

Problem 1

(i) Flux arriving at a wafer distance $r \quad F' \propto (\cos \theta)^2 / r^2$

Thickness deposited on wafer $\propto F' \times \cos \phi$ (with $\phi = \theta$) $\propto (\cos \theta)^3 / r^2$

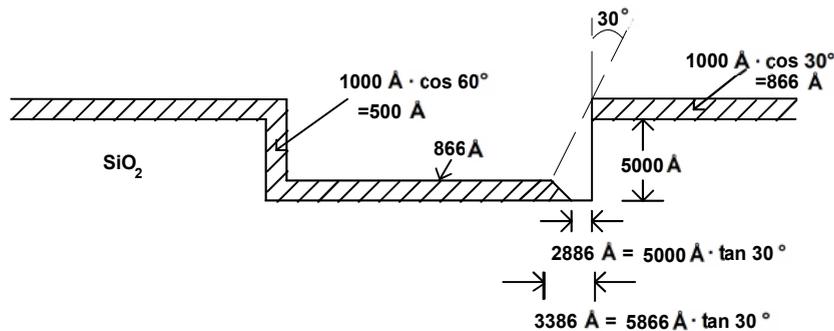
Since $\cos \theta = (r/2)/R$, therefore **thickness $\propto r$** .

(ii) Step coverage problem is due to directional flux used for deposition (e.g. both evaporation and sputtering). Even the spherical receiving surface will be making different angles to the wafer surface normal with different r positions, we will still see step coverage effects. The step coverage morphology will vary at different r positions.

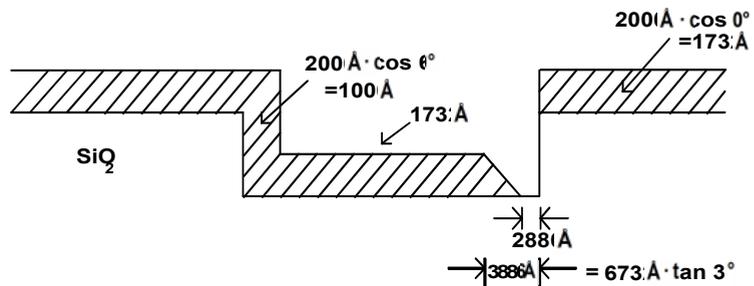
Problem 2

The corner profiles shown in sketches below are approximate only. The exact shape depends on the initial roundness of the corners.

a.) After 1min:

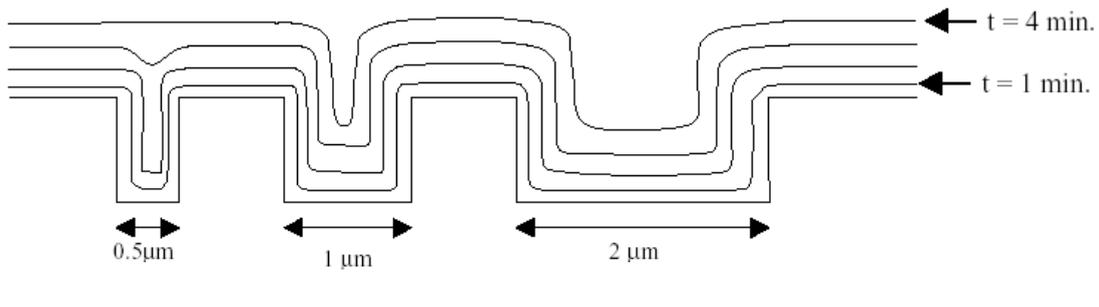


b.) After 2min:



Problem 3

(a)



(b) For conformal deposition, **less** deposition thickness is needed to planarize high aspect ratio (large height /narrow width) trenches.

Problem 4

(i) Surface reaction limited implies deposition rate $\propto \exp[-E_A /kT]$

$$\text{Therefore rate (800 }^\circ\text{C)} = \text{rate (700 }^\circ\text{C)} \times \exp [(-2/ 8.617 \times 10^{-5}) (1/1073 -1/973)] = 9236 \text{ \AA}/\text{min}$$

(ii) If measured rate is less than predicted rate based on reaction-limited value, it suggests the actual deposition is also be limited by gas transport mechanism according to the Grove Model.

(iii) **Proposal 1**: measure the actual deposition at higher temperatures ($> 800^\circ\text{C}$), and see whether the rate approaches a $T^{3/2}$ dependence (the mass transport limited regime).

