HW#2 Solutions **EE143, Spring 2006**

Problem 1

a) The sharp angle between the (100) surface and (111) surface: $\theta = \cos^{-1}(1/\sqrt{3}) = 54.7°$

For 200nm oxidation thickness on (100) surface, and 1100°C steam temperature, from Fig. 3.6 on Jaeger, we can find the oxidation time is about **1.6hrs.**

From Fig. 3.7, we find the oxide thickness on (111) surface is about **300nm.**

Then the oxide thickness (as defined in the plot of problem) on the sidewall is $d = 300 / \sin(54.7°) \approx$ **367nm**.

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. we have:

$5\times10^{22}\times\pi\times(100^2-r^2) = 2.3\times10^{22}\times\pi\times[(r+100)^2-r^2]$

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

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

$\Rightarrow$ r=**40.7 (nm)** so the radius of silicon left in middle is 40.7nm

Problem 2

B-side: 1000°C, 30 min in steam → **0.2 μm SiO_2 grown**

A-side: 1100°C, 60 min in O_2 → 0.11 μm SiO_2 . This step is equivalent to 10 min in steam at 1000°C.

∴ 1000°C, (30 + 10) min, in steam → **0.25 μm SiO_2 grown**.

Problem 3

(a)

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

(i) For 900°C, O_2 : B = 5600 (Å $)^2$/minute, $\frac{B}{A} = 2$ Å /min ∴ A = 2800 Å

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

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

$\therefore (5000)^2 + 2800 \bullet (5000) = 5600\,(680) + x_i^2 + 2800\,x_i \Rightarrow$ $\mathbf{x_i}$ **= 4700Å**.

(b) oxide grown in window area = 1000 Å

new oxide grown in field oxide area = 300 Å

Si step height = (1000 - 300)/2.17 = 323 Å

Problem 4

B/A = 1.2 μm/hour and **B= 0.3 μm²/hour** → **A=0.25 μm** ,

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

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

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

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

or $$x = \frac{-0.25 + \sqrt{(0.25)^2 + 4\times3\times3\times0.3}}{2\times3} = 0.508\ \mu m$$

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

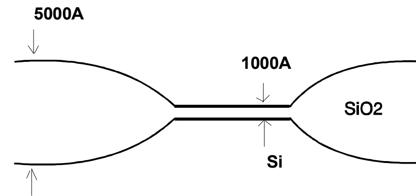
or $$\tau = \frac{2\times0.25\times0.508}{3\times0.3} = 0.28 \text{ hours}$$

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

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

Problem 5

(i)



(ii) For 1000 °C, steam: $\mathbf{B = 5.2\times10^5\ (\text{Å})^2/minute}$, $\frac{B}{A} = 111$ Å /min $\Rightarrow$ $\mathbf{A = 4684\ \text{Å}}$

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

For x_i= 1000 Å, $\tau = \frac{x_i^2 + Ax_i}{B} = \frac{1000^2 + 4684 \bullet 1000}{5.2\times10^5} = 10.9$ min

For x_{ox} =5000 Å, $(t+\tau) = \frac{x_{ox}^2 + Ax_{ox}}{B} = \frac{5000^2 + 4684 \bullet 5000}{5.2\times10^5} = 93.1$ min

Therefore **t = 82.2 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.

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 (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}/cm^3) which is less than 1000 Å thick. **TRUE**
The Si wafer has a highly doped surface layer (N>10^{19}/cm^3) which is less than 1000 Å thick (i.e., 0.46×2000 Å ≈1000 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}/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.