu\text{m}/\text{hour}$

(b)

$B/A = 1.2 \mu\text{m}/\text{hour}$ and $B=0.3 \mu\text{m}^2/\text{hour} \rightarrow A=0.25 \mu\text{m}$,

Deal-Grove model: $x_{\text{ox}}^2 + A x_{\text{ox}} = B(t+\tau)$

Growth data : $x^2 + Ax = B(1+\tau)$ [1]

$4x^2 + 2Ax = B(4+\tau)$ [2]

Using $2 \times [2] - [1]$ gives $3x^2 + Ax - 3B = 0$

$$\text{or } x = \frac{-0.25 + \sqrt{(0.25)^2 + 4 \times 3 \times 3 \times 0.3}}{2 \times 3} = 0.508 \mu\text{m}$$

We then solve for τ . Using $4 \times [1] - [2]$ gives $2Ax = 3B\tau$

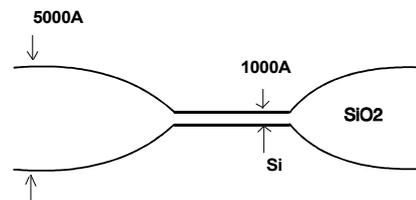
$$\text{or } \tau = \frac{2 \times 0.25 \times 0.508}{3 \times 0.3} = 0.28 \text{ hours}$$

From $x_i^2 + Ax_i = B\tau$, we obtain

$$x_i = \frac{-0.25 + \sqrt{(0.25)^2 + 4 \times 0.3 \times 0.28}}{2} = 0.19 \mu\text{m}.$$

Problem 5

(i)



(ii) For 1000°C , steam: $B = 5.2 \times 10^5 (\text{\AA})^2/\text{minute}$, $\frac{B}{A} = 111 \text{\AA}/\text{min} \Rightarrow A = 4684 \text{\AA}$

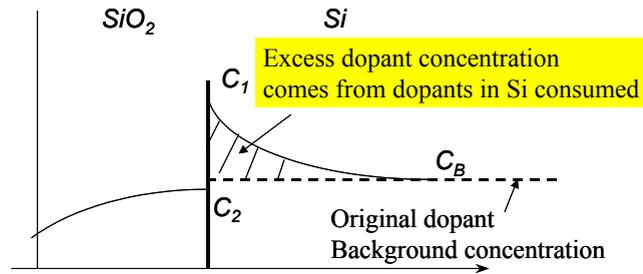
$x_{\text{ox}}^2 + A x_{\text{ox}} = B(t+\tau)$

$$\text{For } x_i = 1000 \text{\AA}, \tau = \frac{x_i^2 + Ax_i}{B} = \frac{1000^2 + 4684 \cdot 1000}{5.2 \times 10^5} = 10.9 \text{ min}$$

$$\text{For } x_{\text{ox}} = 5000 \text{\AA}, (t+\tau) = \frac{x_{\text{ox}}^2 + Ax_{\text{ox}}}{B} = \frac{5000^2 + 4684 \cdot 5000}{5.2 \times 10^5} = 93.1 \text{ min}$$

Therefore $t = 82.2 \text{ min}$

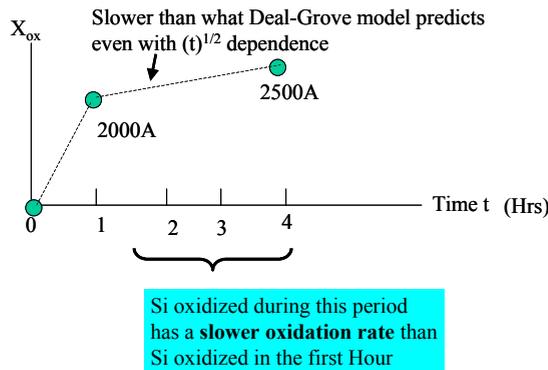
(iii) The As pile-up (due to dopant redistribution during oxidation) increases with more substrate Si consumed. Since the field oxide region consumes more Si than the pad oxide region, the field oxide region will have a higher As concentration at the Si/oxide interface.



More oxide grown \Rightarrow More As pileup

Problem 6

The observed results indicate that the growth rate is slower than the Deal-Grove model after 2000 Å of oxide is grown. Even if we take the limit that growth rate is proportional to $(\text{time})^{1/2}$, the oxide will be thicker than 4000 Å after 4 hours of oxidation. The Si surface layer must have a faster oxide rate than the bulk of the wafer.



Conjecture 1: The processed Si wafer was oxidized first to an oxide thickness of 100 Å and then have the oxide dissolved in HF. **FALSE**

Dopant segregation can enhance oxidation rate but the small oxide growth cannot change the surface layer dopant concentration due to dopant segregation.

Conjecture 2: The processed Si wafer has a highly doped surface layer (doping $> 10^{19}/\text{cm}^3$) which is less than 1000 Å thick. **TRUE**

The Si wafer has a highly doped surface layer ($N > 10^{19}/\text{cm}^3$) which is less than 1000 Å thick (i.e., $0.46 \times 2000 \text{ Å} \approx 1000 \text{ Å}$). The underneath substrate is lightly doped. The Si wafer has a highly doped region underneath a lightly doped surface region. Oxidation rate is higher when the doping concentration is higher than $10^{19}/\text{cm}^3$, mainly through the linear term B/A . After this layer of highly doped Si is consumed, the growth rate slows down.

Conjecture 3: The processed Si wafer has a thin layer of poly-Si layer deposited on top. **TRUE**
Initial oxidation of poly-Si is very fast. After poly-Si is all consumed, the oxidation rate slows down.