Proposal 2: Increase the gas flow rate to change the mass transport mechanism, a plot of the deposition rate versus (flow rate) $^{1/2}$ will show first a linear dependence and then followed by a saturation regime when flow rate is very high according to the Grove model.

plus other proposals.....

Problem 5

(a) At the region where growth rate is independent of gas flow rate, we have the surface reaction limited regime. The corresponding value is $1.5 \mu\text{m}/\text{minute} = 2.5 \times 10^{-6} \text{ cm}/\text{sec}$.

$$\text{From } dy/dt = k_s \frac{C_G}{\rho}$$

$$\therefore k_s = 2.5 \times 10^{-6} \times \frac{5 \times 10^{22}}{4 \times 10^{16}} = 3.1 \text{ cm}/\text{sec} = 10^7 \exp(-\Delta E/kT) \text{ or } \Delta E/kT = 15$$

$$\Rightarrow \Delta E = 8.62 \times 10^{-5} (\text{eV}/\text{K}) \times (1270+273) \times 15 \approx 2\text{eV}.$$

(b) When the growth rate is at $1.4 \mu\text{m}/\text{min} = 2.3 \times 10^{-6} \text{ cm}/\text{sec}$, we have to use the full Grove Model:

$$dy/dt = 2.3 \times 10^{-6} \text{ cm}/\text{sec} = \frac{1}{(1/h_G + 1/k_s)} \times \frac{C_G}{\rho}$$

Since k_s does not depend on flow rate, we can use the k_s value derived in part(a) ($=3.1 \text{ cm}/\text{sec}$)

$$\frac{1}{h_G} + \frac{1}{3.1} = \frac{4 \times 10^{16}}{2.3 \times 10^{-6} \times 5 \times 10^{22}} = 0.34 \quad \text{or } h_G = 39 \text{ cm}/\text{sec}$$

(c) At low flow rates, we expect growth is dominated by transport limited regime and

$$dy/dt \propto h_G \propto \sqrt{U} \text{ where } U \text{ is the gas flow rate. Experimental curve shows } dy/dt = K \sqrt{U} .$$

We choose $\sqrt{U} = 0.4 (\text{litre}/\text{min})^{1/2}$, $dy/dt = 0.65 \mu\text{m}/\text{min} = 1.1 \times 10^{-6} \text{ cm}/\text{sec}$ to find K.

$$\therefore K = 2.75 \frac{\text{cm/sec}}{(\text{litre/min})^{1/2}}$$

If we extrapolate this linear dependence to $\sqrt{U} = 0.92 (\text{litre/min})^{1/2}$ where $dy/dt = 1.4 \mu\text{m/min}$ (i.e., condition of part (b) where h_G is calculated from the Grove Model), the corresponding h_G is only 2.5 cm/sec. This obviously shows a discrepancy between the experimental h_G from flow rate dependence and h_G calculated from the Grove Model.

(d) Let $v \equiv dy/dt$.

$$dv/dT = (dv/dk_s) (dk_s/dT)$$

$$dv/dk_s = \left(\frac{h_G}{k_s + h_G} \right) \frac{v}{k_s}$$

$$dk_s/dT = k_s \frac{\Delta E}{kT^2}$$

$$\therefore \frac{dv}{v} = \left(\frac{h_G}{k_s + h_G} \right) \frac{dT}{T} \frac{\Delta E}{kT}$$

$$= \left(\frac{37}{3.1 + 37} \right) \times 0.01 \times 15 \approx 0.14 \text{ or } 14\%$$

If the temperature changes by 1%, the growth rate will change by 14%.

Problem 6

- (1) Different elements of the compound will have various vapor pressure when heated to the same evaporation temperature. The deposited film composition is very different from that of the compound.
If separate evaporation temperature are used for each element of the compound, one can in principle control the vapor fluxes. However, the $\exp[-E/kT]$ dependence of vapor pressure will require very precise temp control.
Sputtering of compound targets will give same composition for the deposited films. This simplifies the control issues.
- (2) NO. Diffusion of dopant from the surface always give a high to low concentration profile with depth.
- (3) Each gas cycle (gas A, purge, gas B) yields a monolayer of deposited film. Thickness is controlled by the number of gas cycles.
- (4) CVD is conformal and will not create a clean break between the deposited feature and the mask sidewall.